SOIL TESTING

PERENNIAL CROP SUPPORT SERIES
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Roots of Peace is a humanitarian, not-for-profit organization based in California, USA. Roots of Peace, established in 1997, focuses on post-conflict countries to eradicate remnants of war and to re-establish and promote economic livelihoods and social programs. Roots of Peace is funded by public and private sources.

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Introduction

This manual was produced to support perennial crop development in Eastern Afghanistan. It is the second of a series of manuals that will be produced.

Vegetative Propagation Techniques
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Man's perception of soil varies according to how it is used, and so it is difficult to give a single correct definition. For an agriculturist, the classic definition of soil is "the outer layer of the earth's crust capable of supporting plant growth". That definition was correct until hydroponics technology showed it is possible to grow plants in liquid substances.

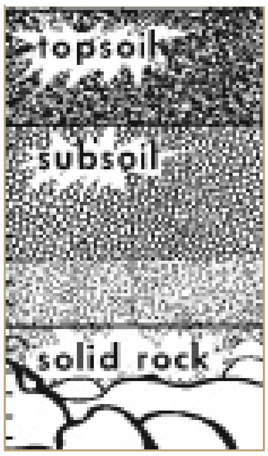
It is more practical to use the concept that soil is the place where the plant interacts with other organisms. Soil also provides nutrients, water and oxygen to the plant as well as space and support for the root system. Soil, just like the atmosphere and water, contains many forms of life. The living organisms in the soil provide vegetation to protect the soil, supply nutrients to the plant, support roots to bind soil particles, mix soil components and process nutrients.

All living organisms in the soil are integrated into its ecosystem. Where soil conditions are poor all these biological processes suffer, including plant development.

Soil has a complex structure. It can be described as a three-phase system composed of solids (organic and inorganic matter), liquids (especially water) and gases (mainly nitrogen, oxygen and carbon dioxide). It is a three-dimensional resource. Its profile shows many layers; their depth and the complexity of their structure give a clear picture of soil quality. Higher quality soils are characterised by a more complex structure and deep top layers.

Annex 1 and 2 contains a protocols for the steps to be used to test soil.

Figure 2 Soil Profile



Source: K. McSweeney, S. Grunwald., 1999 Soil Morphology, Classification and Mapping. University of Wisconsin-Madison

Soil Profile

The soil profile, a vertical cross-section, shows four main fractions of the soil. The top level is the topsoil (A horizon) divided into two main fractions: loose litter and below it, fermented litter. Both are divided into sub-fractions, indicated as follows: A_{00}, A_0, A_1, A_2, A_3.Topsoil is high in organic matter and clay content; it also contains a mass of microbiological life forms, more than any other soil fraction. The subsoil (B horizon) lies beneath the topsoil. This fraction is rich in accumulated minerals and lime. Like topsoil, it is generally divided to different sections - B_1, B_2, B_3. The third main fraction is called parent material (C horizon), the result of mechanically weathered rock. The last fraction is the bedrock (R horizon).

The soil developed from parent material that has been broken down, sorted, moved and deposited. But the parent material is not the main determinant for the type of soil. In fact, different types of parent material produce the same type of soil under similar conditions and the same types of parent material produce different types of soil under different conditions. These conditions are soil-forming factors.

Soil Properties

As explained above, soil is a complex structure - a three-phase system with physical, chemical and biological properties. An average soil consists of about 45% mineral matter, 25% air, 25% water and 1-5% organic matter. It holds living organisms. It owns distinct layers or horizons that compose the soil profile and are developed by soil-forming factors.

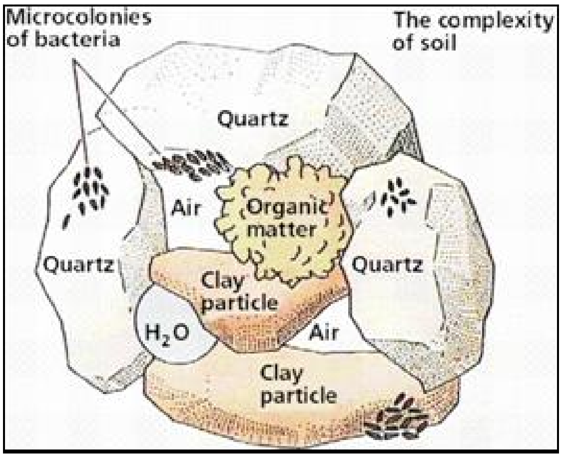
Source: Ferenc Sandor

Physical Properties of Soil

Soil is composed of a mixture of particles from 2µm to small gravels and stones. These mineral fractions are known as soil separates. According to the size of the particle they can be sand, fine sand, silt or clay particles. Normally the smaller particles are “glued” together by organic matter, iron oxides and other substances. We call the products of this aggregation aggregates. These can be natural aggregates, “peds”, or artificial aggregates “clods” that are evidence of human intervention.

Like other matter, soil has density. There are two kinds of soil density: bulk density and real density. Bulk density is the weight of a given volume of soil, including the network of pore spaces, i.e. the gaps between the particles. Real soil density excludes the pore spaces, leaving only the volume of the soil solids.

Figure 3 Soil Aggregate



Source: K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison

The network of pore spaces plays an important role in the life of soil. Through these spaces the soil exchanges water and gases with the environment. This network is the path for the flow of nutrients and heat. The main soil characteristic like structure, texture or organic matter content is related with the pore space system. There are two types of pore spaces: macro (larger than 0.06 mm), indicating the spaces between aggregates, and micro (smaller than 0.06 mm.) for the space within individual aggregates. Micro pores look like a trap, with no way for the trapped water and air to flow in or between them. The pore space content of the soil is called porosity.

The porosity of the soil gives us important information about its physical characteristics. Normally, lower layers have higher bulk density than upper horizons. The subsoil has high real density and less organic matter to build up granular structure.

The mineral fractions in the soil are, as we have seen, a mixture of soil with different sizes. The proportion of the separates from one to another determines the soil texture. The relationship between texture and porosity is a closed one, with soil texture as the sole determinant of very important characteristics of the soil, like water-holding capacity and movement, fertility, etc.

The classification of the soil based on soil textures gives us: loam, clay, silt, silty loam, silty clay loam, and so on.

The grouping of soil aggregates together produces the soil structure. There are five types of soil structure:

Figure 4 Soil Structures

Source: D. Pennock., 2005, University of Saskatchewan

Granular structure: Rich in organic matter, with good porosity, easy water-air exchange and capacity for movement. This is typical surface soil structure, where aggregates are glued together by organic matter.

Platy structure: Sub-surface soil, where the platy layers separate more easily. Normally this soil is the result of leaching and compaction.

Blocky structure: Common in sub-soils, or surface soils with high clay content. When the surface dries up, it shows features of cracking and peeling of the clay.

Massive structure: Amorphous material, a coherent mass showing no evidence of any distinct arrangement of soil particles; separates into clusters of particles, not peds (Clayey soils).

Prismatic structure: Typical in "B" horizon. The prisms are very dense, therefore these types of soils are not fertile.

Unstructured soils: Typical in wind blown, or Aeolian sands. There are no discernible peds.
Another source of important information about the soil is its color. Darker soils have more organic matter. The difference between the color of the level areas and other areas informs us about erosion activity. Red and brown strips in the layers mean waterlogged and dry conditions; they are oxidized iron compounds or rust. The darker color allows the soil to warm up faster for plant growth.

Water is life. The capacity of the soil to hold water, to allow it to flow and to fix it is one of the most important conditions for successful agricultural production. These characteristics of the soil are closely related to other physical properties of the soil, e.g. porosity, density, color, texture and structure. In other words, the water in the soil is determined by the soil's physical properties on one hand and by the hydrologic cycle of the ecosystem on the other. The latter can be modified by human intervention through irrigation and other agro-technical methods.

There are three types of soil water:

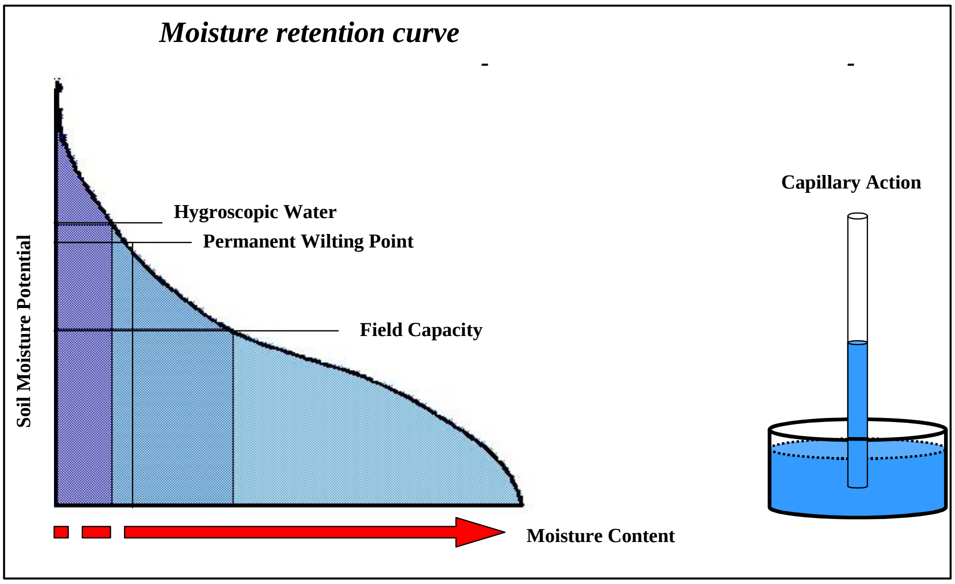
- Gravitational water: This is excess water and drains downwards in the soil. The soil lacks the capacity to hold water in the pore system.

- Capillary water: The soil holds water in the pore system or in thin film form around the soil particles. The water rises up in the pore's capillary system until the tension in the pore space balances out the surface tension, creating a "sponge" effect. The water also moves horizontally through the pore spaces.

Where organic matter in the soil is abundant, the soil is able to hold large quantities of water.

- Hygroscopic water: Even dry soil holds hygroscopic water in microscopic pore spaces, but it is not available for plant roots because the surface tension is too high.

Figure 5 Water Retention Curve



Source: F. Sandor, ROP Soil Test Laboratory, Jalalabad, Afghanistan (2007)

Chemical Properties of Soil

The mineral composition of soil, the organic matter within it and the environment, all are determined by the soil's chemical properties. These properties include cation exchange capacity, soil pH and salinity; we will also deal with the processes of acidification and alkalinization.

An understanding of how different soil particles react with each other shows the soil's cation exchange capacity. Mineral particles and organic matter (humus particles) have a negative charge and many soil nutrients have a positive charge. The negatively charged soil particles attract positively charged nutrients, preventing them from leaching downward through the soil. These nutrients will be available for the plant.

The pH level shows the hydrogen ion activity in the soil. The pH range is between 0 and 14. The neutral factor is 7. Less that seven means acidic soil, more than seven means alkaline or basic soil. Seven is a neutral value and is the pH of water. The pH has strong interaction with nutrients, soil biology and soil structure. Most plant and micro-organisms prefer pH around neutral.

Salinity is the concentration of soluble salt in the soil, therefore saline soil is a soil that contains a high concentration of these salts, mainly sodium, magnesium and calcium sulphate. The salt can be deposit on the soil's surface in different ways:

- Water moves up in the capillary system carrying the dissolved salt. When the water evaporates from the soil the salt will be deposited on the soil surface

- Low annual rainfall and hot weather cause more intensive evaporation
- Internal drainage problem
- Underground water-table is close to the surface
- Irrigation practice

Any chemical condition of the soil is related to the nutrients' ion concentration in the soil solution and how strongly the nutrients are absorbed by soil particles and by micelles. The chemical condition of the soil also depends on the nutrients' capacity to move. Some nutrient ions move faster than others. Nitrate ions move faster than phosphate ions. Ion movement occurs in three ways in the soil:

- Root interception: The root expands from areas of depleted nutrients to areas rich in nutrients.
- Mass flow: The nutrients are transported along with water.
- Diffusion: Nutrient ions in the soil solution mix together in the random movement of molecules, and disperse in it.

Biological Properties of Soil

Soil biology studies all the life forms present in the soil. Species from all five kingdoms live here: animal (Animalia), Fungi, plant (Plantae), Protista (such as protozoa) and Monera (such as bacteria). Soil fauna (animal life) and soil flora (plant life) are two of the three main biological properties of the soil. The third one is the food chain or food web.

The food web or food chain is a complex path of food, beginning with producer organisms and passing through consumer organisms, one eating the next. The term *food web* is more fitting, since the mechanism consists of interlocking food chains. The same kind of organism can be eaten by various other organisms, which can in turn eat other kinds of organisms, and so on.

All living organisms play an important role in the whole food web cycle in the ecosystem independent of the impact – positive or negative – that they may have on agricultural production. The population of these living organisms is well balanced by the main driving energy of the food chain and the available nutrient sources flowing through it.

Testing Soil

Soil testing on regular bases is an important part of nutrient management. From the farmer's point of view, nutrient management is the process to maximize the proportion of applied nutrients that is used by the crop; in other words, maximizing the "Nutrient Use Efficiency (NUE)". Soil tests are used to evaluate soil fertility, which ultimately measures the soil nutrient content. It focuses on the measurement of available nutrients for the plants and excludes the total nutrient content. Total nutrient content value of the soil is useless for the farmer, because only a small quantity of them is available for the plant. Therefore it cannot provide information for fertilizer calculations.

Soil testing program is an analysis of the soil physical and chemical properties and an evaluation of the soil nutrient-supplying capacity at the time of sampling. It contains four activities:

- Taking soil samples
- Analysis of soil samples
- Interpreting the results of the sample analysis
- Making recommendations for soil management and plant nutrition practices

Sampling Procedure

Soil nutrient content varies with the season. Therefore we should take samples as close as possible to planting or the time when the crop needs the nutrient. It can be 2-4 weeks before planting or applying fertilizer.

Avoid taking samples when the soil is very wet, dry or frozen. These conditions will not affect the result of the analysis, but they will make difficult to take and handle the samples.

We might test the soil each year or at least once during each crop rotation cycle. The results of the analysis should be maintained for each field separately to evaluate long-term trends in nutrient levels and other properties.

The first rule in taking soil samples is to use clean and proper tools. Soil auger is the most convenient, but a shovel can also be used. Be sure to have clean plastic containers for the samples to collect and mix them. Clean and well -labelled containers must be used to store the samples. The tools cannot be galvanized or brass due to the fact that it will affect the result of the analysis for Zinc and Iron. For Iron and Manganese tests, do not dry the sample for transport.

Soil Sampling Designs

The accuracy of soil analyses and the subsequent interpretation of test results depends on various factors: how the soil samples were collected in the field, how they were handled and how they were processed during the analysis.

In collecting soil samples we have to remember that soil characteristics vary even in a small piece of land. Their texture and chemical composition depends on different factors. Therefore we have to divide the area into small units and collect sufficient samples to represent the whole area. The size of a sampling unit is often decided by various factors, such as the differences in soil color or texture, slopes and/or drainage characteristics, the previous use of the land for cropping and the consideration of uneven growth areas.

Source: Photograph by Ferenc Sandor.

There are two different methods for sampling. The first sampling method is performed at a fixed depth while the second sampling technique is taken from each horizon. The specific method and processing strategies of the sampling collection are indicated in the soil sampling design. The designer should have a simple map of the area; it does not to be exact – a rough sketch will do. First, one must indicate on the map the number of sampling areas, selected on the basis of uniformity of size and type of important in order to achieve the objective as well as factual information about this part of the farm. After this division of land, one composite soil sample must be taken from each area. Soil sampling is carried out using different sampling designs, which are indicated in the map or sketch of the targeted area. The selection of the sampling areas must follow these rules:

The sampling area is no bigger than two hectares and is a field or part of it.
The area should be uniform to avoid a mix of different kinds of soil.
The area should have the same kind of vegetation or crop.

The most common samplings collection designs are the following:

1- Grid sampling: A grid with suitable spacing is placed on the map and measured. The sampling will be taken at the intersections of the grid or from inside of the grid cells. Grid sampling provides equally spaced observations and it reveals any systematic variation across the tract under study.

2- Random sampling: Sample locations are selected at random, with equal probabilities of selection and independently from each other. The sample produced from one sampling area consists of 10-20 sub-samples collected randomly throughout the sampling area using a zigzag pattern. The sub-samples should only be collected from representative sites, avoiding areas like anthills, bunds, boundaries, etc. The sampling process starts with the cleaning of the surface area then removing the top litter from the surface to approximately 1 cm deep. Dig a “V” shaped hole to a depth of 15 cm to collect a sample of the topsoil; for a sample of subsoil, the hole should be about 45 cm deep.

3- Random stratified sampling: The area is first divided into a number of sub-sections, called strata, and then random sampling design is applied to each of the strata separately. The random sampling method is not a systematic collection technique; meanwhile the stratified random sampling method provides a kind of mixture of the systematic and non-systematic soil sampling collection methods.

4- Transects: Soil samples are taken along straight lines across the targeted area. The spacing between sampling points might be equal, nested, or random.

5- Target sampling: Based on specific attributes (e.g. slope, aspect, plan or profile curvature, color, etc.) the technician identifies homogeneous and heterogeneous patterns of the targeted area, which will allow the fixation of representative sampling points where the sampling will be taken. This technique minimizes the effort and cost and maximizes the information content.

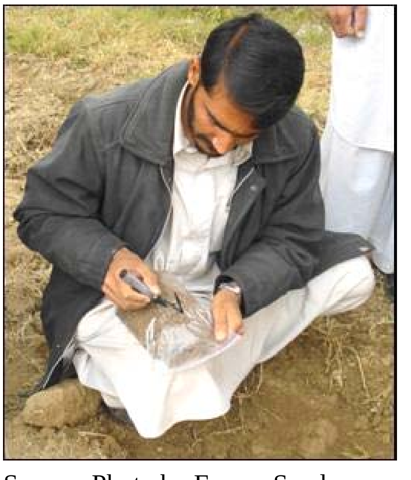
Taking Soil Samples

Step 1:
The first activity is to collect subsamples from the soil. A V-shaped hole must be dug with the required depth. When the V- shaped hole is ready, a slice is cut approximately 2.5-3.0 cm thick. Both sides of the slice must then be trimmed leaving a 3.0 cm strip, which is then put it in a clean container. This process is to be repeated several times until a sufficient number (15-20) of subsamples to make a representative sample is acquired. After that, the soil should be mixed thoroughly in the container and all soil clods should be broken up. From the bulked sample, take about 500 g. If the samples are not dried, they should be kept in a cool or frozen place. If the sample cannot be kept refrigerated, it should be air-dried at room temperature within 12 hours of extraction. A circulating fan can be used to move the air over the sample if it is available. Air-drying samples prevents microbes from mineralizing the organic matter soil content.

Source: Photo by Ferenc Sandor

Step 2:
Put labels and attach a record to the sample. The record will assist in the interpretation of the results and this should include information on the following:

- Type of soil (light sandy, heavy, etc)
- Yield records (this provides some indications whether there is anything seriously wrong with the soils of that particular field).
- Reason for taking sample – routine or specific problem for investigation.
- Replanted or virgin soils
- Previous crop grown on the same piece of land
- Nutrition history of the crop - when was it fertilized, what type of fertilizer was used and what rates were used. (Not all of the fertilizer applied is absorbed by the plant; much is left as a residual and this can account for some abnormally nutrient contents in soil samples upon analysis.)



Source: Photo by Ferenc Sandor

Step 3:
The label contains your name, serial number of the sample according to the sampling design, the sampling depth and field number.

Source: Photo by Ferenc Sandor

Depth of Sampling

The depth of the sampling is important because the mobility of the nutrients varies with the nutrient content in the different soil zones. The mobility of each nutrient in the soil is also varying from each other. The recommended depth for sampling is the following:

- 0-15 cm	To measure pH, P, K, Cl, S, Ca, Mg, Zn, NH_4^+ -N, Fe, Mn, Cu, soluble salts
- 15-60 cm	To measure soluble salts, NO_3-N, S, Cl (in addition to 0-15 cm depth)
- 60-120 cm	To measure NO3-N (in addition to 0-15 cm and 15-60 cm depth)

Source: Photo by Ferenc Sandor

The depth of the sampling also varies according to the crop in use:

- Annual Flowers: Sample the top 15 to 20 cm of soil.
- Perennial Flowers: Sample the top 15 to 30 cm of soil.
- Commercial Production of Field-Grown Flowers: Sample the top 20 or 30 cm of soil.
- Home Landscape Trees, Shrubs, & Field-Grown Nursery Stock: Sample the top 15 to 30 cm of soil. Take samples from under the established trees (under tips of the longest branches all the way around the tree), or just outside the root ball or planting area for newly planted trees.
- Home Vegetable Gardens: Sample the top 15 to 30 cm of soil
- Commercial Vegetable Fields: Sample the top 20 or 30 cm of soil.
- Fruit Trees: Sample the top 30 to 45 cm of soil. Take samples from area under branch tips (or closer to trunk for newly planted trees).
- Bush and Vine Fruits: Sample the top 20 or 30 cm inches of soil.

Soil Sampling in Areas Under Special Conditions

Under tillage, 0-15 cm, 15-60 cm and the 60-120 cm depths are appropriate for sampling. For areas not used for a long period of time or tillage that was not applied to the non-mobile nutrient, soil pH shows a stratification pattern in the different soil zones. Phosphate and soil pH stratification are common, with high Phosphate and lower pH levels at the surface (0-6 cm depth) and lower Phosphate and higher pH levels at deeper depths. Frequently the lower zones become depleted in Phosphate. Soil pH tends to become mote acidic at the surface, especially if Nitrogen fertilizers are applied to the surface. Separating the 0-12 cm depth into a 0-6 cm depth and 6-12 cm depth would identify these trends.

Source: Photo by Ferenc Sandor

Productions, which use ridges, are considered as area under special conditions. During the activities on the field, the top of the ridge moves into the middle of the rows and fertilizer is also applied under the top of the ridge. For this type of area, we collect samples at 15 cm depth on either side of the top of the ridge and straight down into the ridge.

Furrow irrigated areas always need special techniques for sampling. The flow of water in the soil shows special pattern in furrow-irrigated areas. This, in turn, influences the movement of mobile nutrients in the soil. In these areas, 3 samples must be taken; one from the hill top, one from the middle section and one from the bottom of the furrow. The depth of the sampling is based on the middle section sampling location, which is usually 30 cm.

Testing Soil Physical Properties

Soil Color Test

Test. The first test that we have to make is to register the color of the soil. This process does not require any sophisticated technique. It is usually described from the Munsell color chart. For our purposes, the simple identification of the main color of the soil is sufficient. Notice that wet soil looks darker than when it is dry.

Step 1: Take some soil ped from each soil horizon

Step 2: Break the ped

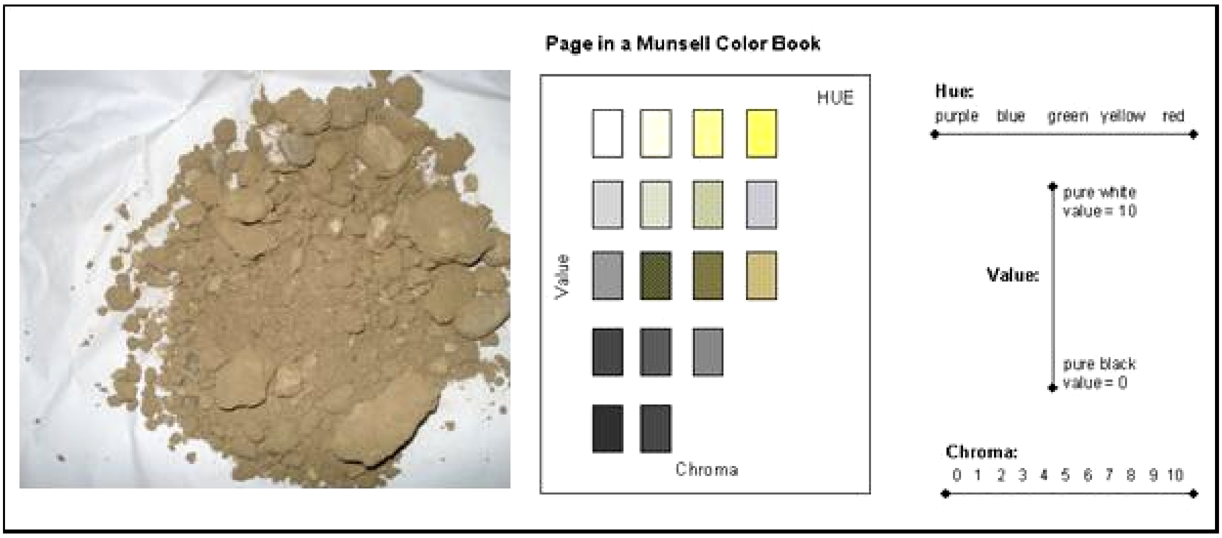
Step 3: Check the color of the ped according to the Munsell color chart. If the ped shows more than one type of color, indicate the dominant and the sub-dominant color.

Key to use the Munsell Color Chart:

- The Munsell Color Chart shows the different colors and a code
- The code below each color indicates the Hue, Value and Chroma, which belong to each color.
- The Hue is the first set of numbers and the letter indicates the position of the color on the color wheel. The symbol indicates the following:
    - Y=Yellow
    - R=Red
    - G=Green
    - B=Blue
    - YR=Yellow Red
    - RY=Red Yellow
- The number of Value indicates the lightness of the color (ranging from 0 to 10).
- Chroma indicates the intensity of the color from 0 on upwards. There is no arbitrary end on the scale to determine the maximum value.

Data analysis. Soil can be categorized in six groups according to the color and tone of the sample.

- Brown to Dark Black
- Black for surface horizon
- Dark Grey to Bluish
- White to Grey
- Dark Red
- Yellow to Reddish



Source: Photograph by Ferenc Sandor, Charts by K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison, Department of Soil Science

Existence of Coarse Fragments

Test. Estimate the percentage volume of coarse fragments (i.e. >2 mm) in each of the three size classes (gravel, cobbles, stones). The record should follow the fragment shape classification guide (rounded; sub-rounded and sub-angular; angular; thin, flat).

Step 1: This method uses samples collected in a metal can with specific volume (means that instead of collecting soil samples to fill up the can, the can is pushed into the soil horizon to obtain the sample).

Step 2: Dry the soil sample in oven and measure its weight

Step 3: Remove the sample from the can and measure the weight of the can.

Step 4: Fill the empty can with water. After that measure the volume of the water in a graduated cylinder.

Step 5: Sieve the soil sample using a #10 sieve (2 mm openings)

Step 6: Separate the rock fragments by size.

Step 7: Measure the weight of each group.

Step 8: Place a specific volume of water in a graduated cylinder.

Step 9: Place the group of fragments in the cylinder.

Step 10: Record the increase of water in volume. Do the measurement process for each group separately.

Data analysis

Key to classify coarse fragments by size:

- Gravel: Less than 75 mm size
- Cobbles: Between 75 mm and 250 mm size
- Stone: Between 250 mm and 600 mm size
- Boulders: More 600 mm size

The weight and volume of each group divided by the weight and volume of the original sample and multiplied with 100 will give us the percentage of rocky fragments in the sample (in weight or volume percentage).

<u>Equations:</u>

Proportion of coarse fragments = Weight of rock / weight of soil sample x 100 (%)

Source: Photos by Ferenc Sandor.

Proportion of coarse fragments =
Volume of rock / Volume of soil sample x 100 (%)
Key to classify coarse fragments by shape:

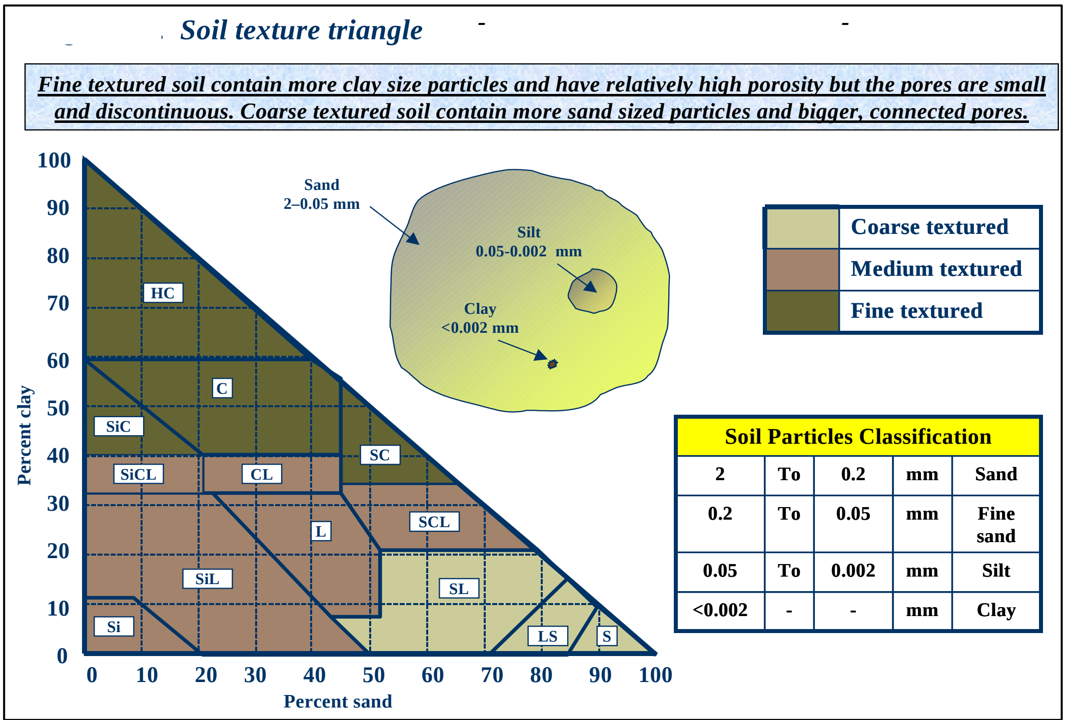
- Rounded
- Sub-rounded and Sub-angular (Slightly rounded or angular)
- Angular
- Flat-thin

Soil Texture Analysis

Soil texture is one of the most important physical properties of soil. It refers to the basic composition of the soil, which consists of sand, silt and clay contents. The soil texture directly or indirectly affects almost every single characteristic of the soil. The classifications of particle sizes are as following (units: mm):

- clay: < 0.002 (It is recognizable by its stickiness. It is hard and cloddy when dry)
- silt: 0.002 - 0.05 (Particles cannot be detected, but their presence makes the soil feel smooth and soapy and only very slightly sticky.)
- fine sand: 0.05 - 0.1 (Sand particles grate against each other and they can be detected by sight. Sand shows no stickiness or plasticity when wet.
- medium sand: 0.1 - 0.5
- coarse sand: 0.5 - 1.0
- very coarse sand: 1.0 - 2.0

Figure 6 Soil Texture Triangle



Soil Particles Classification				
2	To	0.2	mm	Sand
0.2	To	0.05	mm	Fine sand
0.05	To	0.002	mm	Silt
<0.002	-	-	mm	Clay

Source: F. Sandor, ROP Soil Test Laboratory, Jalalabad, Afghanistan

There are different methods to establish the soil sample's textural class.

Test - Method 1

1. Collect about 500 ml (2 cups) of soil and remove the bulk of organic matter from the top.
2. Let the sample dry.
3. Break up any clumps with a hammer.
4. Take a litre glass jar and put in 200 ml of soil sample (3/4 of a cup).
5. Fill up the jar with water and shake it for five minutes.
6. Wait 24 hours and measure the depth of the settled soil with a ruler.
7. Shake the jar again for 5 minutes, wait 40 seconds and measure the settled soil again.
8. Wait a further 25 minutes (total 30 minutes) and measure again.

Data analysis. After 24 hours the depth of the settled soil gives us the total amount of soil particles in the sample. The depth of the settled soil particles after 40 seconds gives the total sand content of the sample. Further 25 minutes of waiting enables the measuring of the sand and silting contents together in the sample.

Figure 7 Soil Particle Content Test

Source: Photos by Ferenc Sandor

Equations:

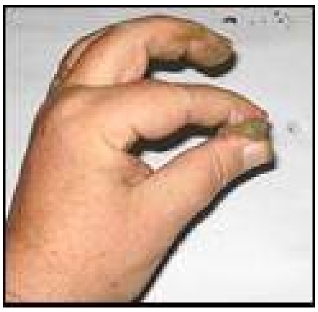
Silt content = [(Total silt + sand – Total sand) / Total soil] * 100
Clay content = [Total soil – (Total silt + sand)] / Total soil] * 100
Sand content = (Total sand / Total soil) * 100

Measuring unit: %

Test - Method 2

Graininess test: Rub the soil between your fingers. If sand is present, it feels “grainy”. Determine if the sand constitutes more or less than 50%.

oist cast test: Compress some moist soil by clenching it in your hand. If the soil holds together, toss it from hand to hand. The more durable it is, the more clay is present.



Stickiness test: Moisten the soil thoroughly and compress it between thumb and forefinger. Determine degree of stickiness by noting how strongly the soil adheres to the thumb and forefinger when pressure is released, and how much it stretches. Stickiness increases with clay content.

Worm test: Roll some moist soil between the palms of your hand to form the longest and thinnest worm possible. The longer, thinner and more durable worm contains more clay.

Taste test: Work a small amount of moist soil between your front teeth. Silt particles are distinguished as fine grittiness, sand is distinguished as individual grains and clay has no grittiness.

Soapiness test: Work a small amount of wet soil between your thumb and fingers. Silt feels slick and not too sticky (=clay) or grainy (=sand). The slicker it feels, the higher the silt

Source: Above five photos by Ferenc Sandor content. Generally, we can say that sand feels gritty, silt feels smooth and silky and clay feels sticky.

Table 1 Key for Test - Method 2.

Graininess Test		
Code	**Description**	**Details**
<50% sand	Contains less than 50% sand	Non-grainy to slightly grainy
>50% sand	Contains more than 50% sand	Grainy to very grainy

Moist Cast Test		
Code	**Description**	**Details**
FNC	Forms no cast	Less than 10% clay content
VWC	Very weak cast	Less than 15% clay content, no-handling
WC	Weak cast	Less than 20% clay content, careful handling
MC	Moderate cast	Less than 20% clay content, easily handled
SC	Strong cast	20-55% clay content, very easily handled
VSC	Very strong cast	More than 40% clay content, very easily handled

Stickiness Test		
Code	**Description**	**Details**
NS	Non sticky	Less clay content
SS	Slightly sticky	Moderate clay content
S	Sticky	High clay content
VS	Very sticky	Very high clay content

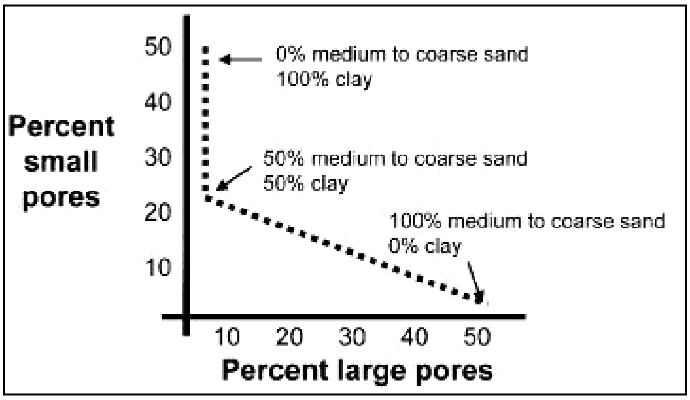
Worm Test		
Code	**Description**	**Details**
N	Worm: none	Very high sand content
>3d	Worm: variable	More than 3 mm diameter
3d	Worm: variable	3 mm diameter
1.5-3d	Worm: moderate	1.5-3 mm diameter
S	Worm: strong	1.5 mm diameter

Taste Test		
Code	**Description**	**Details**
NG	Non-gritty	High silt particle content
SG	Slightly gritty	High silt content, less sand content
G	Gritty	Moderate silt content, high sand content
VG	Very gritty	High sand content, less silt content

Soapiness Test		
Code	**Description**	**Details**
GC	Grinding compounds	High sand content
NSo	Non-soapy	Less silt content
SSo	Slightly soapy	Little silt content
So	Soapy	Moderate silt content
VSo	Very soapy	High silt content

Source: K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison, Department of Soil Science

Figure 8 Relationship Between Soil Textures and Pore Space Types



Source: K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison

Data analysis. The results of the second method can be transferred to a soil texture class using the following table:

Table 2 Soil Texture Classification Key for Test - Method 2

Soil Texture Classification (based on the test results)				
A side	**Result Code**	**Test Description**	**Result Code**	**B side**
Sand	> 50% sand	Graininess Test	< 50% sand	Silt
	FNC	Moist Cast Test	MC	
	NS	Stickiness Test	NS to SS	
	N	Worm Test	N or >3d	
	NG	Taste Test	VG	
	GC	Soapiness Test	VSo	
Loamy Sand	> 50% sand	Graininess Test	< 50% sand	Silt Loam
	VWC	Moist Cast Test	MC	
	NS to SS	Stickiness Test	NS to SS	
	N	Worm Test	N or 3d	
	NG to SG	Taste Test	G to VG	
	GC	Soapiness Test	So to Vso	
Sandy Loam	> 50% sand	Graininess Test	< 50% sand	Loam
	WC	Moist Cast Test	MC	
	NS to SS	Stickiness Test	NS to SS	
	N or >3d	Worm Test	N or 3d	
	NG to SG	Taste Test	SG to G	
	GC	Soapiness Test	SSo to So	
Fine Sandy Loam	> 50% sand	Graininess Test	< 50% sand	Silty Clay Loam
	MC	Moist Cast Test	SC	
	NS to SS	Stickiness Test	S	
	N or 3d	Worm Test	1.5-3d	
	G to VG	Taste Test	SG to G	
	GC	Soapiness Test	SSo to So	
Sandy Clay Loam	> 50% sand	Graininess Test	< 50% sand	Clay Loam
	SC	Moist Cast Test	SC	
	SS to S	Stickiness Test	S	
	3d	Worm Test	1.5-3d	
	NG to SG	Taste Test	NG to G	
	GC	Soapiness Test	NSo to So	
Sandy Clay	> 50% sand	Graininess Test	< 50% sand	Silty Clay
	SC	Moist Cast Test	VSC	
	S to VS	Stickiness Test	VS	
	1.5-3d	Worm Test	1.5d	
	NG	Taste Test	SG to G	
	GC	Soapiness Test	SSo to So	
		Graininess Test	< 50% sand	Clay or Heavy Clay
		Moist Cast Test	VSC	
		Stickiness Test	VS	
		Worm Test	1.5d	
		Taste Test	NG to SG	
		Soapiness Test	NSo to So	

Source: K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison

Test – Method 3. A field analysis is carried out in the following way: a small soil sample is taken and water is added to the sample.

- Place the soil in your palm and knead it to break up aggregates
- Place a ball of soil between your thumb and forefinger. Push the ball with your thumb, squeezing it upwards into a ribbon. Allow the ribbon to emerge and extend over the forefinger. It should break from its own weight.
- Saturate a small pinch of soil in palm and rub with forefinger

Source: Photo by Ferenc Sandor.

Data analysis.

- If the soil does not remain in a ball when squeezed the soil is sand
- If the soil remains in ball when squeezed continue with the formation of ribbon. If the soil does not form a ribbon the soil has Loamy – Sand texture
- If the ribbon is less than 2.5 cm long before breaking and feels gritty, the texture class is Sandy – Loam
- If the ribbon is less than 2.5 cm long before breaking and feels smooth, the soil is a Silt – Loam
- If the ribbon is less than 2.5 cm long before breaking and does not feel gritty and smooth, the texture is a Loam
- If the ribbon is 2.5-5.0 cm long before breaking and feels very gritty the texture class is Sandy – Clay – Loam
- If the ribbon is 2.5-5.0 cm long before breaking and feels smooth the soil is a Silty – Clay – Loam
- If the ribbon is 2.5-5.0 cm long before breaking and does not feel gritty and smooth, the texture is a Clay - Loam
- If the ribbon is strong, equal or more than 5.0 cm long before breaking and feels gritty, the texture class is Sandy – Clay

- If the ribbon is strong, equal or more than 5.0 cm long before breaking and feels smooth, the soil is a Silty – Clay

- If the ribbon is strong, equal or more than 5.0 cm long before breaking and does not feel gritty and smooth, the texture is a Clay

Soil Consistence Test

Test. This is a very simple test. Take a soil ped between your thumb and forefinger and squeeze it until it pops or fall apart. If the soil is too dry squirt a small quantity of water on it.

Source: Photos by Ferenc Sandor

Data analysis. There are four categories for the result of the test:

- Loose: The soil structure falls apart before you handle it
- Friable: The ped breaks under small pressure
- Firm: The ped breaks under strong pressure
- Extremely firm: The ped does not break at all

Soil Structure Test

This test is based on observation instead of a laboratory analytical test. Therefore, it requires some experience from the observer.
Test. Remove a sample of soil from the soil horizon and hold it gently. Look and analyze the geometric shape of the macro aggregates.

Data analysis. There are seven main categories for soil structure.

Source: Photo by Ferenc Sandor

Table 3 Soil structure classification

Code	Description	Details
BK	Blocky	Irregular blocks that are usually 1.5-5.0 cm in diameter. Peds bounded by flattened, rectangular faces intersecting at relative sharp angles or bounded by slightly rounded, sub-rectangular faces with vertices of their intersections mostly sub-rounded
GR	Granular	Spheroidal peds bounded by curved or very irregular faces that do not adjoin those of adjacent peds. Resembles cookie crumbs with less than 0.5 cm diameter. Typical structure for surface horizons.
PL	Platy	Peds flat or plate like, horizontal planes more or less well- developed. Usually found in compact soils.
PR	Prismatic	Vertical faces of peds well defined and vertices angular (edges sharp), prism tops essentially flat. Frequently found in lower horizons.
COL	Columnar	Vertical edges near top of columns not sharp (vertices sub-rounded); columns top flat, rounded or irregular. This type of structure is common in arid areas.
SGR	Single grained	Loose, incoherent mass of individual primary particles, as in sands. No soil class.
MA	Massive	Amorphous, a coherent mass showing no evidence of any distinct arrangement of soil particles; separates into clusters of particles, not peds. No soil class.

Source: K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison

Bulk Density Test

There are several methods, from the simple to the sophisticated, to measure the bulk density of the soil. Bulk density indicates how dense the soil is and how tightly it is packed according to the shape of the soil peds and the percentage of air space or pores. It is directly related to the compaction level of the soil. The bulk density indicator is measured with the dry mass per volume in g/cm^3 or g/ml.

Test – Method 1. The volumetric displacement procedure uses a ring with a hook gage and plastic sheet. First, fix the ring on the soil and place a plastic sheet inside the ring. With a graduated cylinder, fill up the ring to measure the background volume. After removing the plastic, take the soil sample to a specified depth. Place the plastic sheet back in the ring and fill it up again from the graduated cylinder (thus measuring the total quantity of water). After that, dry the soil in the oven (110 Cº) and measure its weight.

Data analysis. The method provides representative values, therefore it can be used for fields are not sampled.

Equations:

Step 1: Soil sample volume = Total volume of water – Volume of background water

Step 2: Bulk density = Dry soil weight / Soil sample volume (g/cm^3 or g/ml)

Test – Method 2. Take a graduated cylinder and measure its weight. Fill up the cylinder with a dry soil sample. After that, record the marking indicated on the cylinder. Measure the weight of the soil and cylinder together. This test is accurate for single grained sandy soils.

Source: Photos by Ferenc Sandor.

Equation:

$$\text{Bulk density} = \frac{\text{Weight of cylinder and soil – weight of cylinder (soil mass)}}{\text{Volume of soil}}$$

Measuring unit: g/cm^3 or g/ml

Data analysis. This method cannot compete with other more accurate laboratory measurements, but it is simple and can be used to analyze soil properties. It is mostly applicable for sandy soils.

Test – Method 3. This method uses samples collected in a metal can with a specific volume. Instead of collecting soil samples to fill up the can, the can is pushed into the soil horizon to obtain the sample.

The soil must be removed, dried and finally measured for weight. After recording its weight, the soil sample should be sieved and particles larger than 2 mm (rock content) should be removed, measured for weight and kept separately.

The empty and cleaned can will then be filled with water. After that, the volume of the water will be measured in a graduated cylinder.

Take a graduated cylinder and fill it with water to a specific volume (e.g. 100 ml). The last part of the testing process is to take the larger particles (more than 2 mm) and place them in the graduated cylinder, which contains the specific volume of water. After this, measure and register the value shown on the scale of the cylinder.

Data analysis. The weight of the dry soil sample gives the mass of the soil. The measured water volume, which needs to be filled up in the metal can, is equal to the volume of the soil sample.

Equations:

Total Bulk density = Dry soil sample / Volume of can (g/cm^3 or g/ml)

Volume of rock content = Rock and water volume – water volume (cm^3 or ml)

$$\text{Soil Bulk density} = \frac{\text{Dry soil weight – Rock content weight}}{\text{Can volume – Rock content volume}}$$

Measuring unit: g/cm^3 or g/ml

Source: Photos by Ferenc Sandor.

Particle Density (Real density) Test

The particle density test measures the mass of the soil in a specific volume, which is very similar to the bulk density test. The main difference is that the particle density only measures the density of the soil particle component and excludes the volume of pore spaces, which contains air and water.

Test. First we take a graduated glass container and measure its weight. Then place 25 g of a soil sample inside the container. Measure and register the weight of the soil together with the container.

With some water added, boil the mixture for 10 minutes to remove all air bubbles. Once the container has cooled, place it in a cup and let it sit for 24 hours.

After 24 hours, fill up the container with water to a total volume of 100 ml and measure the weight and temperature of the mixture.

Data analysis. The particle density is calculated from the mass of the solid particles in a specific volume.


Source: Photographs by Ferenc Sandor.

Equations:

Mass of soil = Mass of soil and container – Mass of empty container (g)

Mass of water = Mass of water, soil and container - Mass of soil and container (g)

Volume of water = Mass of water / Density of water (cm^3 or ml), where the density of water equal to 1.0 g/cm^3 or g/ml

Volume of soil = Given volume of mixture (100 ml) – Volume of water (cm^3 or ml)

Soil particle density = Mass of soil / Volume of soil (g/cm^3 or g/ml)

Soil Porosity Test

The fraction of pore space in the soil is called soil porosity and it measured in percentage.

Test – Method 1. The measurement procedures include two test:

- Bulk density test
- Particle density test

Data analysis. The porosity value always will be less or equal than 1. This value multiplied by 100 gives the percentage of porosity.

Equation:

Porosity = [1 – (Bulk density / Particle density)] x 100 (%)

Test – Method 2. This method directly calculates the porosity from the volume of air and volume of soil of the sample. The method is accurate for testing sandy soils. It is simpler and less accurate then that the previous method, which is used to calculate the two density indicators and establishes the soil porosity value. However, it is a sufficient representative for the description of the soils main physical properties.

Source: Photos by Ferenc Sandor.

Step 1. Weight an empty graduated cylinder and record the value. Then pour a sample of dry soil into it and measure the weight again.

Step 2. Measure also the volume of dry soil in the cylinder alone and record it.

Step 3. Measure a specific volume of water in another graduated cylinder and record the value. Once finished, add the water to the soil and then place it in the other cylinder. Stir the mixture until the water can completely penetrate the soil. (It not will be entirely as accurate as the procedure described in the particle density test due to the fact that, without heating the sample, some microscopic volumes of air will remain between the soil particles.)

Step 4. Measure and record the volume of the soil and water mixture.

Data analysis. Use the recorded values to calculate the total porosity of the soil.

<u>Equations:</u>

Mass of the soil = Mass of cylinder and soil – Mass of cylinder alone (g)

Bulk density = Mass of the soil / Volume of the soil (g/cm^3 or g/ml)

Pore space volume = Volume of soil + Volume of water – volume of soil and water (cm^3 or ml)

Porosity = Pore space volume / Volume of soil x 100

Soil Moisture Tests

The water holding capacity of a specific soil type is very important to calculate the necessary volume and frequency for irrigation during production.

Test 1. – “0” Bar Water Holding Capacity. Take a Gooch Crucible or make one (small pot with sufficient small holes to retain soil samples in the pot). Record its weight. Fill up to ¾ of the pot with soil sample, record the weight and place the pot in a small dish, which is half filled with water. Leave it for 20 minutes in the water and measure its weight again.

Data analysis. The water holding capacity will be the relationship between the weight of wet soil and dry soil in percentage.

Source: Photos by Ferenc Sandor.

Equations:

Weight of the dry soil = Weight of dry soil and pot – Weight of the pot (g)

Weight of wet soil = Weight of wet soil and pot – Weight of the pot (g)

Weight of water = Weight of wet soil – Weight of dry soil

Water holding capacity by mass = (Weight of water / Weight of the wet soil) x 100 (%)

Volume of water = Weight of water / Density of water (1g/cm^3 or ml)

Water holding capacity by volume = (Volume of water / Volume of Gooch Crucible) x 100 (%)

Test 2. – "European" Maximum Water Holding Capacity. Saturate the soil sample with water in a cylinder. Place the cylinder on an absorbent membrane until the excess water is drawn away by gravity. Wait until the equilibrium is reached.

Source: Photos by Ferenc Sandor.

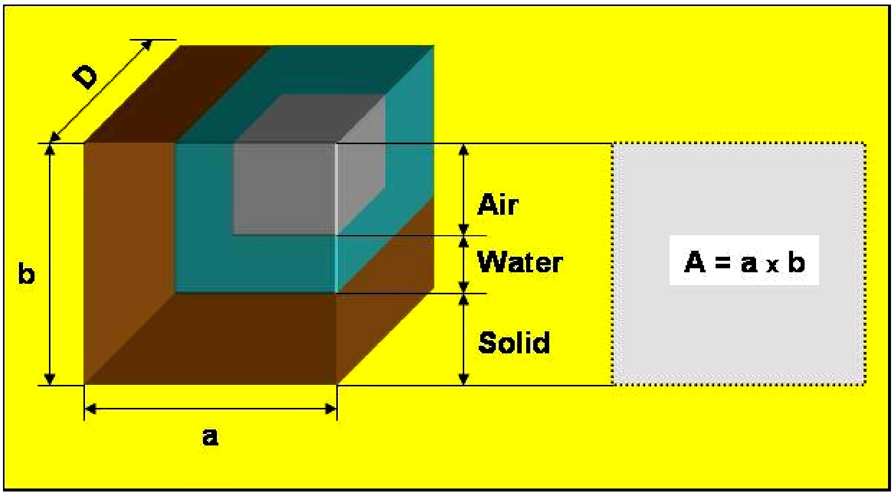
Data analysis. The water holding capacity is calculated based on the weight of the water held in the sample vs. the sample dry weight. (See equations of "0" Bar water holding capacity)

Test 3. - Depth of water and Aeration porosity test allows one to calculate and compare the solid, water and air proportion capacity between different types of soil. It does not require additional laboratory tests, since we have already obtained these results from the previous tests. This method enables one to analyse the density, porosity and water holding capacity indicators so that the depths of water and aeration porosity can be established. Aeration porosity is the volume of air, which fills the pore space in the soil.

Data analysis. The calculation uses the volume of a cube, which measures 10cm x 10cm x 10cm equal to V = 1000 cm^3 or ml (1 litre). If the previous tests were not made, take a container cube of soil sample with this measurement and calculate the different test indicators. This cube will have 100 cm^2 surface area (A) and 10 cm depth (D). The result will be a 3 dimensional diagram. The necessary indicators for the equations are:

- Weight of the wet soil (Total wet mass) for 1000 cm^3
- Weight of the water (Water mass)
- Particle density
- Cubic volume = Wet soil volume = Soil bulk volume (V): 1000 cm^3 or ml
- Surface area (A): 100 cm^2

Figure 9 Air, water and soil depth



Source: F. Sandor, RoP Soil Test Laboratory, Jalalabad, Afghanistan (2007)

Equations:

Water volume = Weight of water / Water density (cm^3 or ml), where water density equal to 1g per cm^3 or ml.

Depth of water = Water volume / Surface area (A) (cm)

Weight of solid (Dry soil) = Weight of wet soil – Weight of water (g)

Volume of solid = Weight of solid / Particle density

Depth of solid (soil) = Volume of solid / Surface area (A) (cm)

Depth of air = Depth of cubic (D) – [Depth of solid + Depth of water] (cm)

Water weight when saturated = (Water depth + Depth of air) x Water density (g)

Weight of dry soil = Depth of soil x Particle density (g)

Water holding capacity (Saturation water content) = [Weight of water when saturated / weight of solid (Dry soil)] x 100 (%)

Air volume = Depth of air x Surface area (A) (cm^3 or ml)

Aeration porosity = [Air volume / Cubic volume (V)] x 100 (%)

Interpretation of Soil Test Results for Physical Properties

Soil Color

Color indicates chemical, biological and physical transformations and translocations that have occurred within a soil. Soil organic matter causes a dark brown to black color in the soil. The higher the organic matter content of the soil, the darker the color. A bright and light color can be related to an alluvial horizon, where carbonates and clay minerals have been leached out. Subsoil color is related more to physical and chemical processes. In well aerated soils, Fe^{3+} is present, which gives the soil a yellow or reddish color. In poorly drained soils under anaerobic conditions, the iron compounds are reduced and the Fe^{2+} content shows itself as a dark grey color. The presence of iron sulphides is indicated by with a bluish-green color. A black color in the subsoil can be related to an accumulation of manganese. In arid or sub-humid regions, surface soils may be white due to evaporation of water and soluble salts. Sometimes the parent material influences the color of the soil. Basalt parent material can cause a black color in the sub-surface soil. Light gray or nearly white color is often inherited from parent material, such as marl or quartz.

Table 4 Main soil color categories

Soil color	Attributes and conditions
Brown to dark black	It has high organic matter content, which is well humified. Fertile soils. Developed under humid grassland. Organic matter content is around 7%
Black (subsurface horizon)	It indicates Manganese accumulation. Very hard when it is dry. Slowly permeable for water and roots. Usually the subsoil is rich in clay content. Frequently sodic or alkali soil.
Dark grey, bluish	It contains reduced Iron (Fe_2^+). They normally poorly drained soils. Its permeability is very low, which causes anaerobe conditions in the soil. It frequently waterlogged.
White to grey	Accumulation of salts. Developed under conditions, when the evapo-transpiration is higher than precipitation. There is an upward movement of water and soluble salts in the soil.
Dark red	Iron and aluminium accumulation. Feral and Ferro soils
Yellow to reddish	Rich in oxidized Iron (Fe_3^+). They are well aerated soils.

Source: K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison, Department of Soil Science

Existence of Coarse Fragments

Particles larger than 2 mm can modify the physical properties of the soil (water penetration, soil aerated condition, etc.), which is mainly determined by the soil texture and structure. It also influences the kind of crops that can be planted and dictates the ease in which the soil can be handled during land preparation. For example, citrus can be cultivated even in extremely bouldery soil.

Table 5 Coarse fragment classification

Shape	Size in mm	Definition
Rounded, Sub-rounded, Sub-angular, Angular	2-5	Fine gravely
	5-20	Medium gravely
	20-75	Coarse gravely
	75-250	Cobbly
	250-600	Stony
	>600	Bouldery
Flat	2-150	Channery
	150-380	Flaggy
	380-600	Stony
	>600	Bouldery

Source: K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison,

During soil tests, remove the course particles larger than 2 mm. In accordance to the abundance of these fragments in the soil, a modifier can be added to the soil textural class.

Table 6 Modifiers for coarse fragments

Volume of fragments in %	Modifier definition
<15	No modifier
15-30	Gravelly loam
30-60	Very flaggy loam
>60	Extremely bouldery loam

Source: K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison

Soil Texture

When the soil texture class of the sample is established, one can have quite a good picture about the soil physical properties. This information is crucial to establish adequate land husbandry practices. It also enables one to measure the possibility of risks, such as erosion, and it helps to select adequate crops for production.

Table 7 Description of soil texture categories

Code	Description	Details
S	Sand	Coarse textured soils with sand size minerals. They have more porosity with bigger pores, which does not allow storing water efficiently. Sandy soils are generally dry and infertile. Available water for plant: 2.5-3.0 cm per 30cm soil
LS	Loamy sand	
SL	Sandy loam	
FSL	Fine sandy loam	
SCL	Sandy clay loam	Fine textured soil with more clay size minerals, high porosity, but small discontinuous pores.
SC	Sandy clay	
Si	Silt	Silt is more cohesive than sandy soils. Silt particles are between 0.05 and 0.002 mm large.
SiL	Silt loam	
L	Loam	Balanced soil with 40-45% sand, 30-40% silt and 20-25% clay. Preferred for crop production. Silty soils warm fairly quickly and have good water-holding capacity without becoming waterlogged. The most suitable texture for the greatest variety of living organisms. The texture of loam type soils lies between coarse and fine. Loam type soil with high organic matter content generally has a granular structure and is dark in color. Available water for plant: 3.8 cm per 30 cm soil.
SiCL	Silt clay loam	Fine textured soil with more clay size minerals, high porosity, but small discontinuous pores. The soil usually shows platy structure because they subject to leaching or compaction.
CL	Clay loam	
SiC	Silt clay	
C	Clay	Very dense, slowly permeable layer for plant roots. Little porosity. Fine textured soil with more clay size minerals, high porosity, but small discontinuous pores. Clay and heavy clay soils have a large total pore space, although individual pores have a small diameter and are tortuous. This type of soil is capable of holding a huge quantity of water, but water movement is very slow due to high surface tension. Often waterlogged. Problems with ventilation, because air movement is also very slow. The process of mineralization is restricted in this type of soil. Available water for plant: 5.0 cm per 30 cm soil.
HC	Heavy clay	High bulk density and little porosity. Fine textured soil with more clay size minerals, high porosity, but small discontinuous pores. Very difficult for plant roots to penetrate it. High clay content soils generally have a blocky structure. When the surface is dried up it shows cracking and peeling.

Source: F. Sandor. Modified version of K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison

The fine and medium-textured soils (e.g. clay loams, silty clay loams, sandy silt loams) are favorable for production, due to their high available retention of water and exchangeable nutrients.

The coarse-textured soils permit rapid infiltration due to their large pores between particles. The infiltration rates of finer-textured soils are smaller sine the pore space between particles are mainly micro pores.

Soil texture also affects the soil temperature. Fine-textured soils hold more water than coarse-textured soils, therefore, the fine-textured soil heats up slower than the coarse-textured soils.

The adsorption of cations (nutrients) and the microbial activity are dependent on the total surface area of the soil. The fine textured soil has a larger total surface area than that of the coarse textured soil (Decreasing the particle size, increasing the surface area and vice-versa).

Sandy textured soil: It is characterized by its high porosity. These are coarse textured soils with sand size minerals. They have bigger pores that do not permit the efficient storage of water. Generally, they are dry, infertile soils. The available water for plant: 2.5-3.0 cm per 30cm soil. The organic matter content reduces fast. Conditions inside the soil are aerobic. There is high risk for erosion.

Loam textured soil: These are well-balanced soils with 40-45% sand, 30-40% silt and 20-25% clay. They are preferred for crop production. Loamy soils with a high proportion of silt warm fairly quickly and have good water-holding capacity without becoming waterlogged. Loam has the most suitable texture for the greatest variety of living organisms. The texture varies between coarse and fine. Loam type soil with high organic matter content generally has a granular structure and is dark in color. Available water for plant: 3.8 cm per 30 cm soil.

The main problem with this type of soils is the loss of organic matter and degradation of soil structure. Human intervention in cultivation can cause this. Intensive fertilizer application and land use reduce the available micronutrients in the soil and lower the pH factor to a damaging degree. Under strong heat, uncovered land quickly loses its organic matter content, increases the erosion and microbiological decomposition.

Clay textured soil: It is fine textured soil with more clay size minerals, high porosity, but small discontinuous pores. These soils generally have a blocky structure. When the surface is dried up, it shows cracking and peeling. Clay and heavy clay soils have a large total pore space, although individual pores have a small diameter and are tortuous. The process of mineralization is restricted in this type of soil. Available water for plant: 5.0 cm per 30 cm soil. They are very fertile soils, but hard to work. There is high bulk density and little porosity. It is very difficult for plant roots to penetrate. Clayey soils are often waterlogged. These types of soils are capable of holding a huge quantity of water, but movement of water is very slow due to high surface tension. Inside the soil the ventilation is poor and air movement is very slow, too.

Between production, soil texture and several other indicators of the soil, such as bulk density, particle or real density, air space fraction, porosity and water holding capacity, the relationship is direct. These indicators provide valuable information about soil conditions and characteristics, which influences the production and yield of the crops.

Soil Consistence

This loose category indicates single grained structure, which is very typical for sandy soils. The particle size is large and organic matter content is very low. They are extremely poor soils. Friable consistence indicates the composition of different size of particles, the presence of organic materials and microbiological activities in the soil. Firm consistence indicates the dominance of small particles such as clay with higher soil particle density. The extremely firm consistence is typical for hard, very compact and massive soil structure with a lack of macro pores in the pore space of the soil. In this type of soil, the biochemical reactions thrive under anaerobe conditions.

Soil Structure

Granular Structured Soil

This soil tends to lose fertility. Intensive chemical fertiliser use can change the soil pH, which will result in a decrease both in useful microbiological life and in organic matter content. It is especially likely that micronutrients will be absent because the applied fertilisers do not contain them.

Tilling the soil radically lowers its fertility. When tilled for the first time, soil can lose up to 50% of its organic matter. Many farmers plough the soil twice for land preparation. This practice should be avoided. Microbes burn up the organic matter and release carbon dioxide. Humus is lost from the unprotected surface of the already thin top layer. The application of organic fertiliser will not redress the imbalance, because the microbes will burn up the humus content faster than the soil is able to produce it.

Ploughing too deeply as well as intensively will turn up less structured soil into the topsoil level. Moreover, intensive ploughing, in destroying the structure of the soil, increases the leaching mechanism in it.

Farmers frequently break up the surface soil structure into dust. This method causes irreparable damage in the soil structure, and the term given to the outcome is *fine laboured soil surface*. After irrigation the dust becomes a cemented film on the surface hindering the proper ventilation of the soil.
Shifting production areas without replacing nutrients lost to the soil decreases fertility. It is a common practice for smallholder farmers to shift their production areas every 2-3 years, rather than replenish lost nutrients.

Exposed to the heat of the sun, the uncovered soil surface is generally damaged in subtropical areas during the dry season.

This type of soil carries a risk of compaction by animals and machinery. The wheels of machinery and continuous cropping reduce both the organic matter content and the granular structure of the soil as well as lowering the pore space. Compaction also happens in open land with granular soil that has been subjected to shallow cultivation.

Platy Structured Soil

The main problem with platy structured soils is soil compaction caused by the action of animals and machinery. These soils usually have higher bulk density, because they have less pore space, especially the fine-texture platy soils. This high bulk density heavily affects root penetration into the soil.

The loss of color and fertility is usually found in the subsurface layer. The soils are often grey, and become pale, with the soil's organic matter leaching down from the soil horizon. The greyish, thin A-horizon characterized by the eluviations of clay, Fe, Al, or organic matter alone or in combination. The B-horizon is slightly altered by hydrolysis, oxidation and solution, or all three of them giving a change in color and/or structure.

Blocky, Prismatic and Columnar Structured Soil

They are very hard soils, difficult to work with. The plant root has difficulty penetrating these dense soils, and in some cases it is almost impossible. These soils tend to swell under wet conditions, and crack when dry. The clay content is high, mainly 2:1 type expanding clay. Land preparation for planting is an especially difficult task.

The prismatic types of soil are of especially low quality and infertile. They normally occur in the lower horizons instead of the surface, but their presence in the surface horizon usually indicates sodic or alkaline conditions. Prismatic and columnar structured soils crack vertically.

Un-structured and Massive Soil

Un-structured and massive soils may be sandy or clayey soils. Both kinds of soil are very commonly found in young soils called entisols, such as are found in the river alluvium or shifting sands. They are typically associated with bedrock outcrops and salt flats. Human activity contributes to the formation of these soils, because the high erosion resulted by deforestation and other human activities provides appropriate conditions for the development of shallow, eroded soils.

Sandy soils have high bulk density and low porosity. The air ventilation is high, the chemical reactions are mainly aerobic, resulting in the almost complete loss of organic matter. Sandy soil cannot retain water and dries up very fast.

Massive clayey soils have less bulk density and higher porosity. The water retention capacity is high, but this is poorly ventilated soil, therefore the anaerobic conditions do not permit the fast decomposition of the organic matter accumulated in the higher horizon.
They cannot be farmed intensively. The restrictions on their depth, clay content and water balance do not allow the intensive use of these soils over large areas.

Bulk Density

If the bulk density is less or near to 1.0 it means, that the soil density is low and it should have high organic matter content. Dark color of the soil may confirm this fact. If the value is higher than 2.0, we consider the soil a very dense soil. The reason can be various, but usually we can find the cause in compaction of the soil and low organic matter content. Sandy textured soils have higher bulk density than clayey soils.
The bulk density of sandy soils is higher than 1.6, the value for loam type soils are generally between 1.2 and 1.6 and clayey soils have a bulk density less 1.2. When soil's bulk density value is less the available water and water holding capacity of the soil is higher.

Particle Density

The particle density measures the mass of the soil in a specific volume without the pore space volume. In other words, it is focusing on particle volume and not total volume of the soil. Therefore, its value comes from the chemical composition, structure of the soil minerals and organic matter. High particle density indicates the presence of minerals with high density, which usually comes from the parent material. Therefore, the particle density value also provides information about the pedogenesis (soil formation) of that particular type of soil. Low value of particle density indicates the presence of high organic matter content. If the organic matter content is high, we know that the soil erosion risk is low, the soil nutrient content is usually balanced, the moisture retention in the soil is high and the soil is fertile.

In the case of dense soils, particle density value is higher than 2.6-2.7 and can even be higher than 3.0. Low particle density has a value lower than 0.9. Bulk density and particle density value allow us to calculate the soil porosity.

Soil Porosity

The pore space content of the soil is called *porosity* and is calculated from the ratio between the bulk and the real density and converted into a percentage, thus:

Porosity = (1 – Bulk density / Particle density) x 100

There are two types of pore spaces: macro (larger than 0.06 mm) indicating the spaces between aggregates and micro (smaller than 0.06 mm.) for the space within individual aggregates.

Table 8 Pore space content in the main soil types

Soils different in texture	Porosity [%]	Macro pores [%]	Medium-sized pores [%]	Micro pores [%]
Sandy soils	46 (+/- 10)	30 (+/- 10)	7 (+/- 5)	5 (+/- 3)
Silty soils	47 (+/- 9)	15 (+/- 10)	15 (+/- 7)	15 (+/- 5)
Clayey soils	50 (+/- 15)	8 (+/- 5)	10 (+/- 5)	35 (+/- 10)
Organic soils	85 (+/- 10)	25 (+/- 10)	40 (+/- 10)	25 (+/- 10)

Source: Scheffer et al, 1989

Coarse-textured soils permit rapid infiltration because of the predominance of large pores, while the infiltration rates of finer-textured soils is smaller because of the predominance of micro pores.

Porosity also influences the soil hydraulic conductivity, which means the simplicity of how water can move through pore spaces in the soil. More open area for the flow of water shows higher hydraulic conductivity. However, the relationship between the two indicators is mainly useful for the comparison of two similar textured soils, such as two sandy soils. In this case the higher porosity indicates higher hydraulic conductivity. In case of differently textured soils the complications are more significant. A clayey textured soil has high porosity, but its hydraulic conductivity is low. Therefore, these types of soils can hold a large volume of water without releasing it. The pore sizes and their connectivity determine whether a soil has high or low permeability. Water flows easily through soil with large pores with good connectivity between them. Small pores would have lower permeability, because water would flow through the soil more slowly.

Highly developed soils are well sorted. The soil peds and particles generally have the same size, which also creates a well - developed and interconnected pore space structure. Therefore, the soil has higher porosity too. Granular structured soils with optimal organic matter content show this characteristic. Poorly sorted soils with different size of peds have lower porosity, because the smaller particles fill the pores, where air and water flow. Intensive agro-technique and chemical use break down peds and create this effect in two ways: first, breaking down the peds to different sizes; secondly, affecting microbiologic activities and reducing organic matter content, which glue together the soil particles into soil peds. It frequently causes soil compaction too.

Porosity of surface soil typically decreases as particle size increases. Porosity of subsurface soil is lower than in surface soil due to compaction by gravity.

Soil Moisture Analysis

Moisture, water holding capacity and aeration in soil are directly related to the soil texture. The soil texture tells us about the particle distribution in the soil, which allows us to guess quite accurately the “behavior” of the soil.

Part of this behavior is the water-solid-air combination and characteristics. The small particles, such as clay and silt, are able to hold large quantities of water due to their total surface area being much larger than that of the bigger, sand sized particles. The combination and proportion of the three basic types of particles will have a specific water holding capacity, which indicates the type of particle dominant in the soil.

This type of soil behavior is also applied for studying other soil characteristics. For example, water flow slows down in clayey soils due to the smaller pore sizes between particles. These types of soils would reach the saturation point later than the sandy soils, which have limited water holding capacity. This fact is crucial to establish adequate irrigation practices. After the soil reaches the saturation point, all excess water with the soluble nutrients and chemicals will leach downward into the lower horizons from the topsoil.

The soil and water depth together, along with the aeration porosity, give us a good picture about the proportion of air, moisture and solids in the soil. In a “healthy” soil, the three have an optimal relation to each other.

Obviously there is a plus-minus margin for each soil texture characteristic. It exists according to the higher or lower content of the modifier elements. The two most important modifiers are the organic matter content and the presence of coarse fragments in the soil. Both of them directly modify the soil structure even if the texture types are the same.

Table 9 Physical properties of sand, loam and clay

Texture		Bulk Density (g/cm^3)	Porosity (%)	Field capacity (%)	Available water (Volume %)	Available water (cm H_2O/30cm soil)
Sand	Coarse	1.6	40	17	8	2.5
Loam	Medium	1.2	55	24	13	3.8
Clay	Fine	1.05	60	36	16	5

Source: F. Sandor. Modified version of K. McSweeney, S. Grunwald., 1999. Soil Morphology, Classification and Mapping. University of Wisconsin-Madison

Testing Soil Chemical Properties

The following chapter will present and explain the use of two types of soil testing kits in order to give opportunity for soil property analysis where the service of a soil chemistry laboratory is not available. The results may give sufficient information to the growers and allow for recommendations for fertilizer use and application.

La Motte Soil Test Kit

Source: Photos by Ferenc Sandor

The La Motte soil testing equipment allows one to test the soil quickly and simply. To perform the different tests, use dry and sieved soil samples. The drying process might be an air drying process. Do not use oven dried samples for these tests.

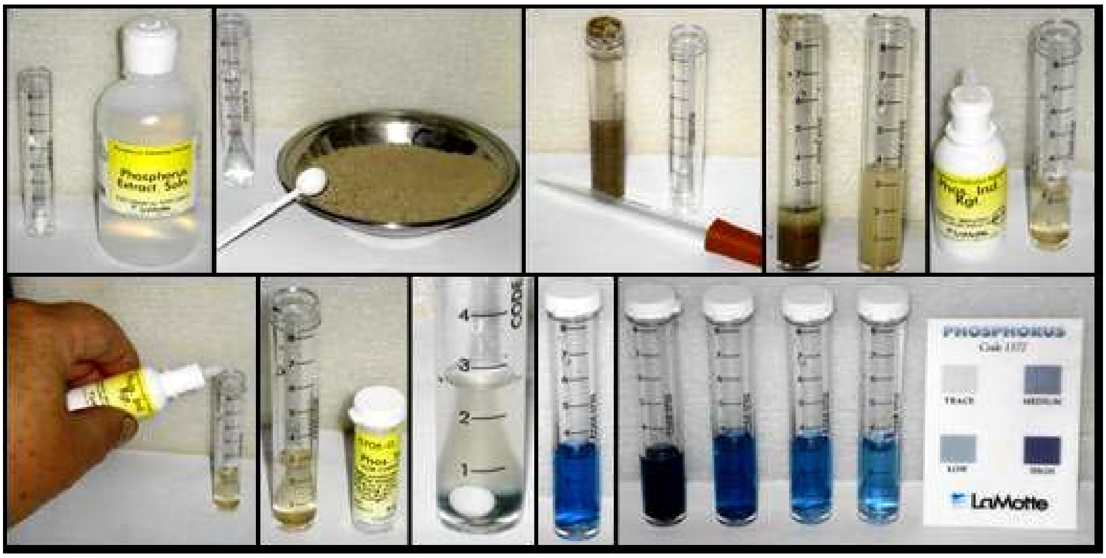
Test. pH analysis test uses the pH scale numerical system to measure the acidity or alkalinity of the soil. After filling the test tube with the indicator solution, add some soil sample to the indicator. Cap the tube and gently mix the soil and indicator solution for 1 minute. After 10 minutes of waiting, match the color of the solution with pH Color Chart.

Data analysis. The color chart indicates the pH numeric value of the sample. It is not indicate decimal values. According to obtained color, the soil sample belongs one of the three main groups: alkaline, neutral or acidic. The Neutral point is 7.0 and the neutral range is between 6.0 and 8.0 (With other pH test methods, which are able to indicate decimal values, this range would be considerably less). pH value less than 7.0 are considered acidic and values higher than 7.0 are considered to be an alkaline.

Source: Photos by Ferenc Sandor

Test. Available Phosphorus analysis measures the available phosphorus in the soil sample. First, fill up the tube with Phosphorus Extracting Solution. Then add the soil sample to the solution and cap. After gently mixing the soil with the extracting solution, wait until the soil settles down in the tube. From the clear liquid, transfer some of the sample into the other test tube and add six drops of Phosphorus indicator to the sample.

Finally, put one Phosphorus Test Tablet in the tube. Shake the tube until the tablet completely dissolves and match the color with the Phosphorus Color Chart.

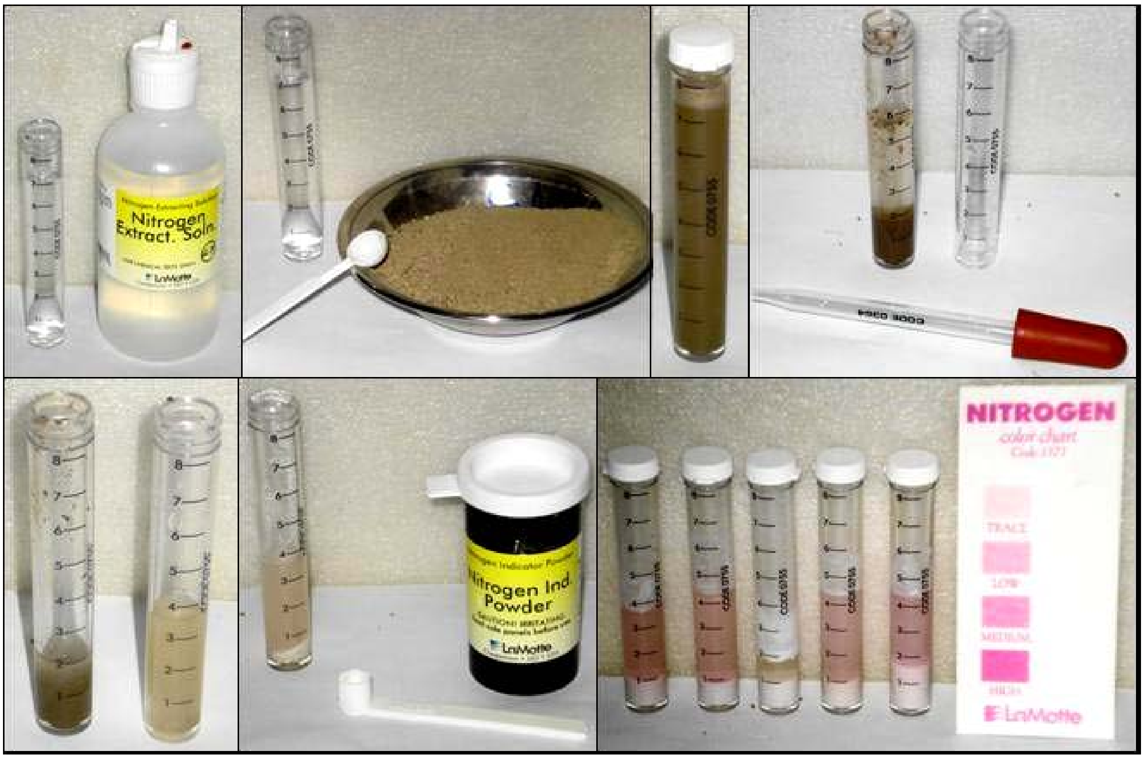


Source: Photos by Ferenc Sandor

Data analysis. The Phosphorus Color Chart allows soil samples to be classified into four groups based on the phosphorus content of each group. The four categories are as follows:

- Trace: Indicates very low available phosphorus content in the soil
- Low: Indicates low available phosphorus content in the soil
- Medium: Indicates optimum level of available phosphorus content in the soil for production
- High: Indicates high available phosphorus content in the soil. The plant does not need additional phosphorus fertilizer application.

Test. Available Nitrogen analysis uses a preparation method similar to the phosphorus test. First, mix the Nitrogen Extracting Solution with the soil sample for one minute and wait until the soil settles in the test tube. When the liquid is clear, pour part of it into another test tube and add to it 0.5 g Nitrogen Indicator Powder. After mixing the tube content, wait another 5 minutes before the solution color can be compared with the Nitrogen Color Chart.



Source: Photos by Ferenc Sandor

Data analysis. The color chart shows a similar four categories, as opposed to the Phosphorus Color Chart. According to the chart, the available nitrogen in the soil sample can be in quantified in trace, low, medium and high levels.

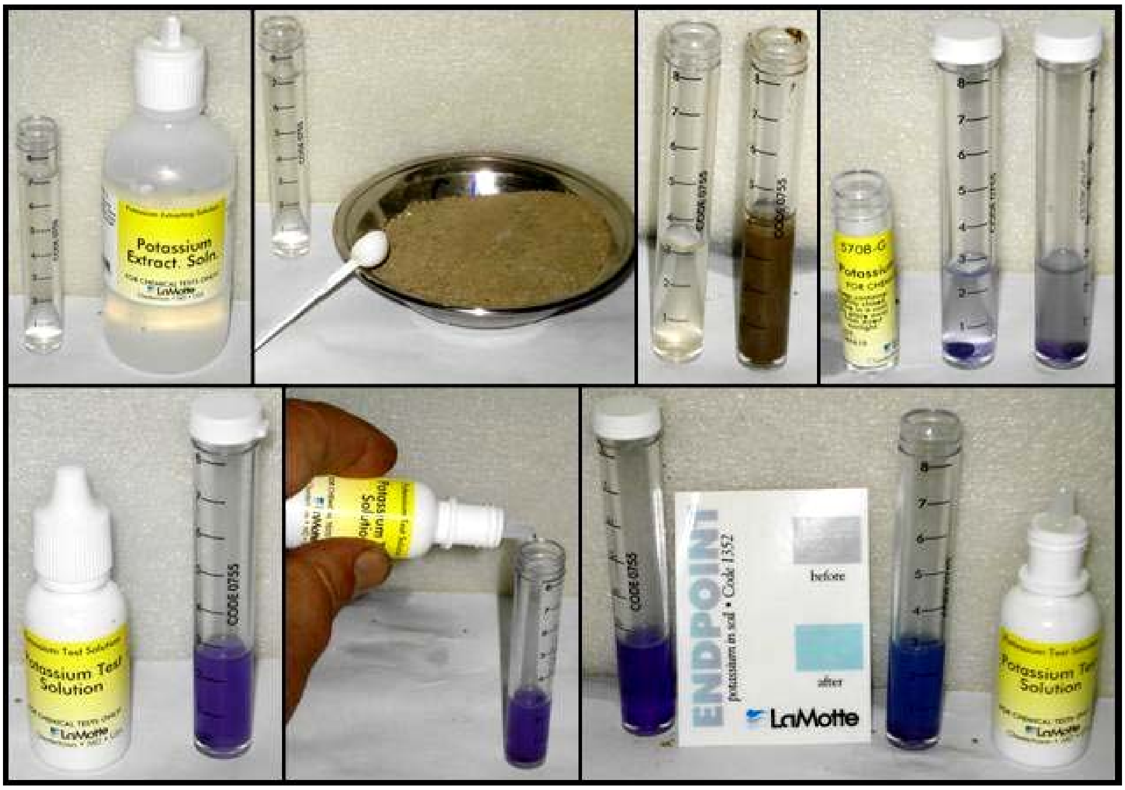
Test. Available Potassium analysis differs a little bit from the previous testing methods. After mixing the soil sample with the Potassium Extracting solution, vigorously shake the test tube for one minute. Remove the cap and allow soil settle down. When the liquid becomes clear, pour part of it into another test tube and add one Potassium Indicator tablet to the soil extract in second tube. Shake the tube until the tablet completely dissolves. Finally, add Potassium Test Solution, two drops at a time, keeping count. Stop adding drops when the color changes from purplish to blue.

Data analysis. The Potassium End Point Color Chart indicates only two colors:

- Before: Means before we added the Potassium Test Solution to the extract and this is a purplish color
- After: When the color of the extract changes from purplish. This color is blue

The accurate count of the number of drops until the color of the extract change will indicate the potassium level in the soil sample:

- 0-8 drops: Very high level of potassium
- 10 drops: High level of potassium
- 12 drops: Medium to high level of potassium
- 14 drops: Medium level of potassium
- 16 drops: Medium to low level of potassium
- 18 drops: Low level of potassium
- More than 20 drops: Very low level of potassium



Source: Photos by Ferenc Sandor

HACH NPK-1 Soil Test Kit

Test. pH analysis test uses aqueous soil extract. The extract contains 20g of soil sample and 20 ml of de-ionized water. Stir the contents for 1 minute, at 10 minutes intervals over a 30 minute period. After 30 minutes the extract will be ready for pH test.

Source: Photos by Ferenc Sandor

The pH test uses the Pocket Pal pH Tester. Add a pH 7.0 Buffer Powder Pillow the 50 ml of water. Mix it until the powder becomes completely dissolved. The result will be a pH 7.0 Buffer Solution. Next, switch on the Pocket Pal pH Tester and immerse its pH electrode tip 2.3 cm (1 inch) below the solution surface. If necessary, calibrate the tester to the 7.0 reading. Immerse the tester 1 inch below the surface of the aqueous extract obtained from the soil sample.

Data analysis. Record the digital reading to the nearest 0.1 pH unit. Once complete, clean up the tester with de-ionized water and dry it with a tissue before using for other

pH tests.

Test. Nitrate-Nitrogen analysis requires the soil sample extract that was made with Calcium Sulfate. The process is called Calcium Sulfate Extraction for Soil. For every 5 g of soil, 0.1 g of Calcium Sulfate and 20 ml de-ionized water are needed. For 1 minute, vigorously shake the bottle. When finished, filter the contents using a funnel with filter paper.
The extract should be analyzed within 2 hours or refrigerated for 24 hours before analysis. The

Source: Photos by Ferenc Sandor

Nitrogen-Nitrate test uses a Color Comparator, two Color Viewing Tubes (S=sample and B=blank) and a High Range Nitrate Color Disk. First, thoroughly rinse the two tubes with de-ionized water and discard the water. Repeat the process with the "S" marked tube using small amount of extract. When the tubes are ready for testing, add the extract to both tubes up to the 5 ml mark. Put one NitraVer 5 Powder Pillow to the "S" tube, cap it and shake the tube vigorously for 1 minute. Place the color disk and the two tubes into the comparator and wait 5 minutes. The "B" should be placed into the outside hole.

Data analysis. After 5 minutes hold the comparator up to a light source and rotate the disk until the color in the window for tube "B" matches the color in the window for tube "S". Record the value in the window. Repeat the process two more times. The three readings should be taken within 10 minutes.

Source: Photos by Ferenc Sandor

Equation

Available Nitrate-Nitrogen = Average of 3 readings x 2

Test. Phosphorus analysis uses Mehlich 2 extract. In a bottle, place 2 g of soil sample and 20 ml diluted Mehlich 2 Soil Extractant. Cap the bottle and shake it for 5 minutes. Finally, using a funnel and filter paper, filter the contents into another bottle.

Source: Photos by Ferenc Sandor

Prepare the two Color Viewing Tubes in the same way (how they were for the Nitrate-Nitrogen test). Add 2.5 ml extract to a 25 ml graduated cylinder and dilute it to the 25 ml mark with de-ionized water. Fill up the two Color Viewing Tubes with the diluted extract (up to the 5 ml mark). Add the contents of one PhosVer 3 Powder Pillow to the "S" tube. Immediately place both tubes into the comparator using the same method as the Nitrate-Nitrogen Test.

Data analysis. After 3 minutes hold the comparator up to a light source and rotate the disk until the color in the window for tube "B" matches the color in the window for tube "S". Record the value in the window. Repeat the process two more times. The three readings should be taken within 10 minutes.

Equation

Available $P\text{-}PO_4$ = Average of 3 readings x 3.3

Source: Photos by Ferenc Sandor

Test. Potassium-Exchangeable in Soil uses Mehlich 2 extract. In a bottle, place 2 g of soil sample and 20 ml diluted Mehlich 2 Soil Extractant. Cap the bottle and shake it for 5 minutes. Finally, using a funnel and filter paper, filter the contents into another bottle.

Add 3.0 ml extract to a 25 ml graduated cylinder and dilute it to the 21 ml mark with de-ionized water. Add one Potassium 2 Reagent Powder Pillow and 3 ml of Alkaline EDTA Solution to the cylinder. Invert it several times and wait at least 3 minutes. After three minutes, add one Potassium 3 Reagent Powder Pillow to the solution. Shake the cylinder vigorously for 10 seconds and wait 3 to 10 minutes. A white turbidity will develop in the cylinder.

Look straight into the cylinder. Slowly insert the potassium Dip Stick into the solution until the black dot is no longer visible from above the cylinder. Hold the dipstick and record the number, which is indicated on the scale of the dipstick. Repeat the process two more times and take the average of the three readings.

Data analysis. To determine the potassium level in the sample, refer to the conversion table.

Table 10 Conversion Table for Potassium

Readings	Mg/Liter	Lbs/A	Kg/Ha	Mq/100g
80	87	174	194	0.22
75	94	188	210	0.24
70	101	202	225	0.26
65	109	218	243	0.28
60	118	236	263	0.30
55	129	258	281	0.33
50	143	286	319	0.37
45	159	318	355	0.41
40	180	360	401	0.46
35	207	414	462	0.53
30	243	486	542	0.62
25	294	588	656	0.75

Source: HACH Company., 1992. NPK-1 soil kit manual, USA

Source: Photos by Ferenc Sandor.

Free Carbonate Test

Test. Free Carbonate Analysis Is a very simple test. Take a portion of the soil sample. Be sure that the sample was not oven dried. It is also important to avoid touching the sample. Take an acid bottle and fill it up with vinegar. Squirt some vinegar on the soil particles and carefully observe the presence of effervescence. The more carbonates that are present, the more bubbles can be observed.

Data analysis. According to the presence of effervescence, the samples belong to one of the three categories:

- None: No reaction observed. The soil sample has no free carbonates

- Slight: Very slight bubbling action observed. It is indicates the presence of free carbonates in small quantities.
- Strong: The strong reaction between soil sample and vinegar indicates large amount of free carbonates in the sample.

Source: Photos by Ferenc Sandor

Soil Conductivity and Salinity

Test. Soil Conductivity and Salinity Test easily can be measured with Twin Cond B-173 conductivity instrument. First, perform an aqueous extraction from the sample.

- Crush the sample
- Weigh a quantity of soil. e.g. 10g into a suitable container
- Add distilled water or deionised water with the ratio of 5ml water to each gram of soil. Thus, if you have 10g soil, add 50mL water
- Shake the container to thoroughly mix the soil and water
- Allow the soil to settle.

Source: Photos by Ferenc Sandor

To calibrate the instrument, drop 1.41 standard solution onto the sensor cell. After pressing the CAL/MODE button, the window will display the CAL mark and 1.41. When the mark disappears, the calibration is finished and sensor can be washed.

For conductivity, the mark should be mS/cm or µS/cm. For salinity, the mark should be in % on the window screen. Now, drop the sample solution onto the sensor cell or immerse the sensor into the sample until the indicated immersion level line is reached.

Data analysis.
Record in a table both readings, one for conductivity and one for salinity.

Interpretation of Soil Test Results for Chemical Properties

Soil tests for chemical properties are used to evaluate soil fertility at a specific time. Nutrient content continuously varies with time. Therefore, soil tests should be made on a regular bases. This measurement of nutrients creates a focus on the nutrient content available for plant growth. The measurement of total content of a specific nutrient is useless for the farmer due to the plants ability to only absorb a small part of it.

Nutrient content does not only vary with time but also with soil depth. Tests should be conducted using samples from different soil depths.

Available Nitrate-Nitrogen Content Analysis

Plants are able to use Nitrogen from soil in the form of nitrates and ammoniums. Its content in the soil depends on biological activity. It can easily be leached from soil with rainfall or irrigation water.

Nitrate accumulates in the soil, but ammonium does not. The ammonium can convert to nitrate if the soil temperature and moisture are suitable for that. Generally the ammonium concentration in the soil varies between 2 and 10 ppm. Ten ppm or more occurs in extremely wet soils or in soils that contain fertilizer residue. According to the nitrate content, soils can be classified in four categories.

Table 11 Nitrate-Nitrogen content categories for soil analysis

Content	Value
Low NO_3^--N content	<10 ppm
Medium NO_3^--N content	10-20 ppm
High NO_3^--N content	20-30 ppm
Excessive NO_3^--N content	>30 ppm

Source: E.S. Marx, J. Hart, R.G. Stevens., 1999, Soil test interpretation guide, Oregon State University

The values are shown as Nitrate-Nitrogen content. Nitrogen concentration can be described in three forms: Nitrate, Nitrate-Nitrogen or Potassium Nitrate form. All of them mean the same concentration of Nitrogen.

Equation:
Nitrate content = Nitrate- Nitrogen content x 4.4 = Potassium Nitrate x 0.6

Soil nitrate-nitrogen measurement is most useful to evaluate nitrogen management after the harvest. Nitrate remains in the soil after being harvested as residual nitrate. This information can help to calculate the input level of nitrogen for production. If the residual nitrogen level in the soil is high, the nitrogen fertilizer input should be reduced. The fact that nitrates can be leached from the soil should always be considered when the grower decides the date of sampling recollection. Nitrogen tests may be conducted near the time when production starts. Long periods of time before production can be misleading for farmers with regards to the necessary amounts of nitrogen fertilizer application.

There are 4 nitrogen sources to calculate available nitrogen content in soil in Kg per hectare.

Equations:

- Residual nitrate in soil = NO_3^--N (ppm) x Soil depth (cm) x 0.133
  - Soil depth = Depth were the sample was taken,
  - 0.133=Based on a soil bulk density of 1.2 g/cm^3

- Nitrate from irrigation = NO_3^--N (Kg)/1,000 x Irrigation water (m^3/Ha)
- NO_3^--N (ppm) = NO_3^--N Kg/1,000 m^3
- Irrigation water = Total irrigation water per hectare during growing season
- Organic matter nitrogen (Estimate) = % of soil organic matter x 22.0
- 22.0 = Approximate nitrogen mineralized per year
- Manure/Compost nitrogen = Total Available N x Applied manure Mt/Ha

Table 12 Manure nutrient content at the time of application

Nutrients in solid and liquid manure at the time of land application											
Type	Bedding or litter	Dry matter %	$NH^{4+}N$	Total N	Organic N	Minerali-zation factor (%)	Organic N available (1st year)	Plant Available N (PAN)	N lost in aplication (30%)	Total available N
			a	b	c c=b-a	d	e e=c*d	f f=e+a	g g=f*0.30	h h=f-g
			Kg per MT or 1000 Litres							
Beef	NO (concrete)	15	1.82	4.99	3.18	0.35	1.11	2.93	0.88	2.05
	NO (dirt lot)	52	3.18	9.53	6.36	0.35	2.22	5.40	1.62	3.78
	Yes	50	3.63	9.53	5.90	0.25	1.48	5.11	1.53	3.58
	Liquid pit	11	41.19	68.64	27.46	0.30	8.24	49.42	14.83	34.60
	Lagoon	1	3.43	6.86	3.43	0.25	0.86	4.29	1.29	3.00
Dairy	No	18	1.82	4.09	2.27	0.35	0.79	2.61	0.78	1.83
	Yes	21	2.27	4.09	1.82	0.25	0.45	2.72	0.82	1.91
	Liquid pit	8	20.59	41.19	20.59	0.30	6.18	26.77	8.03	18.74
	Lagoon	1	4.29	6.86	2.57	0.25	0.64	4.93	1.48	3.45
	Veal calf liquid pit	3	32.61	41.19	8.58	0.30	2.57	35.18	10.55	24.63
Sheep	No	28	2.27	8.17	5.90	0.25	1.48	3.75	1.12	2.62
	Yes	28	2.27	6.36	4.09	0.25	1.02	3.29	0.99	2.30
Poultry	No	45	11.80	14.98	3.18	0.35	1.11	12.92	3.87	9.04
	Yes	75	16.34	25.42	9.08	0.30	2.72	19.07	5.72	13.35
	Deep pit	76	19.98	30.87	10.90	0.45	4.90	24.88	7.46	17.42
	Liquid pit	13	109.83	137.29	27.46	0.45	12.36	122.19	36.66	85.53
Horse	Yes	46	1.82	6.36	4.54	0.20	0.91	2.72	0.82	1.91

Source: Brad C. Joern and Sarah L. Brichford., 1993. Calculating Manure and Manure Nutrient Application Rates, Department of Agronomy, Purdue University

or using a more simple equation:

- Available Manure/Compost N = Total manure N x Applied manure Mt/Ha x 50% (approximate)

The Total Available Nitrogen in Kg/Ha is the nitrogen content summary of the four nitrogen sources.

Available Phosphorus Content Analysis

Phosphorus has low mobility in the soil. Its availability decreases in wet and cold soils. Phosphorus availability for plants can be measured using two types of tests. The Bray P1 test is commonly used for acidic soils and the Olsen sodium bicarbonate test is used for alkaline soils. The results cannot be used to calculate available P_2O_5 per hectare, but they do indicate the available phosphorus content level in the soil.

Table 13 Phosphorus content categories for Bray P1 and Olsen test

Content	Bray P1 test	Olsen test
Low phosphorus content	<20 ppm	<10 ppm
Medium phosphorus content	20-40 ppm	10-20 ppm
High phosphorus content	40-100 ppm	20-40 ppm
Excessive phosphorus content	>100 ppm	>40 ppm

Source: E.S. Marx, J. Hart, R.G. Stevens., 1999, Soil Test Interpretation Guide, Oregon State University

The sufficiency ranges also should be part of the phosphorus test. The phosphorus sufficiency range estimates the amount of yield response for each phosphorus soil test range. According to the test with Mehlich 2 extraction, the categories are as follows:

Table 14 Categories fro phosphorus content and sufficiency in soil

Content	Value	Sufficiency (%)
Very low	0-5 ppm	25-50
Low	6-12 ppm	45-80
Medium	13-25 ppm	70-95
High	26-50 ppm	90-100
Excessive	>50 ppm	100

Source: E.S. Marx, J. Hart, R.G. Stevens., 1999, Soil Test Interpretation Guide, Oregon State University

Exchangeable Potassium Content Analysis

Potassium is one of the three primary cations in the soil. The other two are Calcium and Magnesium. This fact is important since having an excess of one of these cations can cause plant deficiencies of the other cations. Calcium and magnesium deficiency mainly occurs in acidic soils.

Table 15 Categories for the main exchangeable cation contents in soil

Content	Potassium	Calcium	Magnesium
Low content	<150 ppm	<1000 ppm	<60 ppm
Medium	150-250 ppm	1000-2000 ppm	60-180 ppm
High	250-800 ppm	>2000 ppm	>180 ppm
Excessive	>800 ppm		

Source: E.S. Marx, J. Hart, R.G. Stevens., 1999, Soil Test Interpretation Guide, Oregon State University

The potassium sufficiency range estimates the amount of yield response for each potassium soil test range. According to the test with Mehlich 2 extraction these categories are the following:

Table 16 Categories for exchangeable potassium content in soil

Content	Value	Sufficiency (%)
Very low	0-40 ppm	20-25
Low	41-80 ppm	45-80
Medium	81-120 ppm	70-95
High	121-200 ppm	90-100
Excessive	>200 ppm	100

Source: E.S. Marx, J. Hart, R.G. Stevens., 1999, Soil Test Interpretation Guide, Oregon State University

pH Test Analysis

The pH value measures the ratio of H^+ ions to OH^- base ions in the soil. If the soil solution has more H^+, the soil is acidic. If the OH^- dominates, the soil is alkaline. The equal balance between them is neutral and its value 7.0. The soil pH value interacts with the mineral nutrients. Availability is determined by the soil pH and varies for each nutrient. High or low pH causes toxicity and decreases microbiological life in the soil. Sodium raises pH and destroys soil structure. High pH makes elements such iron zinc and manganese less soluble. Low pH leads to continuous acidification in the soil. Acidification can be the result of the excessive use of fertiliser, or it can also occur naturally. For example, a mass of vegetation in a warm and moist condition during decomposition produces high quantities of carbon dioxide. In another instance, acidic cations in large amounts replace the natural nutrients and cause acidity in the soil.

Strong and extremely acidic soils are deficient in calcium and magnesium. Alkaline and strong alkaline soils contain high levels of free limes. Extremely alkaline soils are usually sodic soils. The positively charged sodium ions attract the negatively charged soil particles. The soil particles move close to each other, which creates a soil compaction. As a result, the water infiltration into the soil is slow and organic matter dissolution is possible. Root penetration is also extremely difficult.

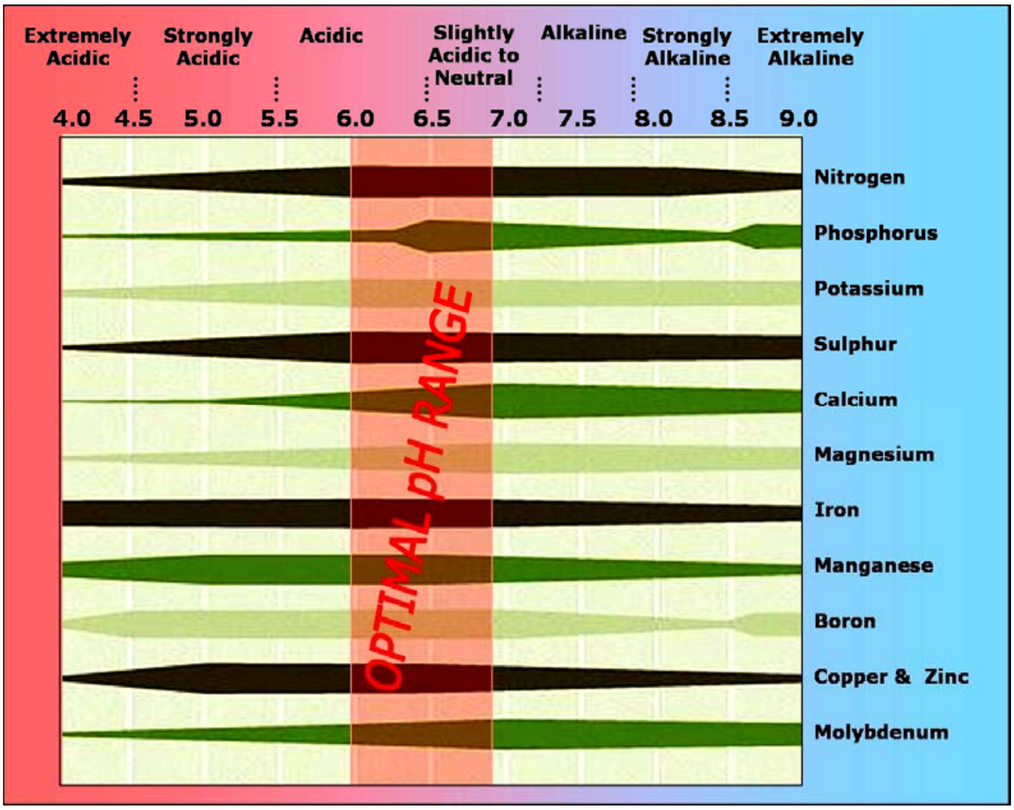
According to the range of the pH test there are seven different categories:

Table 17 Soil pH categories

Categories	pH value
Extremely acidic	<4.0
Strongly acidic	4.5 – 5.5
Acidic	5.5 - 6.5
Slightly acidic to neutral	6.5 – 7.2
Alkaline	7.3 – 7.8
Strongly alkaline	7.8 – 8.5
Extremely alkaline	>8.5

Source: F. Sandor, ROP Soil Test Laboratory, J alalabad, Afghanistan (2007)

Figure 10 Nutrients availability at different pH value



Source: F. Sandor, ROP Soil Test Laboratory, Jalalabad, Afghanistan (2007)

Table 18 Criteria for soil salinity

Type	pH value
Calcareous (High lime content)	7.5 – 8.4
Saline (High soluble salt content)	<8.5
Sodic (High exchangeable sodium content	>8.5
Saline – Sodic (High soluble salt and sodium content)	<8.5

Source: F. Sandor, ROP Soil Test Laboratory, Jalalabad, Afghanistan (2007)

Soil Conductivity and Salinity Analysis

Electrical Conductivity (EC) is the ability of a material to transmit an electrical charge. Its magnitude varies according to the material. The measurement unit is called Siemen, which is the measure of a material's conductance. The conductivity is expressed in volume, which is milliSiemens per cm (mS/cm) or microSiemens per cm (µS/cm). It can be expressed in meters also.

The value of the soil electrical conductivity helps to describe some of the most important properties of the soil. The relationship between EC and soil properties is strong.

Soil texture is significantly expressed by electrical conductivity. Clay textured soil with high water holding capacity is highly conductive. Sandy soils with poor water holding capacity are poor conductors. Clay EC value varies between 10 and 1000 mS/m while sand EC value is around 0.4-3.0 mS/m.

The EC value varies on the field even if the soil texture is the same due to the dissolved salt content variance in different parts of the field. Therefore, EC value clearly indicates saline areas on the field through a high electrical conductivity value. This EC value is typically higher than clay EC value.

High cation exchange capacity is also indicated by higher electrical conductivity. It can help to determine the exchangeable calcium or magnesium level in the soil.

In case of high organic matter content the EC value is higher too since it indicates the volume of organic origin nitrogen in the soil.

Electrical conductivity works in three ways:

- Conductance through soil layers and their bound soil solution. It can only be measured in the field and it helps to find clay pan horizon and saline spots.
- Conductance through surfaces of soil particles in direct contact with each other. This test can also be performed in the field. It is useful to determine compaction level in the field. Highly compact soils have higher EC value.
- Conductance through continuous soil solution, which is one the most powerful tools to show nutrient level in the soil. The total dissolved solid (nutrient salt) and its composition determine the value. Generally, the high EC value indicates excess of nutrients, while a low EC value indicates the lack of nutrients in the soil.

Table 19 Categories for Soluble Salt Content in Soil

Content	EC (mS/cm)	ppm	Description
Low	<1.0	<640	Salt leaching with water
Medium	1.0 - 2.0	640 – 1,280	Slightly to non saline
High	>2.0	>1,280	Saline soils

Source: E.S. Marx, J. Hart, R.G. Stevens., 1999, Soil Test Interpretation Guide, Oregon State University

Because the electrical conductivity of the soil is affected by the soluble salt content, the volume and type of applied fertilizer will also affect the measured value. Different types of fertilizer have different levels of conductance.

Table 20 Electrical Conductivity of Some Commonly Used Fertilizer

Fertilizer	EC (mS)	Comment
Calcium Nitrate	2.0	
Potassium Nitrate	2.5	Almost same that Potassium Sulphate
Ammonium Nitrate	2.9	Twice that Manganese Sulphate
Ammonium Sulphate	3.4	Almost twice that Calcium Nitrate
Potassium Sulphate	2.4	Almost same that Potassium Nitrate
Manganese Sulphate	1.5	
Urea	0.0	No electrical conductance

Source: Veris Technologies, Inc. 601 N. Broadway, Salina KS 67401

Soil can be affected by too much salt content or by an excess of Calcium and Magnesium Carbonate. When the soil has an excess of slat content, it is called saline soil. If it contains high amounts of exchangeable sodium, it is called sodic soil. Soils that are high in lime content are called calcareous soils. Saline soils can be associated with high exchangeable sodium contents, but calcareous soils may not be associated with saline soils.

The pH value of calcareous soils is high (between 7.5 and 8.4). The physical properties of the soil may not be affected but the high pH value reduces the availability of certain nutrients, such as phosphate, iron, zinc, copper, boron and manganese. The plant can show nutrient deficiency symptoms even if the soil contains sufficient nutrients.

Soil salinity seriously affects the plant nutrient uptake. The high salt concentration inhibits nutrient flow through osmosis pressure into the plant root. It can even reverse the direction of the flow if the salt concentration outside is higher than inside of the root cell. As a result, the plant root dries up and the plant dies.

High exchangeable sodium content causes severe soil depletion and degradation. If the sodium ions stick together, the soil particles and the soil compaction increase. The reduced soil pore space volume and soil compaction inhibit water and root penetration into the soil. Organic matter content will dissolve and the dispersed organic matter will move upward through capillarity pressure and accumulate in the surface horizon. For this reason, the soil becomes black (Black alkali soils) and the pH value goes above 8.5.

Saline soils with high exchangeable sodium content are soils “in progress”. They have similar characteristics than that of the saline soils except they have more compact structures, indicating high sodium content in the soil. The main difference is that the soluble salt content is continuously leaching out from the soil. This occurs due to the fact that they are soils are in progress. Over time, these types of soils will become sodic soils (if the process goes uninterrupted).

The electrical conductivity of calcareous and sodic soils is less than 2.0 mS/cm and saline and saline-sodic soils are higher than 2.0 mS/cm.

The relationship between soil texture and salinity, according to the North Central Region -13 Testing Committee of the United States, is the following:

Table 21 Electrical conductivity of the main type of soils according to the soil texture

EC 1:1 Soil/Water Suspension (mS/cm)					
Texture	**Non Saline**	**Slightly Saline**	**Moderately Saline**	**Strongly Saline**	**Very Strongly Saline**
S - SL	0 – 1.1	1.2 -2.4	2.5 – 4.4	4.5 – 8.9	>9.0
LS - L	0 – 1.2	1.3 – 2.4	2.5 – 4.7	4.8 – 9.4	>9.5
SiL - CL	0 – 1.3	1.4 – 2.5	2.6 – 5.0	5.1 – 10.0	>10.1
SiCL - C	0 – 1.4	1.5 – 2.8	2.9 – 5.7	5.8 – 11.4	>11.5
Key: S=Sandy, SL=Sandy Loam, LS=Loamy find Sand, L=Loam, SiL=Silt Loam, CL=Clay Loam, SiCL=Silty Clay Loam, C=Clay					

Source: HACH Company, 1992. NPK-1 soil kit manual, USA

Free Carbonate Test Analysis

Free carbonates are compounds that coat soil particles. The presence of high amounts of free carbonates indicates alkalinity in the soil. They form under dry climates where the pH is above 7.0. They are also found in some soil profiles that have parent materials made of carbonates (such as limestone).

Irrigation well water may contain significant quantities of calcium and/or magnesium carbonate and it increases alkalinity in the soil (which can be up to 0.2 pH value per year). Sprinkler irrigation system distributes the lime in the water uniformly across the field. Furrow irrigation system delivers most of the lime content from the water in the upper part of field nearest the water inlet and in the water flow path. Soil pH increases until the equilibrium is reached with atmospheric carbon dioxide levels. Such soil pH increase will occur more rapidly on coarse and medium-textured soils than on clays that are more highly buffered. Elemental sulphur may be used to acidify alkaline soil and correct the pH range.

Recommendations for Soil Management

The soil structure and texture together make one of the most critical factors in land preparation. The farmer's ideal soil is granular in structure, rich in organic matter, with good porosity and a good capacity for water-air exchange and movement.

The soil presents *problems and risks* depending on its structure and texture. This includes whether it has high or low alkali or sodium content, its salinity, pollution and toxicity levels, the status of organic matter within it and its biological features. All these attributes are listed below, with the recommended production practice for each one.

Granular Structured Soil

Intensive use of chemical fertilisers causes this soil to lose fertility. Intensive chemical fertiliser use can change the soil pH, which will result in a decrease both in useful microbiological life and in organic matter content. It is especially likely that micronutrients will be absent because the applied fertilisers do not contain them.

Tilling the soil radically lowers its fertility. When tilled for the first time, soil can lose up to 50% of its organic matter. Tilling too deeply as well as intensively will turn up less structured soil into the topsoil level. Moreover, intensive tilling, in destroying the structure of the soil, increases the leaching mechanism in it.

Shifting production areas without replacing nutrients lost to the soil decreases fertility. It is a common practice for smallholder farmers to shift their production areas every 2-3 years, rather than replenish lost nutrients.

Burning soil during land preparation sterilizes the soil, killing every living organism in it and burning the organic matter content. Burning stubble decreases the organic matter, the mineral aggregates get glued together, and the aggregates release each other, causing the soil to lose its granular structure.
Exposed to the heat of the sun, the uncovered soil surface is generally damaged in subtropical areas during the dry season.

Compaction: This soil carries a risk of compaction by animals and machinery. Compaction also happens in open land with granular soil that has been subjected to shallow cultivation.

Slash-burn type agriculture is very common practice and extremely damaging. The biggest damage is caused in rainforest areas, where the organic matter layer is very thin. The soil loses its organic matter content quickly, as well as its soil life, its structure and fertility. This type of practice should be avoided under any circumstances.

Granular structured soil requires very careful management. The main concept is to keep the soil structure intact and to conserve fertility. Reduce tillage practice to a minimum. The soil should not be tilled any deeper than the top layer, so as to avoid mixing topsoil with lower-quality subsoil.

Testing the soil on regular bases helps monitoring soil management. Changes in physical and chemical properties of soil will indicate necessary changes in the production technology.

Source: Photo by Ferenc Sandor

Platy Structured Soils

The main problem with platy structured soils is soil compaction caused by the action of animals and machinery. These soils usually have higher bulk density, because they have less pore space, especially the fine-texture platy soils. This high bulk density heavily affects root penetration into the soil.

Loss of colour and fertility is usually found in the subsurface layer. The soils are often grey, and become pale, with the soil's organic matter leaching down from the soil horizon. The greyish, thin A-horizon characterized by the eluviations of clay, Fe, Al, or organic matter alone or in combination. The B-horizon, slightly altered by hydrolysis, oxidation or solution or all three and gives a change in color or structure or both.

Moderate deep tillage helps to improve soil structure. The platy structure in the subsurface clearly indicates wrong soil management.

Avoid using fertilizers that increase acidity. Urea, NPK where K=0. If you use them, mix with humic acid other amendment before or after application. Organic matter should be used continuously and abundantly.

There is a high risk of water and wind erosion, therefore, erosion control with windbreaks is an important part of farming practices.

Blocky and Prismatic and Columnar Structured Soils

They are very hard soils; difficult to work with. The plant root has difficulty penetrating these dense soils, and in some cases it is almost impossible. These soils tend to swell under wet conditions, and crack when dry. The clay content is high, mainly 2:1 type expanding clay. Land preparation for planting is an especially difficult task.

Low levels of organic matter content and low fertilitycharacterize them. The prismatic types of soil are of especially low quality and infertile. They normally occur in the layer horizons instead of the surface, but their presence in the surface horizon usually indicates sodic or alkaline conditions. Prismatic and columnar structured soils crack vertically.

Deep tillage practice can help to improve soil ventilation and drainage conditions. With this type of soil, tillage practice plays an important role during land preparation. Tilling the soil deeply can partially restore soil fertility.

Apply additional organic matter to the soil. The deep tillage technique should be accompanied by applying additional organic matter to improve the life, structure and fertility of the soil.

Source: Photo by Ferenc Sandor

Un-structured Soils

Un-structured soils may be sandy (single grained) or clayey (massive) soils. Both kinds of soil are commonly found in young soils called entisols, such as those found in the river alluvium or shifting sands. Entisols are typically associated with bedrock outcrops and salt flats. Human activity contributes to the formation of these soils due to the high erosion caused by deforestation and other human activities. It provides appropriate conditions for the development of shallow, eroded entisols.

Un-structured sandy soils have high bulk density and low porosity. The air ventilation is high and the chemical reactions are mainly aerobic, resulting in the almost complete loss of organic matter. Sandy soil cannot retain water and dries up very fast.

Un-structured clayey soils have less bulk density and higher porosity. The water retention capacity is high, but this is poorly ventilated soil, therefore the anaerobic conditions do not permit the fast decomposition of the organic matter accumulated in the higher horizon.

They cannot be farmed intensively. The restrictions on their depth, clay content and water balance prohibit the intensive use of these soils over large areas.

Land preparation of sandy soils should not include any tillage. This is done to limit possible erosion and to retain soil. All soil preparation should attempt to minimize soil loss.

Large volumes of organic matter improve soil structure and fertility in the soil. The farmer should rake the soil only when this organic matter is applied.
Cover the soil with vegetation or well composted mulch. These soils are exposed to erosion, and so they should be covered all year round.

The same row can be used for planting through 2-3 seasons without disturbing the soil between the rows.

Install soil protective structures or vegetation in and around the field.

When dealing with clayey soils, deep tillage practice and subsoil loosener use are strongly recommended (which is in contrast with the recommended approach for sandy soils).
Apply a high volume of organic matter, which also improves the soil structure.

Biocatalysts help to separate soil aggregates and neutralize damaging salt content.

Sandy Textured Soil

Sandy textured soils have high porosity. These are coarse textured soils with sand size minerals. They have bigger pores that do not permit the efficient storage of water. Sandy soil is dry and infertile. The available water for a plant is a low 2.5-3.0 cm per 30cm soil. Organic matter content reduces fast in the soil, which is related to the highly aerobic conditions inside the soil. The erosion risk is high.

Avoid ploughing or ripping land because it causes more soil depletion. Land preparation should be limited to ridge rebuilding.

Use wind breaks to reduce the danger of wind erosion. Water erosion control measures should also be applied.

Apply organic matter continuously and abundantly. Mulching the surface also protects the soil against heat and erosion. Industrial waste such as molasses or other organic matter may be applied twice a year or more.

Produce fall cover crops, perennial grass or legumes to improve the microbiological activity in the soil and thus its quality.

Loam Textured Soil

These are well-balanced soils with 40-45% sand, 30-40% silt and 20-25% clay. They are preferred for crop production. Loamy soils with a high proportion of silt warm fairly quickly and have good water-holding capacity without becoming waterlogged. Loam has the most suitable texture for the greatest variety of living organisms. The texture varies between coarse and fine. Loam type soil with high organic matter content generally has a granular structure and is dark in colour. Available water for plant: 3.8 cm per 30 cm soil.

Loamy soil easily loses organic matter and structure. Human intervention in cultivation can cause this. Intensive fertilizer application and land use reduce the available micronutrients in the soil and lower the pH factor to a damaging degree.

The main effort should be put into soil quality maintenance. Land preparation should avoid destroying the soil structure. Plant nutrition system should be mixed and based on use of mineral and organic fertilizers.

Maintain pH level through use of biocatalysts and organic matter.

Use rakes rather than tillage for introducing organic matter.

Clay Textured Soil

Fine textured soil with more clay size minerals, high porosity, but small discontinuous pores. These soils generally have a blocky structure. When the surface is dried up, it shows cracking and peeling. Clay and heavy clay soils have a large total pore space, although individual pores have a small diameter and are tortuous. The process of mineralization is restricted in this type of soil. Available water for plant: 5.0 cm per 30 cm soil.

Clayey soils are very fertile, but hard to work with. They are characterized by high bulk density and little porosity. It is very difficult for plant roots to penetrate.

Clayey soils are often waterlogged. These types of soils are capable of holding a huge quantity of water, but movement of water is very slow due to high surface tension. Ventilation is also very poor in the soil.

Rip and till the soil annually to help water, air and plant root penetration.

Apply husk charcoal mixed with the soil to loosen the soil structure.

Use appropriate irrigation practice and surface drainage techniques to help avoid waterlogging.

Build raised beds to give a good drainage profile to the soil and to make for better and easier gardening.

Apply biocatalysts to help separate the soil aggregates and neutralise damaging salt content.

Source: Photo by Ferenc Sandor

Alkalinity, Sodicity, Salinity

High levels of calcium sulphate ($CaSO_4*2H_2O$), called gypsum, are common in young soil. If the gypsic layer is deeper than 60cm, plant growth is adequate, because root penetration into the soil is easy and the soil volume for nutrient uptake is adequate.

If near the surface, high calcium sulphate content limits the nutrients available for the plant, especially in shallow soils.

Fertiliser and organic matter application on a regular basis can help. The correct selection of crops tolerant of gypsum is advised:

Table 22 Some Gypsum Tolerant Crops

Crops tolerant of 40% gypsum	Crops tolerant of 20% gypsum
alfalfa	broad bean
trifolium	sugar beet
wheat	sorghum
barley	maize
lentil	soy bean
oats	sesame
tomato	
onion	

Source: Water quality, Food and Agriculture Organization, Handbook

In rainy conditions gypsiferous soils can be improved through soil terracing, soil tilling and sub-soiling together with organic matter application.

Soil with high calcite properties (calcium carbonate $CaCO_3$) occurs in the silt or clay fraction of young soils, especially in arid areas. The lack of water inhibits weathering processes. These are typically limited leaching soils, pale in colour, with a deficiency of micronutrients such as zinc and iron. This called reducing environment. The soil contains little organic matter.

Source: Photo by Ferenc Sandor

Non-water-soluble phosphorus must never be applied to this type of soil. Instead, it is of primary importance to use techniques designed to manage the appropriate micronutrients.

Saline soil commonly develops in arid and semi-arid conditions. It can also develop if irrigation practice is inappropriate, especially if the water quality is low, and the surface of the soil is exposed to high evaporation. If the irrigation water contains high levels of sodium, the soil structure collapses and salt-pans begin to form. An excess of boron can cause plant toxicity. The level of exchangeable calcium in the soil is low. The application of gypsum on the top layer can increase the exchangeable calcium content. Crop selection should be based on salinity resistance

Soils with high sodium content tend to be very dense, and the root penetration of the plant is extremely difficult. This is caused from the sodium ions forming the soil platelets into compact structures.

Soil improvement involves replacing the positive sodium ions with positive calcium ions, and letting them leach down to the lower soil layers. The following minerals can be used to adjust the balance in the soil: gypsum, phosphogypsum, calcite, aluminium sulphate, lime sulphur, pyrite and iron sulphate.

Biocatalysts such as humic acid are highly effective in neutralising the sodium content. Negatively charged humic acid molecules remove and segregate the positively charged ions, therefore the clay platelets (with negative charges across their face) repel each other. The platelets move apart from each other, loosening the soil structure, thus enabling water penetration.

Table 23 Sodium and Boron tolerance of the different crops

Common name	**Scientific name**	**Tolerance to**	
		Sodium	**Boron**
Lemon	Citrus limon	++	+
Avocado	Persea Americana	++	++
Grapefruit	Citrus X paradise	++	++
Orange	Citrus sinensis	++	++
Apricot	Prunus armeniaca	++	++
Peach	Prunus persica	++	++
Cherry	Prunus avium	++	++
Plum	Prunus domestica	++	++
Persimmon	Diospyros kaki	++	++
Grape	Vitis vinifera	++	++
Walnut	Juglans regia	++	++
Cowpea	Vigna unguiculata	++	++
Onion	Allium cepa	++++	++
Garlic	Allium sativum		++
Sweet potato	Ipomoea batatas		++
Wheat	Triticum eastivum	++++	++
Barley	Hordeum vulgare	+++++	++
Sunflower	Helianthus annuus		++
Bean, mung	Vigna radiate	++	++
Sesame	Sesamum indicum		++
Strawberry	Fragaria spp.		++
Bean, kidney	Phaseolus vulgaris	+	++
Bean, lima	Phaseolus lunatus	+	++
Peanut	Arachis hypogaea	++	++

Common name	Scientific name	Tolerance to	
		Sodium	**Boron**
Pepper	Capsicum annuum		+++
Pea	Pisum sativa	++	+++
Carrot	Daucus carota	++++	+++
Radish	Raphanus sativus	++++	+++
Potato	Solanum tuberosum		+++
Cucumber	Cucumis sativus		+++
Lettuce	Lactuca sativa	++++	++++
Cabbage	Brassica oleracea capitata		++++
Celery	Apium graveolens		++++
Turnip	Brassica rapa		++++
Bluegrass	Poa pratensis		++++
Oats	Avena sativa	++++	++++
Maize	Zea mays	++	++++
Artichoke	Cynara scolymus		++++
Tobacco	Nicotiana tabacum		++++
Mustard	Brassica juncea	++++	++++
Squash	Cucurbita pepo		++++
Muskmelon	Cucumis melo		++++
Sorghum	Sorghum vulgare	++++	+++++
Tomato	Lycopersicon lycopersicum	++++	+++++
Alfalfa	Medicago sativa	+++++	+++++
Vetch	Vicia sativa	++++	+++++
Parsley	Petroselinum crispum		+++++
Beet	Beta vulgaris	+++++	+++++
Sugarbeet	Beta vulgaris	+++++	+++++
Cotton	Gossypium hirsutum	++	++++++
Asparagus	Asparagus officinalis		++++++
Sugarcane	Saccharum officinarum	++++	
Rice	Oryza sativus	++++	
Spinach	Spinacia oleracea	++++	

KEY
+ Very sensitive
++ Sensitive
+++ Moderately sensitive
++++ Moderately tolerant
+++++ Tolerant
++++++ Very tolerant

Source: Water quality, Food and Agriculture Organization, Handbook

Deep tillage and subsoil loosening practice improve drainage, increase leaching and soil porosity. As in the case of other saline soils, good agricultural practice entails selecting crops according to their sensitivity to salt, as is shown in the table below.

Table 24 Salt sensitivity of vegetables and some fruits

Crop	Sensitivity to Salt	Crop	Sensitivity to Salt
Beans	Very sensitive	Flax	Semi-tolerant
Maize	Sensitive	Mustard	Semi-tolerant
Millet	Sensitive	Oats	Semi-tolerant
Groundnut	Sensitive	Safflower	Semi-tolerant
Cassava	Sensitive	Sunflower	Semi-tolerant
Cowpea	Sensitive	Row barley	Semi-tolerant
Mung bean	Sensitive	Sugar beet	Semi-tolerant
Pea	Sensitive	Reed canary	Semi-tolerant
Meadow	Sensitive	Meadow fescue	Semi-tolerant
Red clover	Sensitive	Intermediate wheat	Semi-tolerant
Alsike	Sensitive	Brome grass	Semi-tolerant
Timothy	Sensitive	Tomato	Semi-tolerant
Celery	Sensitive	Lettuce	Semi-tolerant
Radish	Sensitive	Cabbage	Semi-tolerant
Cucumber	Sensitive	Potatoes	Semi-tolerant
Carrot	Sensitive	Pepper	Semi-tolerant
Sweet corn	Sensitive	Spinach	Semi-tolerant
Leucaena	Sensitive	Asparagus	Semi-tolerant
Rubber	Sensitive	Garden beet	Semi-tolerant
Cacao	Sensitive	Barley	Tolerant
Oil palm	Sensitive	Ryegrass	Tolerant
Wheat	Semi-tolerant	Salt meadow grass	Tolerant
Cotton	Semi-tolerant	Sorghum	Tolerant
Berseem	Semi-tolerant	Wheat grass	Tolerant
Alfafa	Semi-tolerant	Rice	Tolerant
Canola	Semi-tolerant	Soya	Some varieties are tolerant

Source: F. Sandor. Based on HACH Company., 1992. NPK-1 soil kit manual, USA and Water quality, Food and Agriculture Organization, Handbook

Acid sulphate soils (peat and cat clays) tend to be water-saturated soils. They usually smell foul, and if the soil is drained it gives off sulphuric acid. Acid sulphate soils should be kept water-saturated and used for fishery or forestry.

Aluminium toxicity results in the inhibition of nodulation in legumes and affects root growth in plants. The plant root is unable to grow down into the soil to find water, which results in drought stress. Compaction of the soil is a common effect. More than 60% of aluminium saturation in soil results in magnesium deficiency. Additional manganese toxicity can occur in some soils if the soil's retention of nutrients is extremely low.

The presence of aluminium can remove pH. The usual practice to solve this problem is the application of lime to reduce aluminium saturation in the soil. This practice, combined with organic matter application at the surface, will correct the pH level. However, humic acid is more effective in resolving the problem, because it avoids the side-effect of pH valor modification. The selection of crops may be calculated based on sensitivity to aluminium, as is shown in the table below.

Table 25 Some crops aluminium sensitivity

Crop	Aluminium sensitivity	Crop	Aluminium sensitivity
Maize	Very sensitive	Centrosema	Semi-sensitive
Mungbean	Very sensitive	Stylosanthes	Semi-sensitive
Cotton	Very sensitive	Kudzu	Semi-sensitive
Crotolaria	Very sensitive	Millet	Semi-tolerant
Leucaena	Very sensitive	Rice	Semi-tolerant
Cacao	Very sensitive	Cowpea	Semi-tolerant
Soya	Sensitive	Mucuna	Semi-tolerant
Sorghum	Sensitive	Rubber	Semi-tolerant
Bean	Sensitive	Oil palm	Semi-tolerant
Wheat	Sensitive	Cassava	Tolerant
Panicum	Sensitive	Brachiaria	Tolerant
Groundnut	Semi-sensitive	Andropogon	Tolerant

Source: Water quality, Food and Agriculture Organization, Handbook

Iron or amorphous materials can cause high phosphorus fixation. If there is a low organic mineralization rate, the process will be more severe. High phosphorus fixation caused by amorphous materials occurs in soils of volcanic origin. It is often observed in massive landslides caused by the presence of impervious substratum layers.

Phosphorus application on regular basis and moderate quantity helps to resolve the effect of high phosphorus fixation.

Extremely low nutrient retention occurs when organic matter content mixes with kaolinitic clays. The soil's cation exchange capacity falls to an extremely low level. These soils are vulnerable to the leaching of large volumes of nutrients. Fertilizer application is useless, because the nutrients will not be retained by the soil. Only the high input of organic matter and biocatalyst application are able to change the clay-humus complex in the soil.

Applying chemical amendments is the most common practice to treat soil and irrigation water problems. Additional gypsum (5 to 40 Mt/Ha) or lime is commonly used for that. Lime is a powerful amendment to raise buffer pH in soil.

Table 26 Recommended application rate of lime to improve soil pH buffer capacity

Lime stone requirement in Mt/Ha			
Categories	**pH value**	**To pH 7.0**	**To pH 6.5**
Extremely acidic	<4.0	29.0	26.0
Strongly acidic	4.5 – 5.5	29.0 - 20.0	26.0 - 17.0
Acidic	5.5 - 6.5	20.0 - 4.0	17.0 - 3.5
Slightly acidic to neutral	6.5 – 7.2	4.0 - 0.2	3.5 - 0.2

Source: E.S. Marx, J. Hart, R.G. Stevens., 1999, Soil Test Interpretation Guide, Oregon State University

To blend two or three different water sources to avoid impurity (Ca, Na, Mg, HCO_3) in irrigation water. In this way we can avoid severe soil degradation. Amendment reduces the sodium : calcium ratio, thus improving the infiltration of the water into the soil. Some acid-forming amendment may help too, such as sulphuric acid or sulphur. These amendments react with the soil's excess calcium carbonate ($CaCO_3$) and release calcium into the soil with the same effect as is achieved by reducing the sodium : calcium ratio. The following table shows the chemicals recommended for amending soil and water:

Table 27 Commonly used amendments for soil and water

Chemical	Composition	Use
Gypsum	$CaSO_4 \cdot 2H2O$	Amendment for water or soil
Sulphur	S	Amendment only for soil
Sulphuric acid	H_2SO_4	Amendment for water or soil
Ferric sulphate	$Fe_2(SO_4)_3 \cdot 9H_2O$	Amendment only for soil
Lime sulphur	9% Ca + 24% S	Amendment for water or soil
Calcium chloride	$CaCl_2 \cdot 2H_2O$	Amendment for water or soil
Calcium nitrate	$Ca(NO_3)_2 \cdot 2H_2O$	Amendment for water or soil
Calcium carbonate	$CaCO_3$	Amendment only for soil

Source: Water quality, Food and Agriculture Organization, Handbook

Organic Matter Status

As we have seen, organic matter is extremely important for:

- maintaining soil fertility
- the mineralization of nitrogen, phosphorus and sulphur in the soil
- the soil's ability to hold nutrients

- structural stability
- water-holding capacity.

Organic matter is also very important in counteracting the negative effect of exchangeable sodium ion accumulation. Some soils contain a low volume of organic matter because of the specific climatic conditions during pedogenesis, but most often this is a problem of poor soils resulting from agricultural production such as:

- Depleted soils: Caused by human intervention diminishing the levels of plant nutrients
- Degraded soils: Damaged or corrupted, also by human intervention

- Soil organic matter maintenance includes the following practices:

- Avoid summer fallow where possible except in those areas where it is necessary to conserve soil moisture or control pests
- .
- Limit or avoid tillage practice (except if the soil is very dense and compact), because tillage introduces oxygen into the soil, thus accelerating the burning of organic matter.

- Any tillage practice should be combined with the addition of organic matter to the soil.

- The practice of permanent crop cover protects the soil against erosion and adds organic matter.

- Crop rotation may include legumes and forages. Regardless of location, it is always necessary to use crop rotation in agriculture.

- Slash - burn agriculture should be avoided under any circumstances.

- The chosen production method should avoid land shifting and soil exhaustion type of agriculture.

The farmer can create favourable conditions for agricultural production by applying organic matter the correct way, without resorting to tillage, or with limited tillage. The following procedures are recommended:

- Smoothen and clean the soil surface with a rake
- Lay down a layer of organic matter over the soil surface and rake it smooth at the start of the growing season
- Apply the balance at the start of summer
- Make sure that the organic matter is well composted
- The volume of organic matter should not exceed 15% of the topsoil volume

Raw sawdust or ground bark causes a temporary drop of available nitrogen in the soil. It is better to apply sawdust or husk charcoal to avoid this effect
Green manure should be applied at least six weeks before planting to ensure its effectiveness.

Raw manure can cause an unhealthy level of nitrates and salt build-up in the soil. It should be composted before use.

Biocatalysts (humic substances) can help in regulating the decomposition processes, pH levels and structural development in the soil, and they can improve the process of nutrient uptake in the plant.

Compost tea application improves the activity of the valuable microfauna.
A mixed application of compost tea and a biocatalyst, combined with the increase and regulation of drainage capacity, can improve the condition of foul-smelling soils.

Recommendations for Soil Nutrient Management

The only way the plant can absorb nutrients is through the uptake of inorganic minerals.

The **genotype of a variety of plant** will help decide its maximum yield. Hybrid varieties can achieve especially high yields, and every year research institutes bring out new hybrid varieties. The phenotype of a plant developed in this way may not necessarily show the characteristics of the genotype, since the final phenotype depends on many factors, including genotype, climatic conditions, watering system, nutrition and soil quality. For this reason the farmer's harvest is generally lower than the genetic capacity of the plant. All these factors impact the development of the plant over its lifetime, with the nutrient content of the soil being of critical importance.

Nutrition and fertility interact with each other. Nutrition refers to the interrelated steps by which a living organism assimilates food and uses it for growth and for the replacement of tissue. A study of plant nutrition will reveal how the mineral elements of the soil are interrelated and the role they play in plant growth. Fertility is the capacity of the soil to supply nutrients to the plant in sufficient quantity and with the right balance between those nutrients. The plant's growth can be affected positively or negatively by the following aspects of nutrition:

Quality of nutrition: Both indispensable and additional elements should be available in the soil water for uptake by the plant.

Quantity of nutrients: The soil should contain a balance of nutrients in optimal quantities.

Timeliness: The various nutrients should be available for the plant at the right stage in the growth of the plant. A plant needs different nutrients in varying quantities in the vegetative and generative periods of its growth. If the plant cannot take up the proper amount of a certain nutrient at the right time, it will not be able to develop the capacity of its genotype and the harvest will be lower as a result. This outcome cannot be rectified, and so any late application of nutrients on the field will affect the resulting yield irreversibly.

The easiest way to calculate the nutrient requirement of crop is the use of the "balance method", which basically measures the quantity of removed nutrient from the soil by the plant. This quantity of nutrients divided with the volume of the yield gives us the approximate requirement of nutrients per one metric tone of yield. To have closer estimates of nutrient's need, we also may consider other factors during the calculation such as the nutrient content of the soil, the growth of the plant, and the capacity of the plant for nutrient uptake and process. Some of the vegetables are "shiftless" (cucumber), because their shallow root system results in poor nutrient uptake and high salt sensitivity. These kinds of vegetables are able to produce good yields, if the available nutrient content in the soil is the optimum.

Table 28 Vegetables nutrient requirement for specific yields

Plant	Requeriment per 1 MT yield (Kg/MT)				Requeriment (Kg) per yield (MT)				
	N	P2O5	K	Total	Yield	N	P2O5	K	Total
Tomato	2.5	1.0	3.6	**7.1**	46.0	115.0	46.0	165.6	**326.6**
Green pepper	2.4	0.9	3.5	**6.8**	19.5	46.8	17.6	68.3	**132.6**
Carrot	4.0	1.5	5.0	**10.5**	12.0	48.0	18.0	60.0	**126.0**
Radish	3.0	3.1	6.0	**12.1**	12.5	37.5	38.8	75.0	**151.3**
Beet root	2.4	1.4	6.0	**9.8**	17.5	42.0	24.5	105.0	**171.5**
Onion	3.4	0.9	2.8	**7.1**	18.5	62.9	16.7	51.8	**131.4**
Green pea	18.9	5.6	15.2	**39.7**	4.5	85.1	25.2	68.4	**178.7**
Bean	12.9	2.8	11.9	**27.6**	6.0	77.4	16.8	71.4	**165.6**
Cucumber	1.7	1.4	4.0	**7.1**	22.0	37.4	30.8	88.0	**156.2**
Cabbage	3.5	1.3	4.3	**9.1**	22.0	77.0	28.6	94.6	**200.2**
Cauliflower	4.0	1.6	5.0	**10.6**	17.0	68.0	27.2	85.0	**180.2**
Lettuce	4.0	1.8	5.0	**10.8**	17.5	70.0	31.5	87.5	**189.0**
Spinach	3.5	1.6	5.2	**10.3**	12.5	43.8	20.0	65.0	**128.8**
Egg plant	5.0	2.5	2.5	**10.0**	20.0	100.0	50.0	50.0	**200.0**
Irish potato	6.8	3.2	11.8	**21.8**	30.0	204.0	96.0	354.0	**654.0**
Okra	10.0	7.5	5.0	**22.5**	15.0	150.0	112.5	75.0	**337.5**
Watermelon	1.2	1.7	2.5	**5.4**	40.0	48.0	68.0	100.0	**216.0**

Source: Brad C. Joern and Sarah L. Brichford., 1993. Calculating Manure and Manure Nutrient Application Rates, Department of Agronomy, Purdue University

In case of vegetable production, under normal circumstances, we only use a basal dose of nutrient application in two ways. One of them is organic fertilizer use and the other is the mineral fertilizer application. Both methods have its pro and contra. Organic fertilizer provides all kinds of micronutrients, which the plant is needed and able to supply 60-80% of the macronutrient requirement too. But its decomposition and availability for the plant takes a long period, usually 2-4 years. It is also good to improve soil structure. Mineral fertilizer is almost immediately available for the plant, but it only includes part of the essential and additional nutrients, which are required for plant growth. However, its excess use results in soil degradation and soil depletion. Therefore the most recommendable method is the balanced application of both methods as a kind of mixed plant nutrition method.

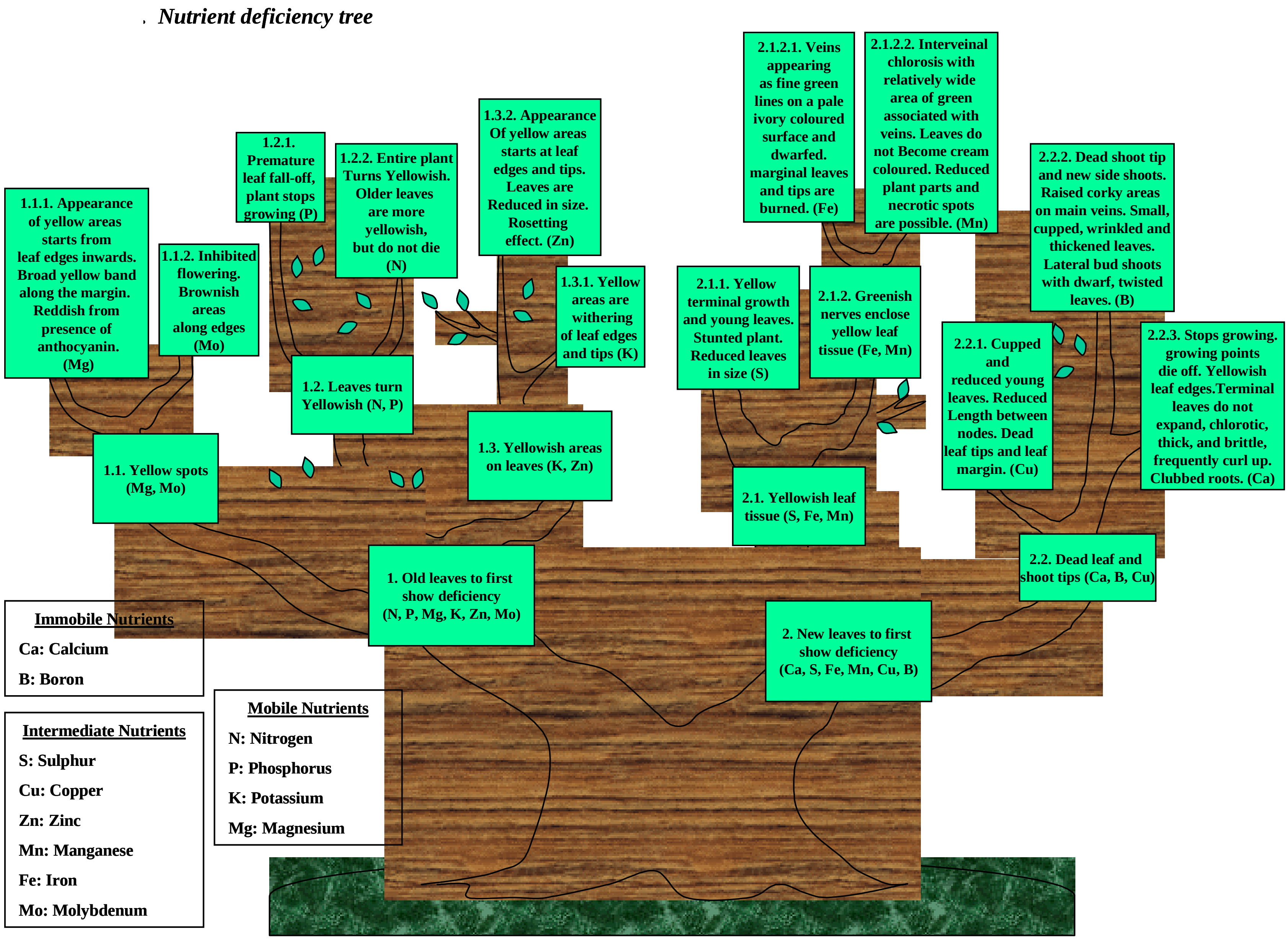
The application of the basal dose of fertilizer is traditionally implemented in three possible ways:

Nest fertilization or application by station: In this method the compost/manure or fertilizer applied directly “under” each plant or closed to the plant (15 cm) if it applied after transplantation.

Line and bed fertilization: It is a commonly used method. During the ridge making process the fertilizer is applied at a depth of 20-25 cm in the open bridge canal, which after application will be closed. With a plant bed, the fertilizer application takes place during the bed preparation.

Broadcast application: Before soil tillage the farmer spreads the fertilizer all over the surface.

Figure 11 Nutrient Deficiency Tree



Source: F. Sandor, ROP Soil Test Laboratory, Jalalabad, Afghanistan

The application of basal dose in vegetable production mainly satisfies the Nitrogen, Phosphorus and Potassium requirement of the plant. But the role of micronutrients is equally essential for plant growth and good yield. Micronutrient fertilizers in dry forms are expensive, therefore the application of these nutrients is implemented through the use of organic fertilizers or through foliar-dressing (Liquid fertilizer use). The liquid fertilizer is also expensive, but the little amount that is needed and it's quick assimilation by the plant justify its use.

Animal Manure Application

Livestock excrete is able to satisfy 70-80 percent of the nitrogen, 60-85 percent of the phosphorus, and 80-90 percent of the potassium requirement for plant growth. The nutrient content of the animal excrete varies according to the species of the animal and to the animal manure processing method.

Table 29 Nutrient value of solid and liquid manure

Nutrients in solid and liquid manure at the time of land application						
Species	Bedding or litter	% Dry matter	$NH^{4+}N$	Total N	Total	
					P2O5	K2O
Kg per Mt or 1,000 Litres						
Beef	NO (Open concrete lot)	15	1.82	4.99	3.18	4.54
	NO (Open dirt lot)	52	3.18	9.53	6.36	10.44
	Yes	50	3.63	9.53	8.17	11.80
	Liquid pit	11	41.19	68.64	46.34	58.35
	Lagoon	1	3.43	6.86	15.45	8.58
Dairy	No	18	1.82	4.09	1.82	4.54
	Yes	21	2.27	4.09	1.82	4.54
	Liquid pit	8	20.59	41.19	30.89	49.77
	Lagoon	1	4.29	6.86	6.86	8.58
	Veal calf liquid pit	3	32.61	41.19	42.90	87.52
Sheep	No	28	2.27	8.17	4.99	11.80
	Yes	28	2.27	6.36	4.09	11.35
Poultry	No	45	11.80	14.98	21.79	15.44
	Yes	75	16.34	25.42	20.43	15.44
	Deep pit	76	19.98	30.87	29.06	20.43
	Liquid pit	13	109.83	137.29	61.78	164.75
Horse	Yes	46	1.82	6.36	1.82	6.36

Source: Brad C. Joern and Sarah L. Brichford., 1993. Calculating Manure and Manure Nutrient Application Rates, Department of Agronomy, Purdue University

Therefore, the volume of animal manure applied on the field is calculated from the relationship between the plant nutrient requirement and the animal manure nutrient content.

Practically all of the phosphate (P_2O_5) and potash (K_2O) applied in manure is available to the crop the first year. Therefore, the manure calculation for application should be based upon the availability of Nitrogen content.

The animal manure during processing suffers a considerable loss of its Nitrogen content. This information helps us to calculate accurately the necessary amount of manure for plant fertilization.

The amount of nitrogen available the first year (or plant available nitrogen, PAN) is a combination of all the ammonium-nitrogen (NH_4^+-N) plus that portion of the organic nitrogen that will mineralize and become available to the crop during the growing season. The amount of organic nitrogen that will mineralize during the first year is the total N content multiplied by a mineralization factor.

Table 30 Mineralization factor for different types of manure

Species	Bedding or litter	Mineralization factor (%)
Beef	NO (Open concrete lot)	0.35
	NO (Open dirt lot)	0.35
	Yes	0.25
	Liquid pit	0.30
	Lagoon	0.25
Dairy	No	0.35
	Yes	0.25
	Liquid pit	0.30
	Lagoon	0.25
	Veal calf liquid pit	0.30
Sheep	No	0.25
	Yes	0.25
Poultry	No	0.35
	Yes	0.30
	Deep pit	0.45
	Liquid pit	0.45
Horse	Yes	0.20

Source: Brad C. Joern and Sarah L. Brichford., 1993. Calculating Manure and Manure Nutrient Application Rates, Department of Agronomy, Purdue University

To calculate the Plant Available Nitrogen (PAN) content, add the ammonium-nitrogen (NH4+-N) content to the organic N available the first year and this amount will be the base of the calculation for animal manure application.

During the application the manure also lose part of its Nitrogen value, which is between 15 and 30 percent (Table 5, column "g"). I f we take the cabbage as an example the calculation looks like the following:

Cabbage N:P:K requirement for 22 MT of harvest per hectare:
Nitrogen: 77 Kg
Phosphorus in P_2O_5 form: 28.6 Kg
Potassium in K_2O form: 94.6 Kg
Using the Beef bedding (Litter) manure the NPK content per metric tons of manure are:
Nitrogen: 3.58 Kg (Real available Nitrogen); Phosphorus in P_2O_5 form: 8.17 Kg; Potassium in K_2O form: 11.8 Kg

The cabbage Nitrogen requirement for 22 MT yield divide by the available Nitrogen content of 1MT animal manure gives us the total amount of animal manure in MT, which is needed for the application on the field (77KG / 3.58 Kg = 21.5). In this case the amount is 21.5 MT of animal manure per hectare (4.3 MT per jerib).

Table 31 Calculation for available nutrient content in manure

Nutrients in solid and liquid manure at the time of land application												
Type	Bedding or litter	Dry matter %	$NH^{4+}N$	Total N	Organic N	Minerali-zation factor (%)	Organic N available (1st year)	Plant Available N (PAN)	N lost in apllication (30%)	Total available N	Total P_2O_5	Total K_2O
			a	b	c	d	e	f	g	h		
					c=b-a		e=c*d	f=e+a	g=f*0.30	h=f-g		
			Kg per MT or 1000 Litres									
Beef	NO (concrete)	15	1.82	4.99	3.18	0.35	1.11	2.93	0.88	2.05	3.18	4.54
	NO (dirt lot)	52	3.18	9.53	6.36	0.35	2.22	5.40	1.62	3.78	6.36	10.44
	Yes	50	3.63	9.53	5.90	0.25	1.48	5.11	1.53	3.58	8.17	11.80
	Liquid pit	11	41.19	68.64	27.46	0.30	8.24	49.42	14.83	34.60	46.34	58.35
	Lagoon	1	3.43	6.86	3.43	0.25	0.86	4.29	1.29	3.00	15.45	8.58
Dairy	No	18	1.82	4.09	2.27	0.35	0.79	2.61	0.78	1.83	1.82	4.54
	Yes	21	2.27	4.09	1.82	0.25	0.45	2.72	0.82	1.91	1.82	4.54
	Liquid pit	8	20.59	41.19	20.59	0.30	6.18	26.77	8.03	18.74	30.89	49.77
	Lagoon	1	4.29	6.86	2.57	0.25	0.64	4.93	1.48	3.45	6.86	8.58
	Veal calf liquid pit	3	32.61	41.19	8.58	0.30	2.57	35.18	10.55	24.63	42.90	87.52
Sheep	No	28	2.27	8.17	5.90	0.25	1.48	3.75	1.12	2.62	4.99	11.80
	Yes	28	2.27	6.36	4.09	0.25	1.02	3.29	0.99	2.30	4.09	11.35
Poultry	No	45	11.80	14.98	3.18	0.35	1.11	12.92	3.87	9.04	21.79	15.44
	Yes	75	16.34	25.42	9.08	0.30	2.72	19.07	5.72	13.35	20.43	15.44
	Deep pit	76	19.98	30.87	10.90	0.45	4.90	24.88	7.46	17.42	29.06	20.43
	Liquid pit	13	109.83	137.29	27.46	0.45	12.36	122.19	36.66	85.53	61.78	164.75
Horse	Yes	46	1.82	6.36	4.54	0.20	0.91	2.72	0.82	1.91	1.82	6.36

Source: Brad C. Joern and Sarah L. Brichford., 1993. Calculating Manure and Manure Nutrient Application Rates, Department of Agronomy, Purdue University

Manure applications based on nitrogen alone usually result in excess phosphorus and potassium in the soil. In this case the cabbage requirement for P_2O_5 is 28.6 Kg and the K_2O requirement is 94.6 Kg. The 21.5 MT of animal manure contains 175.7 Kg of P_2O_5 and 253.7 Kg of K_2O.

Figure 12 Interpreting animal manure analysis

Interpreting animal manure analysis (Based on Calculating Manure and Manure Nutrient Application Rates, Brad C. Joern and Sarah L. Brichford Department of Agronomy, Purdue University, 1993)

• **Phosphorus and Potassium**	• Practically all of the phosphate (P_2O_5) and potash (K_2O) applied in manure is available to the crop the first year
• **Nitrogen**	• Total N – Ammonium N (NH_4^+-N) – Organic N - Plant available nitrogen (PAN)
• **Organic Nitrogen**	• Total N - NH_4^+-N = Organic N
• **Organic Nitrogen Available First Year**	• Organic N (from step 1) x Mineralization Factor = Organic N Available First Year
• **Plant available nitrogen (PAN)**	• Ammonium N(NH_4^+-N) + Organic Available First Year = PAN
• **Effective Nitrogen content after land application**	• Plant available nitrogen (PAN) - Nitrogen loss as ammonia

Source: Brad C. Joern and Sarah L. Brichford., 1993. Calculating Manure and Manure Nutrient Application Rates, Department of Agronomy, Purdue University

Therefore, the calculation should consider the soil P2O5 and K2O content and according to that the farmer should use less amount of animal manure. The mixing amount of Nitrogen can be completed with the use of mineral fertilizer to achieve the optimum and balanced available nutrient value for the plant (Mixed fertilization method).

Mineral Fertilizer Application

For mineral fertilizer application is always necessary to apply soil analysis. If this is out of reach for the farmer, the government institutions usually have the approximate information to recommend the type of fertilizer, which can be used by the farmer. The farmer should know how to calculate the fertilizer application rate and for that the first step is to understand the indication written on the package of the product. The analysis or formula listed on the fertilizer bags. These give the percentage by weight of the major nutrients contained in that bag. For example, in a bag of 23-21-15 starter fertilizer, 23% of the weight of the fertilizer in the bag is nitrogen (N), 21% is phosphorous as P_2O_5 equivalent and 15% is potassium as K_2O equivalent. This means, that one 50Kg bag of fertilizer contains of (50 Kg x 0.23 (% of N) = 11.5 Kg) 11.5 Kg of actual fertilizers.

The next step is to calculate the amount of fertilizer to achieve the desired yield. For example, for 22 MT of cabbage harvest per hectare requires 77 Kg of Nitrogen value. The 23:21:15 fertilizer contains 11.5 Kg of Nitrogen in a 50 Kg bag. Therefore 77 Kg of desired Nitrogen value for 1 hectare requires (77 Kg / 11.5 Kg = 6.69 ~ 7) 7 bags of fertilizers. One bag of fertilizer has 50 Kg weight, therefore the total required fertilizer per hectare is (7 x 50) 350 Kg (70 Kg per jerib).

If we understand this calculation, it is easier to understand an other way to calculate the application rate of the fertilizer approaching the problem from the opposite side. If 77 Kg of Nitrogen needed for 1 hectare using a fertilizer of 23:21:15 the calculation is: 77 divided by 0.23 (percentage of N) and the result will be 334.8 ~ 350 Kg of fertilizer (7 bags).

If the farmer has opportunity to purchase fertilizers, which mixed according to the grower request, the calculation should follow the guideline below.

Establish the volume of required nitrogen:

Again the first step to calculate the nutrient requirement of each crop using the “balance method”, which measures the quantity of removed nutrient from the soil by the plant. This quantity of nutrients divided with the volume of the yield gives us the approximate requirement of nutrients per one metric tone of yield.

This step is followed by the calculation of manure application (See the previously explained calculation method).

Establish the residual nitrate in soil = NO_3^--N (ppm) x Soil depth (cm) x 0.133
Soil depth = Depth were the sample was taken,
0.133=Based on a soil bulk density of 1.2 g/cm^3

Establish the nitrate from irrigation = NO_3^--N (Kg)/1,000 x Irrigation water (m^3/Ha)
NO_3^--N (ppm) = NO_3^--N Kg/1,000 m^3

Irrigation water = Total irrigation water per hectare during growing season

Establish the organic matter nitrogen (Estimate) = % of soil organic matter x 22.0
22.0 = Approximate nitrogen mineralized per year

Calculate the total available nitrogen, which is the summary of the available nitrogen content of the manure, residual nitrate, nitrate from irrigation water and organic matter nitrogen content.

The difference between the nitrogen requirement for a specific crop yield and the total available nitrogen content gives the volume of nitrogen, which should be additionally applied.

Establish the volume of required phosphorus:

Check the phosphorus requirement for a specific yield. The phosphorus content should be expressed in Kg/ Ha.

Check the phosphorus content in the applied manure, also in Kg/ha.

After testing the soil, convert the available phosphorus content from ppm into Kg/Ha. Multiply the ppm value with the conversion factor of 2.227.

Calculate the total available phosphorus, which is the summary of the available phosphorus content of manure and soil.

The difference between the phosphorus requirement for a specific crop yield and the total available phosphorus content gives the volume of phosphorus, which should be additionally applied.

The concentration of phosphorus in the commercial fertilizer is expressed as the percentage of phosphorus (pent) oxide (P_2O_5) in the fertilizer, as grams of P_2O_5 in 100 grams of fertilizer.

The relationship between pure phosphorus (P) and the oxide (P_2O_5) is:
1 Kg (pure) P = 2.3 Kg P_2O_5 (2.3 x the weight of P = the weight of P_2O_5).
Or: 1 Kg P_2O_5 = 0.44 Kg (pure) P (0.44 x the weight of P_2O_5 = the weight of P)

The second number represents the concentration of phosphorus (pent) oxide (P_2O_5) in the commercial fertilizer, in percentage units. In order to calculate the concentration of pure P (in %), multiply that number by 0.44

Establish the volume of required potassium:

To establish the required potassium for a specific yield use the same process, than in case of the calculation of phosphorus need.

The concentration of potassium in the commercial fertilizer is expressed as the percentage of potassium oxide (K_2O) in the fertilizer.

The relationship between pure potassium and potassium oxide is:
1 Kg (pure) K = 1.21 Kg K_2O (1.21 x the weight of K = the weight of K_2O).
Or: 1 Kg K_2O = 0.832 Kg (pure) K. (0.832 x the weight of K_2O = the weight of K)

The third number represents the concentration of potassium oxide (K_2O) in the commercial fertilizer, in percentage units. In order to calculate the concentration of pure K (in %), multiply that number by 0.832.

The phosphorus and potassium requirement for a specific yield is expressed also in P_2O_5 and K_2O. To convert the value to P and K use the conversion factors:

$P = P_2O_5 \times 0.434$
$P_2O_5 = P \times 2.29$
$K_2O = K \times 1.20$

However, especially in case of phosphorus is very difficult to calculate fertilizer recommendation, because phosphorus is held on the surface horizon's soil colloids and is precipitated as insoluble phosphorus compounds.

In this point, it should be mentioned that phosphorus and potassium fertilizer calculation for perennial fruits uses commonly the optimal nutrient content of the plant tissue. According to the analysis of the plant tissue and soil, recommendations will be made for fertilizer application.

Table 32 Optimum nutrient value concentration in fruit plant tissue

Nutrient	Apples	Cherries	Apricots	Grapes	Strawberry
N (%)	1.9-2.6 or 1.7-2.2	2.5-3.5	3.3-4.5	.80-1.2	2-.28
P (%)	.16-.30	.15-.30	.15-.25	.16-.30	.25-.40
K (%)	1.3-1.5	1.4-2.0	1.4-2.0	1.5-2.5	1.5-2.5

Source: Fertilizing fruit crops, Eric Hanson, Department of Horticulture MSUE Bulletin E-852, Major Revision 1996

Table 33 Recommended Application Rate for Phosphorus According to the Soil pH

Soil test level (ppm P)[1]	Recommendation (Kg P_2O_5/Ha)
10	100
20	78
30	45
40	22
50	0

Source: Fertilizing fruit crops, Eric Hanson, Department of Horticulture MSUE Bulletin E-852, Major Revision 1996

Table 34 Recommended doses for potassium (Kg K_2O/Ha)

Soil test (ppm K)	Apples	Grapes	Strawberry
15	190	247	224
25	168	224	190
50	112	168	135
75	56	112	79
100	0	56	22
125	0	0	0

Source: Fertilizing fruit crops, Eric Hanson, Department of Horticulture
MSUE Bulletin E-852, Major Revision 1996

Fertilizer Application Methods

Broadcasting: The fertilizer is evenly spread over the growing area and left to filter into the soil or is incorporated into the soil.

Banding: Narrow bands of fertilizer are applied in furrows 10 to 15 cm from the garden seeds and 3.5 to 5 cm deeper than the seeds or plants.

Starter solutions: To satisfy the need for phosphorus when setting out transplants of tomatoes, eggplant, peppers, or cabbage, liquid fertilizer, which is high in phosphorus, should be used as a starter solution.

Side-Dressing: Dry fertilizer is applied as a side dressing after plants are up and growing. Scatter fertilizer on both sides of the row 15 to 25 cm from the plants.

Foliar-Dressing: It is used when insufficient fertilizer was used before planting. Foliar-applied nutrients are absorbed and used by the plant quite rapidly. Absorption begins within minutes after application and is mostly complete within 1 to 2 days. At transplanting time, an application of phosphorus spray will help in the establishment of the young plant in cold soils.

Annex 1 – Soil Sampling Protocol

1) Prepare sampling procedure
   a) Identify purpose of soil test
   b) Identify sampling method
      i) Field area
      ii) Sampling procedure
      iii) Sample depth
      iv) Sampling time and frequency
      v) Number of necessary sampling

2) Organize sampling tools

3) Organize sampling handling

4) Data sheet for recording

5) Sampling procedure
   a) Surface sampling: This method is used, when all tests will be made in the laboratory or samples from the lower horizons are not required.
      i) Draw a map of the area
      ii) Identify and measure the sampling points
      iii) Take the sampling: An absolute minimum of 10 subsamples from each sampling area is necessary to obtain an acceptable sample.
      iv) If in some point of the area you find a place, which is visible has different characteristics then the rest of the area, do not mix the sample with the other subsamples to have a representative sample. This sample will be analyzed separately.
      v) Label the samples and record it on your data sheet
   b) Open soil profile or pit: This method is used, when we need information about physical and chemical properties of each soil horizon and layers. Part of the test is conducted on the sampling area.
      i) Starting from top, observe profile to determine properties and differences between horizons.
      ii) Place marker at the top and bottom of each horizon to clearly identify it.
      iii) Look for: different colors, shapes, roots, the size and amount of stones, small dark nodules (called concretions), worms, or other small animals and insects, worm channels, and anything else that is noticeable.
      iv) Take photos and record the information in your data sheet
      v) Take samples from each layers and horizons:
         (1) Use a garden trowel or shovel to carefully collect the samples
         (2) If you will proceed with bulk density test, for each horizon in your soil profile, push a can with a known volume into the side of the horizon. If necessary, wet the soil first so that the can will go in easily. Stop when you can see some of the soil poking through the small hole in the bottom of the can.
         (3) Three subsamples from each horizon will give you a representative sample. Do not mix the subsamples, because they will be tested separately.
         (4) Record the exact depth of the sampling point

6) Sample handling: If the sample cannot be refrigerated soon after collection, air dry them
    i) Break up the clods or lumps
    ii) Spread the soil in a layer of 6-7 mm on a plastic sheet
    iii) Dry at room temperature
    iv) Use a circulating fun if it is available. Position it to move air above the sample
    v) Do not use artificial heat and do not expose the sample to direct sun heat

Annex 2 – Soil Testing Protocol

1) Testing on the field
   a) Soil structure test. The used method is observation. Take a sample of undisturbed soil in your hand. Look closely at the soil in your hand and examine its structure.
   b) Soil color test
      (i) Take a ped of soil from each horizon and note on the data sheet whether it is moist, dry or wet. If it is dry, moisten it slightly with water. Break the ped.
      (ii) Compare the color of the ped with the Munsell Color Chart (If it is available)
      (iii) Record the result on your data sheet (Soil class, dominant and subdominant color, intensity).
   c) Soil consistence test
      (1) Take a ped from the top soil horizon. If the soil is very dry, moisten the face of the profile and then remove a ped. Repeat this procedure for each horizon in your profile.
      (2) Holding it between your thumb and forefinger, gently squeeze the ped until it pops or falls apart.
      (3) Record the results on the data sheet.
   d) Soil texture test: All three types of test can be conducted on the field (See chapter soil texture analysis)
   e) Presence of roots and rocks: Observe and record if there are none, few, or many roots and rocks in the horizon
   f) Free carbonate test: The test is performed by squirting vinegar on the soil. If free carbonates are present, they will "effervesce" or bubble when the vinegar reacts with them. Record one of the following based on your observation
2) Finalization protocol of sampling and field test procedure
   a) Place a tape or pole measure along the profile
   b) Photograph the face of the pit, or the soil profile
   c) Take another photograph of the landscape outside the pit or profile

3) Laboratory analysis
   a) Soil sample preparation
      i) Dry the soil sample. According to the nature of the test, you can prepare air dried and oven dried sample (For soil fertility test – Nitrogen, etc. - never use oven dried sample).
      ii) Sieve the sample using #10 Sieve (2 mm mesh openings)
      iii) For coarse fragment test do not use sieved sample. The separation of the fragment will take place during the bulk density test.
   b) Perform the following tests for physical properties:
      i) Existence of coarse fragments
      ii) Bulk density test
      iii) Particle density test
      iv) Porosity test
      v) Moisture test
      vi) Soil texture test (If you did not perform this test on the field)
   c) Soil sample preparation for fertility test
      i) Aqueous extraction
      ii) Calcium Sulfate extraction

    iii) Mehlich 2 extraction
d) Perform the following tests for chemical properties:
    i) pH test
    ii) Nitrate-Nitrogen test
    iii) Phosphorus test
    iv) Potassium, Exchangeable test
    v) Electrical conductivity test
    vi) Salinity test
e) Interpretation of soil test results and recommendations: Use the manual

Annex 3 – Equations

Proportion of coarse fragments = Weight of rock / weight of soil sample x 100

Proportion of coarse fragments = Volume of rock / Volume of soil sample x 100

Silt content = [(Total silt + sand – Total sand) / Total soil] * 100

Clay content = [Total soil – (Total silt + sand)] / Total soil] * 100

Sand content = (Total sand / Total soil) * 100

Total Bulk density = Soil weight / Soil volume

$$\text{Soil Bulk density} = \frac{\text{Dry soil weight – Rock content weight}}{\text{Can volume – Rock content volume}}$$

Soil Particle density = Mass of soil / Volume of soil without air pore space

Porosity = [1 – (Bulk density / Particle density)] x 100

Porosity = Pore space volume / Volume of soil x 100

Water holding capacity by mass = (Weight of water / Weight of the wet soil) x 100

Depth of water = Water volume / Surface area (A)

Weight of solid (Dry soil) = Weight of wet soil – Weight of water

Volume of solid = Weight of solid / Particle density

Depth of solid (soil) = Volume of solid / Surface area (A)

Depth of air = Depth of cubic (D) – [Depth of solid + Depth of water]

Weight of water when saturated = (Depth of water + Depth of air) x Water density

Weight of dry soil = Depth of soil x Particle density

Water holding capacity (Saturation water content) = [Weight of water when saturated / weight of solid (Dry soil)] x 100

Air volume = Depth of air x Surface area (A)

Aeration porosity = [Air volume / Cubic volume (V)] x 100

Nitrate content = Nitrate- Nitrogen content x 4.4 = Potassium Nitrate x 0.6

Residual nitrate in soil = NO_3^--N (ppm) x Soil depth (cm) x 0.133

Soil depth = Depth were the sample was taken,

0.133=Based on a soil bulk density of 1.2 g/cm^3

Nitrate from irrigation = NO_3^--N (Kg)/1,000 x Irrigation water (m^3/Ha)

NO_3^--N (ppm) = NO_3^--N Kg/1,000 m^3

Irrigation water = Total irrigation water per hectare during growing season

Organic matter nitrogen (Estimate) = % of soil organic matter x 22.0

22.0 = Approximate nitrogen mineralized per year

Manure/Compost nitrogen = Total Available N x Applied manure Mt/Ha

Available Manure/Compost N = Total manure N x Applied manure / 2

Dilution = Required ppm x Required volume / stock ppm

Annex 4 – Conversion table

Area		
Square meter (m^2)	Hectare (Ha)	0.0001
Hectare (Ha)	Square meter (m^2)	10,000
Acre	Square meter (m^2)	4,046.85
Acre	Hectare (Ha)	0.405
Hectare (Ha)	Acre	2.471
Density		
Gram/Millilitre (g/ml)	Gram/cubic centimetre (g/cm^3)	1.0
Gram/Litre	Gram/cubic centimetre (g/cm^3)	0.001
Tonnes/Cubic meter (Mt/m^3)	Kilogram/Cubic meter (Kg/m^3)	1,000
Kilogram/Litre	Kilogram/Cubic meter (Kg/m^3)	1,000
Length		
Meter (m)	Millimeter (mm)	1,000
Meter (m)	Centimeter (cm)	100
Meter (m)	Micrometer (µm)	1,000,000
Millimeter (mm)	Meter (m)	0.001
Centimeter (cm)	Meter (m)	0.01
Micrometer (µm)	Meter (m)	0.000001
Mass		
Kilogram (Kg)	Gram (g)	0.001
Gram (g)	Kilogram (Kg)	1,000
Metric tonne (Mt)	Kilogram (Kg)	1,000
Volume		
Litre (L)	Cubic centimetre (cm^3)	1,000
Litre (L)	Cubic meter (m^3)	0.001
Cubic meter (m^3)	Litre (L)	1,000
Part per Million		
Milligram/Kilogram (mg/Kg)	Part per million (ppm)	1.0
Milligram/Litre (mg/L)	Part per million (ppm)	1.0
Milligram/Gram (mg/g)	Part per million (ppm)	1,000
Microgram/Milliliter (µg/ml)	Part per million (ppm)	1.0
Microgram/Gram (µg/g)	Part per million (ppm)	1.0
Gram/Litre (g/L)	Part per million (ppm)	1,000
Part per million (ppm)	Kilogram per hectare (Kg/Ha)	2.227
Part per million (ppm)	Percentage	0.0001
Percentage	Part per million (ppm)	10,000
Electrical conductivity		
Siemen per meter (S/m)	Mhos per meter (Mhos/m)	1.0
Millisiemen per centimetre (mS/cm)	Millimhos/centimetre (mMhos/cm)	1.0
Microsiemen per centimetre (µS/cm)	Micromhos/centimetre (µMhos/cm)	1.0
Millisiemen per centimetre (mS/cm)	Microsiemen per centimetre (µS/cm)	1,000

Glossary of terms

A

abiotic: non-living; usually referring to the physical and chemical components of an organism's environment.

absorption: the process by which water enters and passes into the plant. Absorption is based on **diffusion**.

acid: (1) substance having a **pH** less than 7. (2) substance that releases hydrogen ions (H+).

acidosis: the presence of acids in the soil beyond normal limits

adsorption: of a solid or liquid, the accumulation on the surface of a thin film of the molecules of a gas or liquid that is in contact with it.

aerobe: an organism requiring free oxygen for respiration.

aerobic: involving the activity of aerobes; relating to biochemical change, e.g. effected by aerobes in the presence of molecular oxygen.

aggregate: of soil, group of soil particles adhering together in a cluster; the smallest structural unit, or **ped**, of soil. Aggregates join together to make up the major structural soil units.

agro-ecology: agricultural ecology; a science that maintains that production can satisfy food demand without threatening the ecosystem.

alkali: substance which, when dissolved in water, forms a solution containing hydroxyl ions (OH-).

alkaline soil: soil with a **pH** greater than 7.

alkalinisation: the process of becoming alkaline.

allophane: nondescript hydrated aluminosilicate substance associated with clay minerals.

alluvium: alluvial deposit, i.e. fragmental materials, broken down by weathering and erosion, transported by a stream or river and deposited as the river floodplain.

ammonia: chemical compound composed of nitrogen and hydrogen (NH_3); component of the nitrogen cycle which is immediately released from organic matter upon decomposition.

ammonium: chemical compound composed of nitrogen and hydrogen (NH_4); component of the nitrogen cycle; a product of organic matter decomposition, it can be fixed to clay minerals and later exchanged.

anaerobic: (of an environment) one in which molecular oxygen is absent; (of a process) one that can occur only in the absence of molecular oxygen.

anion: ion carrying a negative electrical charge.

aolian: blown by the wind

aquatic: related to water.

atmosphere: the atmosphere is the vast gaseous envelope of air that surrounds the Earth, with ill-defined boundaries. It contains a complex system of gases and suspended particles that behave in many ways like fluids. Many of its constituents are derived from the Earth by way of chemical and biochemical reactions.

available water capacity: the capacity of water in the soil that enables plant roots readily to absorb it.

B

bacteria: simple single-celled prokaryotic organisms, with many species. Some species of bacteria can be pathogenic, causing disease in larger, more complex organisms. Many species play a major role in the cycling of nutrients in ecosystems through aerobic and anaerobic decomposition. Finally, some species form symbiotic relationships with more complex organisms and help these life forms to survive in the environment by fixing atmospheric nitrogen.

bed: a layer or **stratum** of sedimentary rock; see **lamina.**

bedrock: rock at or near the Earth's surface that is solid and relatively un-weathered. It lies beneath the soil and regolith (layer of unconsolidated weathered material).

biocatalyst: a substance, that produces or speeds up a chemical reaction.

bulk density: of soil, mass per unit volume, samples as a clod or core, dried to constant weight at 105 .

bund: a man-made embankment or dam

C

calciferous: containing lime

calcification: a dry-environment soil-forming process that results in the accumulation of **calcium carbonate** in surface **soil** layers.

cambic horizon: weakly developed mineral soil horizon of the middle part of soil profiles (B horizon); found in brown earths and **gleys**.

capillary: a fine-bored tube

capillary action: in plants, diffusion of water through the vascular capillaries of the xylem.

capillary water: water that moves horizontally and vertically in soils by the process of capillary action. This water is available for plant use.

carbohydrate : organic compound composed of carbon, oxygen, and hydrogen atoms, e.g. sugars, starch and cellulose.

carbonate: compound consisting of a single atom of carbon and three atoms of oxygen (CO_3).

carbon: a non-metallic element, which is unique in the number of compounds it is able to form that contain chains or rings of carbon atoms. Carbon occurs un-combined as diamond or graphite; charcoal, produced by the destructive distillation of organic matter, is also a pure form of carbon.

carboxyl : the radical COOH.

carrier molecule : Often part of the membrane structure of the cell, the carrier molecule acts in such a way that the plant cell is able to select what kind of ion the plant will assimilate. The carrier molecule attracts a specific ion, which will diffuse across the membrane and be released on the other side.

cation: ion carrying a positive atomic charge.

cation exchange: chemical trading of cations between the soil minerals and organic matter with the soil solution and plant roots.

cation exchange capacity: the capacity of a soil to exchange **cations** with the soil solution; often used as a measure of potential soil fertility.

cell: the smallest self-functioning unit found in living organisms. Each cell is enclosed by an outer membrane or wall, and contains genetic material (**DNA**). and other parts to carry out its life functions.

chelate: organic substance that causes the chemical process of chelation.

chelation: chemical weathering process that involves the extraction of metallic **cations** from rocks and minerals by **chelates**.

chemical weathering: breakdown of rock and minerals into small particles through chemical decomposition.

chlorite: important group of sheet silicate minerals, related to the micas.

clay: a soil separate comprising mineral particles less than 0.004 millimetres in diameter. (See also **silt** and **sand**).

climate: general pattern of **weather** conditions for a region over at least 30 years.

clod: compact, coherent block of soil, found *in situ* when soil is broken up by digging or ploughing. Clods are of varied sizes.

cloud: a collection of tiny particles of liquid or solid water occurring above the Earth's surface. Clouds are classified accord to their height, occurrence and shape.

colloid: substance composed of two homogeneous phases, one of which is dispersed in the other. Colloids have very small particle size, (either mineral, such as clay, or organic, such as humus), which therefore have a large surface area per unit volume, providing high cation exchange capacity.

colour classification of soil: The Munsell Colour Notation (MCN) distinguishes **hue** (spectrum dominance), **value** (relative darkness of the colour) and **chroma** (purity of colour)

compaction: physical process that reflects the increase in pressures brought upon sediments as a result of deeper and deeper burial. As the individual particles of sediment are packed closer and closer together, pore space is reduced.

compost: manure consisting of a mixture of decomposed organic substances.

compound: a compound is the atoms of different elements joined together.

concretion: in pedology, the localized concentration of material, e.g. calcium carbonate or iron oxide, in the form of a **nodule**; such nodules are of various sizes, shapes and colours.

condensation: the change in state of matter from vapour to liquid that occurs with cooling. In meteorology, it refers to the formation of liquid water from vapour; this process releases latent heat energy into the environment.

conductivity: the power of specific substance to transmit heat, electricity, etc.

D

decompose: resolve into elements; break down, rot.

decomposition: the act or state of things decomposing; decay.

deflocculate: of soil, strip the flakes from clay particles

degraded soils: worn down, eroded soils

denitrification: conversion of nitrates into gaseous nitrogen and nitrous oxide.

density (**of matter**): the quantity of mass per unit volume. For gases, density involves the number of atoms and molecules per unit volume.

depleted soils: soils whose content has been exhausted by extraction.

diffusion: the molecular mixing of one substance into another through the movement of particles from an area of higher concentration to one of lower concentration, eventually leaving molecules distributed uniformly.

disaggregation: of clay, restoring its component parts, by an action that reverses **compaction.**

E

electron : a sub-particle of an atom that contains a negative atomic charge.

element: a molecule composed of one type of atom. Chemists have recognized or created 112 different types of elements. Two or more different elements form a compound.

eluviation: movement of humus, chemical substances, and mineral particles from the upper layers of a soil to lower layers by the downward movement of water through the soil profile; "outwashing".

erosion: movement of soil and rock material by agents such as running water, wind, moving ice, and gravitational creep (mass movement).

evaporation: the process by which a substance changes into a vapour; the act of drawing off moisture in the form of steam or gas.

evapotranspiration: the amount of water that is removed from a surface through the processes of **evaporation** and **transpiration.**

Exchangeable Sodium Percentage (ESP)**:** Sodium replaces natural nutrients and destroys soil structure. This indicator shows the percentage of the cation exchange capacity occupied by sodium. If the percentage is more then 15%, the soil needs treatment.

F

fauna: assemblage of all forms of animal life of a region or period, especially as distinct from plant life (**flora**)

fertility, soil: condition of a soil relative to the amount and availability to plants of elements necessary for plant growth. Soil fertility is affected by physical factors, e.g. supply of moisture and oxygen, as well as by the supply of chemical plant nutrients.

field capacity: the water content which can be retained by a soil after excess moisture has drained freely away.

fixation: conversion of atmospheric **nitrogen** into a combined form; (in **pedology**) soil process by which certain nutrient chemicals required by plants are changed from a soluble and available form to a much less soluble and almost unavailable form.

fraction: one of the levels seen in a soil profile (vertical cross-section) – there are four fractions - **topsoil (A horizon), subsoil (B horizon), parent material** and **bedrock.**

fulvic acid: one of three main groups of **humic substances**; a mixture of organic acids that remains soluble in weak acid, alcohol or water after its extraction from soil.

G

gibbsite: mineral, Al(OH) , that is a constituent of bauxite; occurs as an alteration product of aluminium silicates in **laterite** and bauxite deposits.

gley: the product of waterlogged soil conditions, and hence an anaerobic environment. The soil is often mottled, a patchwork of grey and rust colours, due to the reduction of iron compounds by microorganisms.

gravitational water: water that moves through soil due to gravitational forces. Soil water in excess of **hygroscopic** and **capillary** water.

groundwater: all the water contained in the void space within rocks.

gypsum: sedimentary rock created by the chemical precipitation of calcium, sulfur, and oxygen.

H

hardpan: impervious layer found within the soil. It can result from the precipitation of iron, illuviation of clay or the cementing of sand and gravel by calcium carbonate precipitates.

humate: compound with hydrogen-replaced **cations**; a salt of **humic acid** (cation saturated humic acid)

humic acid: mixture of dark-brown organic substances, which can be extracted from soil with dilute

alkali and precipitated by acidification to pH <2, i.e. not soluble in water under acidic conditions, but soluble at higher pH value.

humic substances: complex organic molecules resulting from the decomposition of plant and animal remains in the soil. They are pigmented **polymer**s with a high molecular weight. There are three main groups: **humin**, **humic acid** and **fulvic acid.**

humification: the formation of humus

humin: a fraction that is not soluble in water at any pH value; black in colour

humus: dark coloured semi-soluble organic substance formed from decomposition of soil organic matter.

hydration: a form of chemical weathering that involves the rigid attachment of H+ and OH- ions to the atoms and molecules of a mineral.

hydrocarbon: organic compound composed primarily of hydrogen and carbon atoms, e.g. methane (CH_4).

hydrocolloid: a colloid system where the colloid particles are dispersed in water.

hydrogen: a gas which in combination with **oxygen** produces water, is the lightest of all known substances, is very inflammable, and is of great importance in the moderation (slowing down) of neutrons.

hydrolysis: chemical weathering process that involves the reaction between mineral ions and the ions of water (OH- and H+), and results in the decomposition of the rock surface by forming new compounds; it increases the pH of the solution through the release of the hydroxide ions.

hydromorphic soil: a type of **intra-zonal** soil that occurs in wetland conditions, and has the two sub-types gley and peat soils.

hydrophobic: repelling water.

hygroscopic: relating to substances that have the ability to absorb water and therefore accelerate the condensation process.

hygroscopic coefficient: maximum limit of **hygroscopic** water around the surface of a soil particle.

hygroscopic water: water held within 0.0002 mm. of the surface of a soil particle. This water is essentially non-mobile and can only be removed from the soil through heating.

I

Illite: common clay mineral and important member of the sheet silicates; formed by the weathering decomposition or hydrothermal alteration of **muscovite** or **feldspar**.

illuviation: Deposition of humus, chemical substances, and fine mineral particles in the lower layers of a soil from upper layers because of the downward movement of water through the soil profile.

infiltration: downward entry of water into soil.

inorganic: non-living; usually refers to the physical and chemical components of an organism's **environment**, and sometimes called abiotic.

interconversion: the conversion of two things or more into one another; mutual conversion **ion:** an atom, molecule or compound that carries either a positive (cation) or negative (anion) electrical charge.

K

kaolinite: a very important group of clay minerals belonging to the sheet silicates. Kaolinite represents the final product from the chemical weathering of **feldspars** to give **clays**.

L

lamina: the finest sedimentary layer, less than 1cm in thickness. **Strata** more than 1cm thick are termed **beds.**

laterite: hard sub-surface deposit of oxides of aluminium and iron found in tropical soils where the water table fluctuates with seasonal changes in precipitation.

lava: molten rock, normally a **silicate**, erupted by a volcano.

leaching: a process in which water removes and transports soil humus and inorganic nutrients in solution.

lime: compounds, mostly of calcium carbonates but also other basic **alkaline** substances, used to correct soil acidity and occasionally as a fertilizer to supply magnesium.

lithification: a process by which sediments are consolidated into sedimentary rock.

lithosphere: the solid inorganic portion of the Earth (composed of rocks, minerals, and elements). It can be regarded as the outer surface and interior of the solid Earth.

macronutrient: the nine elements, including hydrogen, oxygen and carbon, that are taken up as nutrients by the plant.

loam: class of soil texture composed of **sand**, **silt** and **clay**, which produces a physical property intermediate between the extremes of the three components.

M

micronutrient: nutritional element required by an organism in relatively very small quantities.

mineral: component of rocks. A naturally occurring inorganic solid with a crystalline structure and a specific chemical composition; over 2,000 types of minerals have been classified.

mineralization: decomposition of organic matter into its inorganic elemental components.

moder: a type of humus soil horizon that is intermediate between **mor** and **mull**. It forms a thin layer of litter, and is medium-humified; reducer organisms are mainly **acidophilic fungi** and **arthropods**.

molasses: thick dark treacle that is drained from sugar when refining.

molecule: minute particle that consists of connected atoms of one or many elements.

montmorillonite: hydrated sodium calcium aluminium magnesium silicate hydroxide; a type of clay that has a large capacity to shrink and expand with wetting and drying.

mor: a type of surface humus soil horizon that is acid in reaction, lacking in microbial activity except that of fungi, and composed of several layers of organic matter in different degrees of decomposition.

morphology: the science of the external forms of rocks and land-features

mulch: loose material, strawy dung, etc., laid on the soil around plants, to protect roots, keep down weeds and retain moisture.

mull: a type of surface humus soil horizon that is chemically neutral or alkaline in reaction, that is well aerated, and that provides generally favourable conditions for the decomposition of organic matter. Mull humus is well decomposed and intimately mixed with mineral matter.

N

natric horizon: a mineral soil horizon that is developed in a subsurface position in the profile, that satisfies the definition of an **argillic horizon**, and that also has a columnar structure and more than 15% saturation of the exchangeable cation sites by sodium.

neutralization: the process if making neutral, i.e. neither **acid** nor **alkaline**, neither electrical positive or negative.

nitrate: a salt or compound of nitric acid

nitrification: The biochemical oxidation of ammonium to nitrite and nitrite to nitrate. This process is carried out by specialised bacteria.

nitrite: a salt or compound of nitrous acid

nitrogen: a gaseous element forming nearly four-fifths of common air, a necessary constituent of every organised body.

nutrient: any substance that encourages growth.

O

ochric horizon: a light-coloured, mineral soil horizon, usually at the soil surface and characteristic of arid-environment soils.

organic matter: mass of **matter** that contains living organisms or non-living material derived from organisms. Sometime refers to the organic constituents of soil.

organism: any form of life.

osmosis: the movement of water or of another solvent from a region of low solute concentration to one of higher concentration through a semi-permeable membrane. It is an important mechanism in the uptake of water by plants.

osmotic potential: the difference between the energy of water in the system being considered and of pure, free water at the same temperature. The osmotic potential of pure water is zero, so that of a solution will be negative.

oxic horizon: mineral subsoil soil horizon that is at least 30cm thick and is identified by the almost complete absence of weatherable primary materials, by the presence of kaolinite clay**,** insoluble minerals such as quartz, hydrated oxides of iron and aluminium, and small amounts of exchangeable bases, and by low cation exchange capacity.

oxidation: a reaction in which oxygen combines with, or hydrogen is removed from, a substance.

oxygen: a gas without taste colour or smell, forming part of the air, water, etc and supporting life and combustion.

P

parent material: the original material from which the soil profile has developed through **pedogenesis,** usually to be found at the base of the profile as weathered but otherwise unaltered mineral or organic material.

pedogenesis: the natural process of soil formation, including a variety of subsidiary processes such as **humification, weathering**, **leaching** and **calcification**.

pedology: the scientific study of soils.

peds: unit of soil structure (e.g. an aggregate, crumb, granule or prism) that is formed naturally.

permanent wilting point: the percentage of water remaining in the soil after a specified test plant has wilted under defined conditions, so that it will not recover unless it is given water.

permeability: the ability of a **rock**, **sediment** or **soil** to permit fluids to flow through it.

pH: the negative logarithm of the hydrogen ion concentration in a solution. If the hydrogen ion concentration of a solution increases, the pH will decrease, and vice versa. The pH is measured on a scale of 0 – 14; a neutral medium such as pure water has a pH of 7, numbers above 7 indicate relative alkalinity and numbers below 7 indicate relative acidity.

pore: a void surrounded completely by **soil** or **rock** materials and created by the packing of **mineral** and **organic** particles. Pores can be filled by any proportion of air or water.

porosity: effective porosity is defined as the proportion of **rock** which consists of interconnected **pores**; it is expressed as a percentage of the bulk volume of the **rock.**

precipitation: (1) all the forms in which water falls to the ground, e.g. rain, snow, hail; (2) the process of depositing dust or other substances (pollution) from the air.

prilled: of fertilisers, in the form of pellets.

R

real density: of soil, mass per unit volume, but unlike **bulk density**, real soil density excludes the pore spaces, leaving only the volume of the soil solids.

redox chain: reduction-oxidation reaction involving the transfer or electrons from a donor molecule, the reducing agent, to an acceptor molecule, the oxidising agent.

reduction: chemical reaction in which atoms or molecules either lose oxygen, or gain hydrogen or electrons.

regolith: general term for the layer of unconsolidated weathered material that rest on unaltered, solid bedrock. It reaches its maximum development in the humid tropics, where depths of several hundreds of metres of weathered rock are found.

rock: a consolidated or unconsolidated aggregate of minerals or organic matter.

S

salinity: concentration of dissolved salts found in a sample of water; measured as the total amount of dissolved salts in parts per thousand. salt: (1) the mineral sodium chloride. (2) compounds that are produced as the result of a metal atom replacing a hydrogen atom in an acid. sand: mineral particle with a size between 0.06 and 2.0 mm. in diameter. Also see clay and silt.

sediment: material derived from pre-existing rock, formed from living organisms, or precipitated by chemical processes, and deposited at, or near, the Earth's surface.

sedimentary rock: one of the three main groups of soil **parent material**, the others being **cryptal line rock** and loose rock. Sedimentary **rock** is formed by the **deposition**, alteration and/or compression, and **lithification** of weathered rock debris, chemical precipitates, or organic sediments.

sesquioxide: general term for the hydrated oxides and hydroxides of iron and aluminium.

silica: mineral that is composed of silicon dioxide, SiO_2.

silicon: a non-metallic element, most abundant of all except **oxygen**, forming grey crystals or brown amorphous powder and having semi-conducting properties.

silicate: a salt of silicic acid or derived from silicon; the most important and abundant group of rock-forming minerals, which have crystal structures based on a silica tetrahedron (four-faced crystal form)- SiO_4.

silicic acid: general name for a group of acids derived from silicon.

silt: mineral particle with a size between 0.004 and 0.06 millimetres in diameter. Also see clay and sand.

slickenside: in soils, the natural crack surfaces produced by swelling and shrinkage in clayey soils that are high in swelling clays.

smectite: a family of clay minerals that includes **montmorillonite** and bentonite (clay formed from volcanic material).

soil: layer of unconsolidated material found at the Earth's surface that has been influenced by the soil forming factors: climate, relief, parent material, time, and organisms. Soil normally consists of weathered mineral particles, dead and living organic matter, air space, and the soil solution. It is **regolith** that often contains organic material and is able to support rooted plants.

soil profile: a vertical section through all the constituent horizons of a soil, from the surface to the relatively unaltered parent material.

soil structure: grouping of individual soil particles into secondary units of **aggregates** and **peds.**

soil taxonomy: the classification of types of soil, in a manner similar to that used for biological classification. The most widely used system was developed within the U.S. Department of Agriculture (USDA), and it divides soil into 11 soil orders.

soil texture: in pedology, the proportions of **sand**, **silt** and **clay** in the fine earth of a soil sample, which give a distinctive feel when handled, and which are defined by classes of soil texture.

species: a group of individuals similar in structure and capable of interbreeding and producing fertile offspring. They are different in structure from other such groups and do not interbreed with them.

spodic horizon: subsurface soil horizon in which organic matter together with aluminium and often iron compounds have accumulated amorphously.

stratum, pl. **strata:** term referring to rocks that form layers or **beds.**

subsoil: a layer of broken or partly weathered rock underlying the soil, especially that part below the layer normally used for cultivation.

substratum: the material in which a plant grows or on which an animal moves or rests; an underlying layer of rock or soil.

surface tension: tension of a **liquid**'s surface, due to the forces of attraction between molecules, making it contract, liked stretched elastic.

suspension: a mixture of a fluid with dense particles which are prevented from settling by viscosity and impact of molecules.

T

tectonic shield: the large stable area of pre-Cambrian rocks that form the central part of a continent, with several rigid plates (tectonic plates) continually shifting slightly in relation to each other.

tillage: the practice of cultivating the soil

topography: the detailed study, description or features of the relief of a limited area, district, etc.

topsoil: the upper part or surface of the soil.

turbidity: the violent disturbance of sediment in water, making it muddy.

U

urea: an organic compound of carbon, nitrogen, oxygen and hydrogen, also known as carmamide. 90% of urea is used as a fertilizer with very high nitrogen content. It is used in foliar fertilizers, in combination with ammonium nitrate.

V

vermiculite: member of the sheet-silicates, closely related to clay minerals.

W

water table: the upper surface of **groundwater**, or the level below which an unconfined **aquifer** is permanently saturated with water

weather: the conditions in the air above the Earth, such as wind, rain or temperature, especially at a given time over a given area.

weathering : the breakdown of rocks and minerals at and below the Earth's surface by the action of physical and chemical processes.

Tables

Figures

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