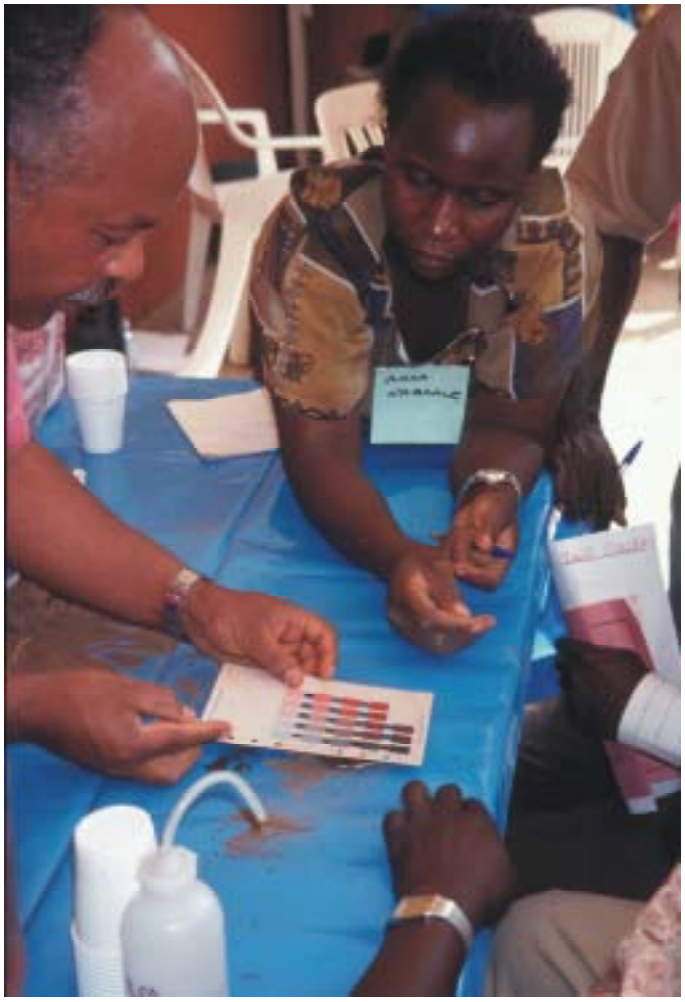
SECTION 2

Technical Indicators of Soil Quality



he soil shall continue to be the most important natural resource for mankind, who shall always need food and fibers to survive.

Section 2: Technical Indicators of Soil Quality

2.1 Introduction

Soils are natural bodies on the earth's surface consisting of solid, liquid, gaseous and biotic components in variable combinations. The variations are generated by natural and human-led processes, and affect the quality of the soil. Assessment of the quality of the soil varies depending on the appreciation of its various users. According to Brady (1974), the evaluation of modern concepts on soil involves two basic sources of knowledge. First, the practical knowledge accumulated over time, and which constituted the only information available before the advent of modern science. This indigenous knowledge has not been sufficiently appreciated, although it is a valuable alternative source of information about soils and their management. Second is the knowledge acquired through the application of the scientific methods, through edaphology (the study of soil properties and their relationship to the function of the soil), and pedology or soil classification.

The manual promotes the knowledge about agricultural use of the soil through both technical terms and the farmer's experiences, so that the producer and the technician share their knowledge, understand and analyze the origin, evolution and distribution of soils. In this section of the manual, a theoretical framework is presented, using a simplified model of soil formation that applies modern concepts of pedology and edaphology.

2.1.1 Objectives

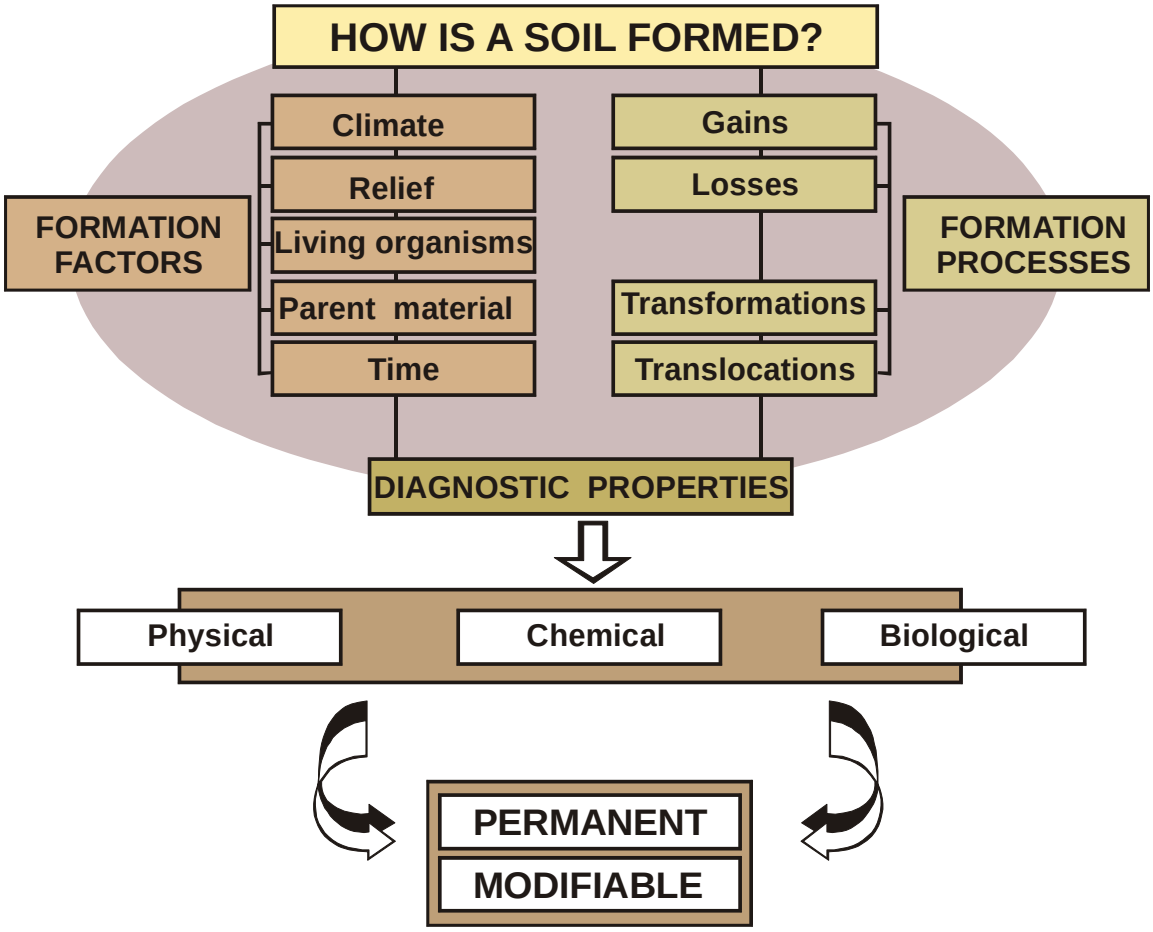
At the end of this section the trainees will be able to,

- Differentiate among the various soil formation factors and processes through the Simplified Model of Soil Formation

- Describe the factors and processes affecting the formation of a soil.

- Identify soil physical, chemical and biological properties, and differentiate between those that are permanent and modifiable.

2.1. 2 Section Structure



2.1.3 Orientating Questions

1. How do soils affect our daily lives?

2. How is a soil formed?

3. What is a soil formation factor?

4. What is a soil formation process?

5. What is a soil permanent property, and a modifiable property?

2.2 Importance of Soil

Soil is important as a natural resource and medium for plant growth because it,

- constitutes the basis for renewable natural resources (flora and fauna)
- provides food for the population, and constitutes the basic resource for the survival of the poorest population
- is a filter of wastes from human activities, as well as a water reservoir for crops
- is not a renewable natural resource.

As a medium for plant growth it:

- serves to anchor plant roots
- supplies water to the plants
- provides air for plant root respiration
- provides minerals for plant nutrition

2.3 Factors and Processes of Soil Formation

As soils naturally develop on the landscape, distinct "soil layers" called horizons may form. The horizons differ from each other in their physical, chemical and biological properties. Soil formation is the evolution of soil horizons through various processes and several soil-forming factors. An understanding of soil formation processes is useful in interpreting soils for specific uses.

2.3.1 Soil-forming factors

A soil-forming factor is an element, element part or agent favouring a given outcome. In this case, soil formation factors are those elements participating as soil development-causing agents; they are climate, parent material, relief, living organisms and time.

Put simply, the type of soil developed depends on the period a parent material on a specific topography is exposed to the effects of climate and living organisms. For instance: in an arid, cold climate with an uneven topography, the evolution of the soil is determined by the relief, moisture availability and low temperatures resulting in a less favourable substrate for the development of organisms, including plants and animals. Another example is of soils formed on flat relief where the main characteristic favouring soil evolution is the tendency to accumulate sediments from the surrounding slopes, as a result of erosive processes.

Climate

Climate is considered to be the most important factor of soil formation and evolution, with temperature and rainfall being the most influential components. Their effects are closely related to the control of physical, chemical and biological (especially organic matter production and decomposition) process rates. In general terms, it is considered that if the climate is very variable and contrasting,

it becomes a factor of utmost influence, and tends to determine the formation of a soil.

Relief

Relief is sometimes referred to as topography. It contributes to soil formation largely through its influence on soil erosion and drainage (these accelerate or delay the soil formation process). For example, soil profiles on steep slopes are shallow because of the high rates of soil erosion. On the other hand, drainage on slopes and uplands is good and allows faster formation of soils than in lowlands where poor soil drainage will result in slow soil formation and high organic matter accumulation due to slower decomposition.

Parent material

This is the substrate or materials from which soils develop. Approximately 99% of the soils have developed from mineral parent material that was derived from the weathering of bedrock. The rest have developed from organic deposits, mainly of plant origin, formed in swamps and marshes. Therefore, parent materials differ in their composition and resistance to degradation.

Parent materials have influence on the soil physical and chemical characteristics, but the best correlation is with texture. Those materials with high quartz content tend to weather into very sandy soils while basic rocks and fine grained sediments weather into fine textured soils. But the same type of parent material can give rise to different soils depending upon the nature of the other factors, particularly climate. For example, basalt may develop into a highly weathered red soil (Ferralsol) in the humid tropics or a black cotton soil (Vertisol) in the semi-arid tropics.

Living organisms

Every organism living on earth has the potential to affect development of soils. Those with direct influence can be grouped as higher plants, vertebrates, macro-organisms and micro-organisms. The major contribution of higher plants is through the addition of organic matter, which varies in amount and quality according to plant communities. The roots of higher plants may bind and prevent erosion, physically disintegrate solid materials, extract and recycle nutrients within horizons, and leave a network of passages after death and decay. Some vertebrates, including rabbits and moles, burrow into and mix soils. Macro and micro-organisms exert a strong influence on soil formation due to the role they play in organic matter decomposition, nutrient redistribution and cycling, and the transformation of such nutrients into forms necessary for plant nutrition.

Time

The extent to which the other soil-forming factors express their effects is a function of the time during which they have operated. In general, the soils developed on alluvial deposits have not had enough time to evolve, as is the case of soils developed in other landscapes. Older soils, like those in tropical humid areas, generally have deeper soil profiles, are more weathered, contain thick horizons and have lost their plant nutrients due to leaching.

2.3.2 Soil-forming processes

These are conditioning processes that might cause the same group of soil-forming factors to generate different types of soils from a given parent material. The formation of soil horizons is a result of differential gains, losses, transformations and translocations (these constitute soil-forming processes) that

occur over time within the profile of the parent material; these are natural and/or human-led processes (see box).

Soils gain from all types of depositions, both beneficial (e.g. mineral fertilisers) and detrimental (e.g. toxic wastes) to their development. The depositions may be in liquid, gaseous or solid forms, and mineral or biological in nature. There is a relationship between the gain and loss processes such that agents affecting one of these processes affect the other. For example, wind and water erode (loss) and deposit (gain) soil materials. Transformation refers to the modification of soil mineral and organic fractions through biophysical and chemical processes, while translocation is a process involving physical movement of soil constituents in the profile, such as clay illuviation.

Examples of natural and human-led processes

Natural processes

Movement of soil particles and nutrients down a slope through water erosion and deposition
Wind erosion and dust deposition
Fertility enrichment and depletion in the soil due to water movement
Movement of clays within soil
Uptake of nutrients by deep-rooting species
Biological nitrogen fixation
Mycorrhizal phosphorus accumulation

Human-led processes

Importing mineral and organic fertilisers
Transporting manures and residues to fields
Transporting farm products to homes, towns and other settlement areas
Burning vegetation and residues

2.4 Properties of Indicators of Soil Quality

Soil quality indicators relate to the fitness of use and ease of management of soils, and may be regarded as pre-requisites of soil fertility. Their properties are physical, chemical and biological in nature.

2.4.1 Physical properties

These are properties that add to the appearance and feel of the soil. By observing soil colour, for example, one may estimate its organic matter and iron content, and drainage. By feeling the soil, one may estimate the type and size of the particles present. Soil physical properties are largely controlled by the relative abundance of the different sized soil particles, and may be grouped into two:

- Primary properties: texture, structure, colour, consistency, density & temperature.

- Derived properties: porosity, air retention capacity, water retention capacity, compaction and effective depth.

Texture

The weathering of rocks and minerals results in a range in the size of particles; from stones through gravel, sand, silt and clay. Soil texture refers to the relative proportion of sand, silt and clay in the soil. The texture is responsible for the potential fertility, aeration, permeability, effective depth and moisture characteristics of soils. For example, a sandy soil will absorb and release water very easily, i.e. permit more rapid water intake or filtration. It also has lesser capacity for nutrient adsorption. A clay soil retains water and nutrients for long,

but is not well aerated. A loam soil falls in between the sandy and clay soil and is suitable for plant growth.

Structure

Soil particles are typically arranged into secondary particles called aggregates. The shape, size and arrangement of the aggregates define the soil structure. Structure formation is influenced by the composition of the organic matter, iron oxides and hydroxides, and clay fractions. It affects water intake, drainage, aeration and root development. Soil structure, especially in the topsoil, can be changed by ploughing or cultivation.

Colour

Soil colour is, perhaps, the most obvious soil property, yet it has little actual effect on the soil. Soil colours vary from black to nearly white, and from red to yellow. They are an indirect measure of other important soil characteristics such as organic matter, temperature, moisture, and parent material.

Consistency

Consistency is the resistance of the soil to deformation under specific moisture conditions. It is determined by the cohesive and adhesive properties of the soil mass. It is a soil quality indicator closely related to the type of clay in the soil, and has noticeable influence on soil tilth and depth of rooting.

Density

This refers to the mass (weight) per unit volume of soil. Distinction is made between particle and bulk density. The former considers only volume of solid soil particles while the latter is the volume of solid and enclosed pore space. Soils

differ in density because of their differences in texture, types of clay minerals and amount of organic matter. Properties such as water retention and gaseous exchange are linked to density, as it is related to the amount and shape of the pores.

Temperature

Soil temperature is a reflection of the solar energy reaching the surface of the earth. The soil chemical processes and activities of soil organisms are temperature dependent. In the tropics, very high or very low temperatures, as well as sudden temperature changes during the daytime influence the rate of soil formation.

Pore space

Pore space, also known as porosity, is the portion of the soil not occupied by solid soil particles, it is occupied by air and water. The arrangement of solid soil particles determines the amount of pore space. It is considered that soils have about 50% porosity which is important for water movement and retention, gas diffusion, root penetration, temperature regulation and soil biological activity. Pore spaces occur in soils in macro (large) and micro (small) pores.

Air retention capacity

This soil property is determined by the amount of macro-pores (>0.05 mm) in the porous space, facilitating the movement of the gases used or released during the activities of soil living organisms.

Water holding capacity

This relates to the amount of water "available to the plant" that a soil can hold. It is the difference between soil retained water, available to be used by the plants (field capacity) and the water retained but not available for the plants (permanent wilting point). This property is related to the nature of the surfaces and pores of the soil. Micro pores retain or hold soil moisture.

Compaction

Compaction is the result of altering the soil porosity caused by the long-term effects of cropping and tillage. Compaction decreases the total pore space and increases bulk density. Ploughing and other tillage operations usually increase pore space and decrease bulk density. Farm machinery have great potential to compact soil.

Effective soil depth

This indicator refers to the depth that roots can reach without confronting any physical or chemical obstacles. Deep soils allow penetration of roots downwards and sideways, and offer greater potential of the soil supplying the plant with the required nutrients and water. It is, therefore, one of the most important properties that determine the potential of the soil for crop production.

2.4.2 Chemical properties

Soil chemical properties indicate the levels of the soil organic and inorganic components, and their influence on crop production and productivity. The most important indicators are pH, organic matter content and cation exchange capacity.

pH

Soil pH is the measure of the quantity of acid or alkali in the soil. A pH scale that extends from 0 to 14 indicates this soil property. The pH values below 7 are acidic and those above 7 are basic or alkaline. Soil that has a pH of 7 is a neutral soil. Soil pH has a direct influence on physical, chemical (nutrient availability) and biological (microbial activity) characteristics that affect crop growth. The pH of most agricultural soils ranges from 4.5 to 8.5. Alkali soils have pH values above 8.5.

Soil organic matter

Soil organic matter consists of roots, plant residues and soil organisms in various stages of decomposition. It has great impact upon the chemical, physical and biological properties of the soil. Organic matter in the soil gives the soil good structure, and enables the soil to absorb water and retain nutrients. It also facilitates the growth and life of the soil biota by providing energy from the carbon compounds, nitrogen for protein formation, and other nutrients. Some of the nutrients in the soil are held in the organic matter, comprising almost all the nitrogen, a large amount of phosphorus and some sulphur. When organic matter decomposes, the nutrients are released into the soil for plant use. Therefore, the amount and type of organic matter in the soil determines the quantity and availability of these nutrients in the soil. It also affects the colour of the soil.

Cation Exchange Capacity

One of the properties of humus and clay minerals (colloids) in soil is that they have negative charge which allow them to "magnetically" hold positively charged nutrient elements (cations, eg. K+, Ca++) on their surfaces. This is important for reducing losses of nutrients through leaching. These nutrients can be exchanged with those dissolved in the soil solution surrounding the colloids.

Because of variations in the colloid structure, soils have widely differing abilities to hold (adsorb) the cations. Cation exchange capacity is a measure of the ability of the soil to adsorb cations, or of the negative charges of the soil arising from its clay and humus content.

In contrast, negatively charged nutrient elements (anions, eg. NO3-) are repulsed by the negative charge of humus and clay minerals and remain in the soil water solution and are therefore prone to leaching.

The process of adsorbing nutrients from, and releasing them into the soil solution is called cation exchange. This process is important for the nutrition of the plants. When soil is unable to release the nutrients required by the plant, natural or artificial fertilisers must be applied. The added fertilisers dissolve; some of the cations are taken up by the plant while some may be adsorbed on the colloid surfaces. Exchangeable cations affect soil structure. The presence of sufficient Na+ on the colloidal surfaces disperse the soil while Ca++ flocculate and aggregate the soil.

2.4.3 Biological properties

The biological properties of the soil are related to the activity of the organisms living in it. Soil organisms (e.g. earthworms, termites, ants, fungi, bacteria, etc.) play a very important role in decomposing soil organic residues, as they fragment, ingest and excrete them, and affect their physical and chemical characteristics. The biological activity easily observed is the one performed by some larger organisms (earthworm casts, ant nests, etc.), while in most cases the activity of micro-organisms is not so easy to observe. There also are some other beneficial micro-organisms, such as nitrogen - fixing rhizobia which live in association with legume plant roots and cause the formation of rounded, easy-to-detect structures (nodules) on the roots of the plant.

The biological processes are either directly or indirectly affected by other soil properties, such as temperature, moisture, aeration, pH, organic matter and nutrient availability. The activity of soil and plant organisms tends to be more intensive in high temperature and moisture conditions, rather than in low temperatures and drought conditions.

2.4.4 Permanent and modifiable properties

An alternative way to group soil quality indicating properties is their own change through agricultural, livestock and/or forest management. The properties can be permanent or modifiable. A permanent property is the one that has been determined by the parent materials and by some formation factors which may not change in the short-term. The texture of the soil is regarded as a permanent property, as it is difficult to change the relative distribution of the particles size making up a fine fraction (< 2mm). Likewise, in the short term, it is difficult to change a pronounced slope in the hillside.

A modifiable property is the one that can be noticeably altered through management actions regularly applied to the soil. An example is the reduction in the content of organic matter in the superficial part of the soil (0-15 cm), which can be modified through the stimulation of greater mineralization caused by practices such as periodic burns, continuos tillage, erosion, etc.

Exercise 2.1: Identifying Soil Formation Factors and Processes

- ✓ ***Objective***

At the end of these exercises, the participants shall be able to identify the processes and factors involved in soil formation.

Guidelines for the Instructor

1. Depending on the number of participants, make four to six member groups and give each group a copy of the instructions to do this exercise.

2. Give 30 minutes to each group, to discuss and analyze the questions and possible responses. Ask the participants to apply the examples to their own smallholdings or their own micro-watershed.

3. Ask them to appoint a co-ordinator to present their responses. They can use the flip chart, the overhead projector or any other aid available.

4. At the end of the presentations, give some examples and suggestions to help the groups to broaden their knowledge on the topic.

Necessary Resources

- Instructions sheet for each group
- Flip chart and paper
- Overhead projector
- Washable overlays and markers

Suggested time: 45 minutes

Exercise 2.1: Identifying soil formation factors and processes

Worksheet No. 1: Soil formation factors and processes

Based on the knowledge you have acquired during this training, mark an X in the blanks against a soil formation factor or process you can identify e. g.: indicate which are factors and which are processes.

	Factors	Processes
1. Climate		
2. Soil losses		
3. Temperature		
4. Rainfall		
5. Wind speed		
6. Cloudiness		
7. Soil gains		
8. Translocation		
9. Relief		
10. Parental material		
11. Organisms		
12. Flora		
13. Fauna		
14. Moisture		
15. Luminosity		
16. Slope		
17. Valley		
18. Hill-foot		
19. Mountain		
20. Geology		
21. Erosion		
22. Burning practice		
23. Flood deposits		
24. Stubble incorporation		
25. Transformations		
26. Movements of clays		
27. Mineralogy of clays		
28. Micro-organisms		
29. Evolution		
30. Washing		
31. Forest		
32. Pastures		

Exercise 2.2 Identifying factors and processes in soils formation

Worksheet No. 2: Formation factors

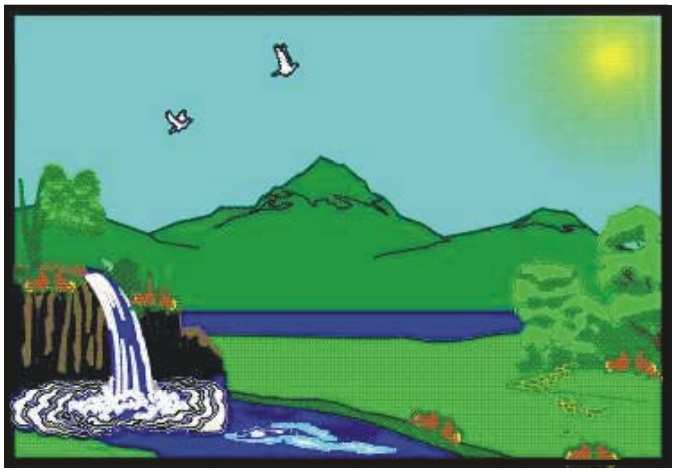
Taking as reference the drawings in the left margin of this worksheet, write on the line below each drawing, the soil formation factor you relate it to. Then, write on

the right hand column, three or more elements involved in the formation factor identified.

Formation factors

_____

1. _____
2. _____
3. _____
4. _____
5. _____



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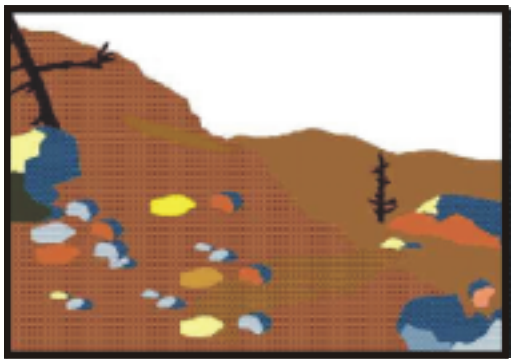

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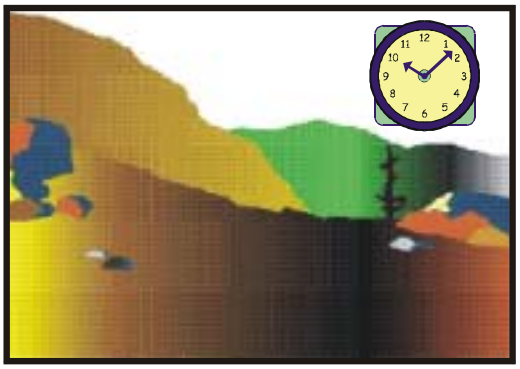

1. _____
2. _____
3. _____
4. _____
5. _____

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Exercise 2.3 Identifying soil formation factors and processes

Worksheet No. 3: Formation processes

Taking as reference the drawings in the left margin of this worksheet, write in the right side of each drawing, the soil formation process you relate it to. Then, write on the right hand column, three or more elements involved in the formation process identified.

Formation processes

_____

1. _____
2. _____
3. _____
4. _____
5. _____

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1. _____
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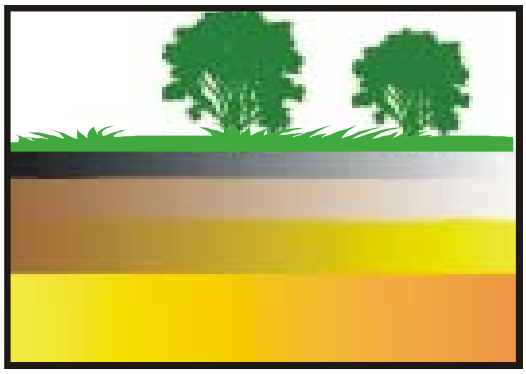

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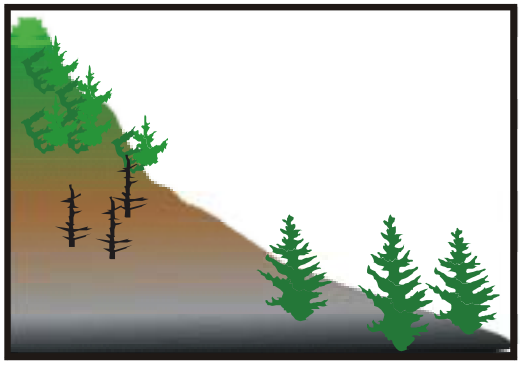


1. _____
2. _____
3. _____
4. _____
5. _____

Exercise 1.1 Identifying soils formation factors and processes Feedback information

	Factors	Processes
Climate	X	
Soil losses		X
Temperature	X	
Rainfall	X	
Wind Speed	X	
Cloudiness	X	
Soil Gains		X
Moisture	X	
Relief	X	
Parental Material	X	
Organisms	X	
Flora	X	
Fauna	X	
Translocation		X
Luminosity	X	
Slopes	X	
Valley	X	
Hill-foot	X	
Mountain	X	
Geology	X	
Erosion		X
Burning Practice		X
Flood Deposits		X
Stubble Incorporation		X
Transformations		X
Movement of clays	X	
Mineralogy of clays	X	
Micro organisms	X	
Evolution	X	
Washing		X
Forests	X	
Pastures	X	

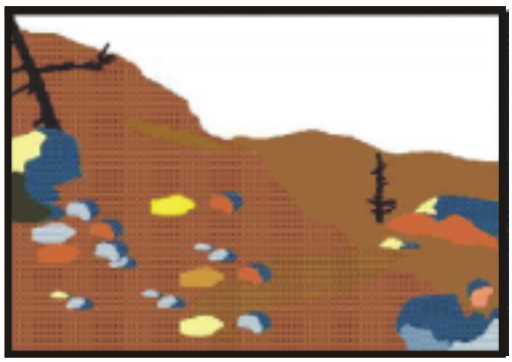
For Worksheet No. 2

Climate

1. Temperature
2. Rainfall
3. Luminosity
4. Cloudiness
5. Wind
6. Fog

Relief

1. Mountains
2. Valleys
3. Hill foot
4. Slopes
5. Hills
6. Plains

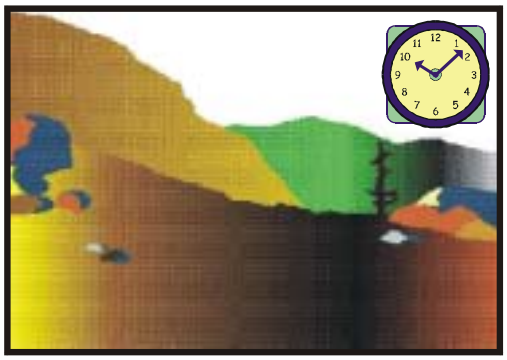


Parent Material

1. Rocks
2. Limestones
3. Tuffs
4. Lutites
5. Disintegration
6. Weathering

Organisms

1. Animals
2. Plants
3. Bacteria
4. Fungi
5. Earth Worms
6. Lichens



Time

1. Evolution
2. Transformation
3. Geological Ages
4. Development
5. Change

For Worsheet No. 3

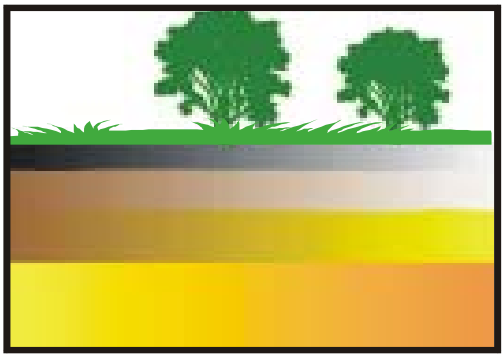
Formation Process

Gains

1. Flood Deposits
2. Incorporation of Stubble
3. Fertilization
4. Liming
5. Mineral
6. Biological

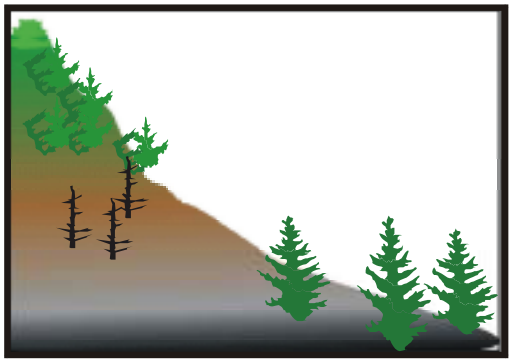
Losses

1. Erosion (wash out)
2. Burning Practice
3. Landslide
4. Crawling
5. Acidification
6. Slope



Translocation

1. Movement of clays
2. Movement of salts
3. Descendent movement
4. Oblique movement
5. Ascendant movement
6. Humus



Transformation

1. Minerals
2. Meteorization
3. Weathering
4. Organic Matter
5. Humus
6. Clays, Oxides

2.6 Summary

In this section we saw how to differentiate among the various soil formation factors and processes, how to describe these factors and processes and to identify soil physical, chemical and biological properties.

In the next section we will identify local indicators of soil quality and in Section 4 these local indicators of soil quality will be integrated with the technical indicators of soil quality that were derived during the exercises in this section. This integration will allow the development of a common language between farmers and researchers which will be essential to allow information exchange and sharing of knowledge.

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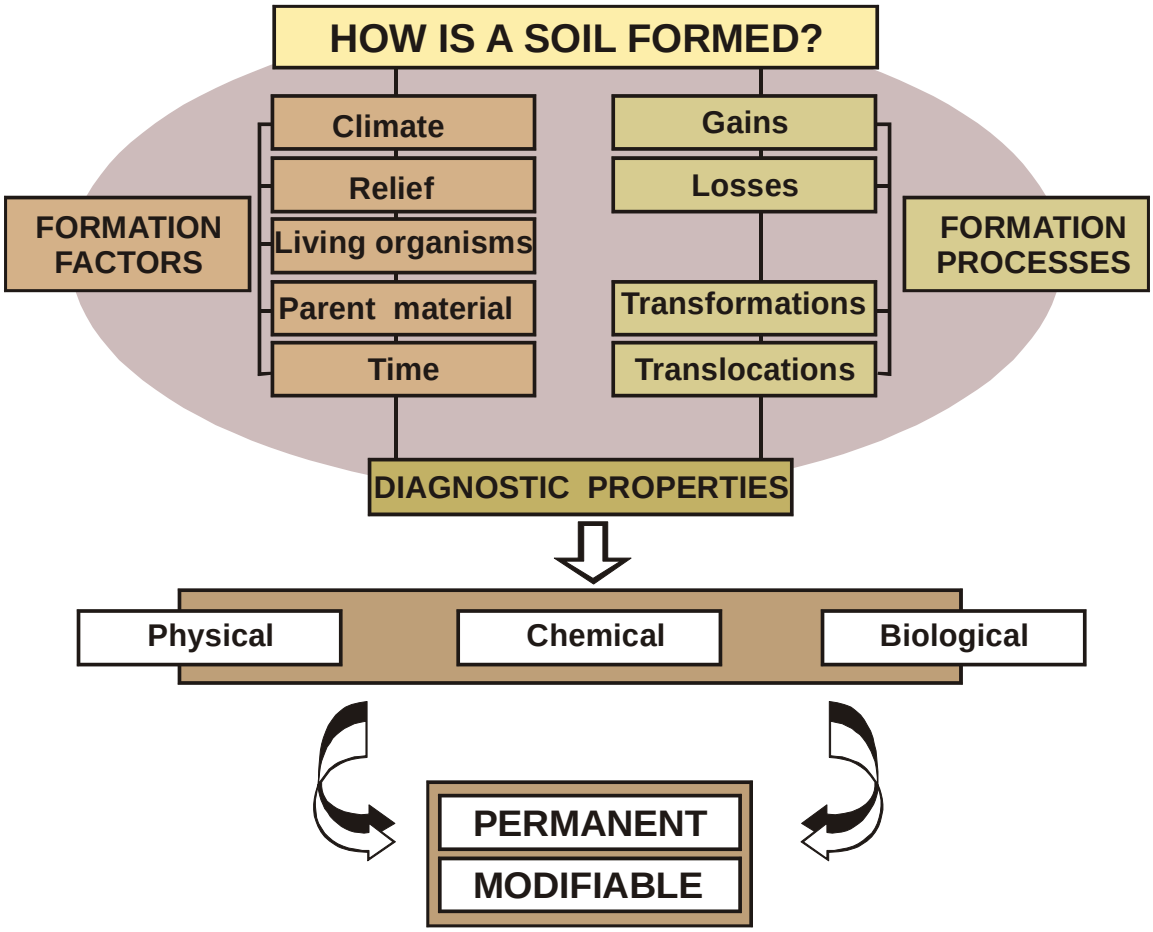
Originals for Overheads

Section Structure



Section objectives:

- Diferentiate among the various soil formation factors and processes

- Describe the factors and processes affecting the formation of a soil.

- Identify soil physical, chemical and biological properties, and differentiate between those that are permanent and modifiable.

Orienting questions:

- how do soils affect our daily lives?
- how is a soil formed?
- what is a soil formation factor?
- what is a soil formation process?
- what is a soil permanent property, and a
- modifiable property?

Soil is a natural resource:

- constitutes the basis for renewable natural resources (flora and fauna)

- provides food for the population, and constitutes the basic resource for the survival of the poorest population

- is a filter of wastes from human activities, as well as a water reservoir for crops

- is not a renewable natural resource.

Soil is a medium for plant growth:

- serves to anchor plant roots
- supplies water to the plants
- provides air for the breathing of plant roots furnishes minerals for plant nutrition

Soil forming factors:

These are soil development causing agents.

- climate
- parent material
- relief
- living organisms
- Time

Soil-forming processes - natural processes:

- Movement of soil particles and nutrients down a slope
- Wind erosion and dust deposition
- Fertility enrichment and depletion in the soil
- Movement of clays within soil
- Uptake of nutrients by deep-rooting species
- Biological nitrogen fixation
- Mycorrhizal phosphorus accumulation

Soil-forming processes - human-led processes:

- Importing mineral and organic fertilisers
- Transporting manures and residues to fields
- Transporting farm products to homes, towns and other settlement areas
- Burning vegetation and residues

Indicators of soil quality:

- Physical properties eg texture, colour, porosity, effective soil depth
- Chemical properties eg pH, organic matter
- Biological properties, related to organisms living in the soil
- Permanent properties do not change in the short-term
- Modifiable properties are noticeably altered through regular soil management actions

Appendices for Section 2

Appendix 2.1 - Answers for Worksheet No. 1: Soils formation factors and processes

	Factors	Processes
1. Climate	X	
2. Soil losses		X
3. Temperature	X	
4. Rainfall	X	
5. Wind speed	X	
6. Cloudiness	X	
7. Soil gains		X
8. Translocation	X	
9. Relief	X	
10. Parental material	X	
11. Organisms	X	
12. Flora	X	
13. Fauna	X	
14. Moisture		X
15. Luminosity	X	
16. Slope	X	
17. Valley	X	
18. Hill-foot	X	
19. Mountain	X	
20. Geology	X	
21. Erosion		X
22. Burning practice		X
23. Flood deposits		X
24. Stubble incorporation		X
25. Transformations		X
26. Movements of clays	X	
27. Mineralogy of clays	X	
28. Micro-organisms	X	
29. Evolution	X	
30. Washing		X
31. Forest	X	
32. Pastures	X	

Appendix 2.2 - Answers for Worksheet No. 2: Formation factors

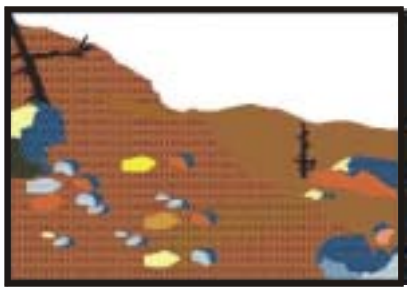
Climate

1. Temperature
2. Rainfall
3. Luminosity
4. Cloudiness
5. Wind
6. Fog

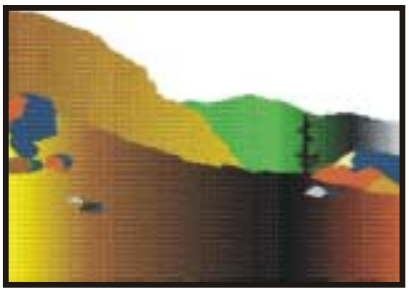
Relief

1. Mountains
2. Valleys
3. Hill foot
4. Slopes
5. Hills
6. Plains

Parent Material



1. Rocks
2. Limestone
3. Tuffs
4. Lutites
5. Disintegration
6. Weathering



Organisms

1. Animals
2. Plants
3. Bacteria
4. Fungi
5. Earth Worms
6. Lichens

Time

1. Evolution
2. Transformation
3. Geological Ages
4. Development
5. Change

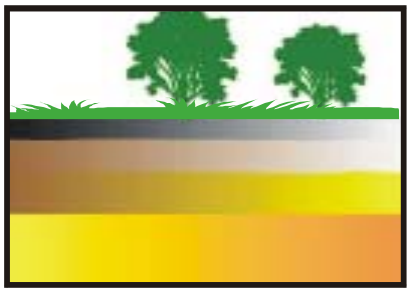
Appendix 2.3 Answers for Worksheet No. 3: Formation processes

Gains

1. Flood Deposits
2. Incorporation of Stubble
3. Fertilization
4. Liming
5. Mineral
6. Biological

Losses

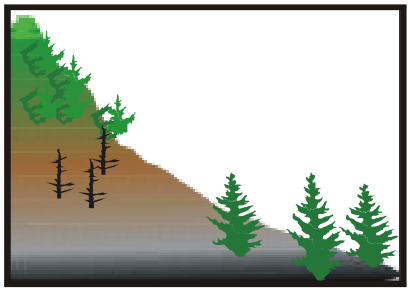
1. Erosion (wash out)
2. Burning Practice
3. Landslide
4. Crawling
5. Acidification
6. Slope



Translocation

1. Movement of clays
2. Movement of salts
3. Descendent movement
4. Oblique movement
5. Ascendant movement
6. Humus

Transformation



1. Minerals
2. Meteorization
3. Weathering
4. Organic Matter
5. Humus
6. Clays, Oxides