COURSE GUIDE

SLM 510
SOIL SURVEY AND LAND EVALUATION

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INTRODUCTION

Soils play a vital role in the quality of our environment. For example, soil impacts the quality and quantity of our food, and serves as foundation of our structures, as well as interact with the hydrosphere and atmosphere. Soil can be a source, a sink, or an interacting medium for many nutrients, as well as contaminants that impact humans, plants, wildlife, and other organisms. An understanding of soil properties and processes is therefore critical to the evaluation of the criteria to be adopted for the soil management. The objective of the course is to be aware of chemical and biological reactions that may influence the behaviour of contaminants according to the different soil types and properties. Because soil is important for cultivation and agricultural production, soil fertility and productivity are important issues to address. Detailed pedological knowledge is useful for land evaluation purposes, i.e. the classification in fertile productive soils and less valuable soils.

Soils are an integral part of landscapes and the knowledge of the distribution of different soils helps to preserve a high standard in environmental quality. For example, site specific management cannot be developed without detailed knowledge of soils. Critical sites, e.g. shallow hill slope soils prone to erosion and leaching of nutrients, can be identified using pedology. Soil surveys furnish basic inputs to soil conservation planning and provide information used in equations for predicting soil loss and water pollution under various management practices on different soils.

WHAT YOU WILL LEARN IN THIS COURSE

The course consists of modules in units and a course guide. This course guide tells you briefly what the course is about, what course materials you will be using and how you can work with these materials. In addition, it advocates some general guidelines for the amount of time you are likely to spend on each unit of the course in order to complete it successfully. It gives you guidance in respect of your tutor-marked assignment in the assignment file. There will be regular tutorial classes that are related to the course. It is advisable for you to attend these tutorial sessions. The course will prepare you for the challenges you will meet in the field of soil pedology and classification.

COURSE AIMS

The aim of the course is not complex. The course aims to provide you with an understanding of soil survey and land evaluation; it also aims to provide you with solutions to problems with soil classification in the field.

COURSE OBJECTIVES

To achieve the aims set out, the course has a set of objectives. Each unit has specific objectives which are included at the beginning of the unit. You should read these objectives before you study the unit. You may wish to refer to them during your study to check on your progress. You should always look at the unit objectives after completion of each unit. By doing so, you would have followed the instructions in the unit.

Below are the comprehensive objectives of the course as a whole. By meeting these objectives, you should have achieved the aims of the course as a whole. In addition to the aims above, this course sets to achieve some objectives.

Thus, after going through the course, you will be able to:

- explain the values, purpose and types of soil survey
- carry out assemblage of maps, photos and imageries
- carry out soil morphological investigations
- explain laboratory determinations and soil correlations
- carry out soil survey report writing and interpretative reports
- carry out land evaluations.

WORKING THROUGH THE COURSE

To complete this course, you are required to read each study units, read the textbook and other materials which may be provided by the National Open University of Nigeria. Each unit contains self-assessment exercises and at certain points in the course you would be required to submit assignment for assessment purpose. At the end of the course there is a final examination. The course should take you a total of 17 weeks to complete. Below you will find listed all the components of the course, what you have to do and how should allocate your time to each unit in order to complete the course on time and successfully. The details that you spend a lot of time to read. I would advise that you avail yourself the opportunity of attending the tutorial sessions where you have the opportunity of comparing your knowledge with that of other people.

COURSE MATERIALS

The main components of the course are:

1. The Course Guide
2. Study Units
3. References/Further Reading
4. Assignments
5. Presentation Schedule

STUDY UNITS

The study units in this course are as follows:

Module 1 Definition, Description, Purpose and kinds of Soil Survey

Unit 1 Definition and Description of Soil Survey
Unit 2 Purpose of Soil Survey
Unit 3 Kinds of Soil Survey
Unit 4 Uses of Soil Survey Reports

Module 2 Soil Maps, Mapping Processes and Mapping Units

Unit 1 Soil Maps
Unit 2 Mapping Processes
Unit 3 Mapping Units

Module 3 Soil Morphological Investigations

Unit 1 Soil horizons and Boundaries
Unit 2 Soil Colour
Unit 3 Soil Texture
Unit 4 Soil Structure
Unit 5 Soil Consistence, Root abundance, pH and Effervescence and Special Features

Module 4 Laboratory Analysis, Soil Survey Report Writing, Interpretative Reports

Unit 1 Laboratory Analysis
Unit 2 Soil Survey Reports Writing
Unit 3 Interpretative Reports

Module 5 Land Evaluations

Unit 1	The Nature and Principles of Land Evaluation
Unit 2	The Concept of Land Evaluation
Unit 3	Land Suitability Classification
Unit 4	Procedures for Land Evaluation

PRESENTATION SCHEDULE

The presentation schedule included in the course material gives you the important dates for the completion of tutor-marking assignments and attending tutorials. You are required to submit all your assignments by due date. You should guide against falling behind in your work.

ASSESSMENT

There are two types of assessments in the course. First is the tutor-marked assignments; and the second is a written examination.

In attempting the assignments, you are expected to apply the information, knowledge and techniques gathered during the course. The assignments must be submitted to your course tutor for formal Assessment in accordance with the deadlines stated in the Presentation Schedule and the Assignments File. The works you submit to your course tutor for assessment constitute 30 % of the total course mark.

At the end of the course, you will need to sit for a final written examination of two hours' duration. This examination will constitute 70% of your total course mark.

TUTOR-MARKED ASSIGNMENT

There are three Tutor-Marked Assignments (TMAs) to be submitted in this course. The TMAs constitute 30% of the total score. You are encouraged to work all the questions thoroughly.

Assignment questions for the units in this course are contained in the Assignment File. You will be able to complete your assignments from the information and materials contained in your set books, reading and study units. However, it is desirable that you demonstrate that you have read and researched more widely than the required minimum. You should use other references to have a broad viewpoint of the subject and also to give you a deeper understanding of the subject.

When you have completed each assignment, send it, together with a TMA form, to your tutor. Make sure that each assignment reaches your tutor on or before the deadline given in the Presentation File. If for any reason, you cannot complete your work on time, contact your tutor before the assignment is due to discuss the possibility of an extension. Extensions will not be granted after the due date unless there are exceptional circumstance.

FINAL EXAMINATION AND GRADING

The final examination will be of two-hour duration and have a value of 70% of the total course grade. The examination will consist of questions which reflect the types of self-assessment practice exercises and tutor-marked problems you have previously encountered. All areas of the course will be assessed.

Revise the entire course material using the time between finishing the last unit in the module and that of sitting for the final examination. You might find it useful to review your self-assessment exercises, tutor-marked assignments and comments on them before the examination. The final examination covers information from all parts of the course.

HOW TO GET THE MOST FROM THIS COURSE

In distance learning, the study units replace the university lecturer. This is one of the great advantages of distance learning; you can read and work through specially designed study materials at your own pace and at a time and place that suit you best.

Think of it as reading the lecture instead of listening to a lecturer. In the same way that a lecturer might set you some reading to do, the study units tell you when to read your books or other material, and when to embark on discussion with your colleagues. Just as a lecturer might give you an in-class exercise, your study units provides exercises for you to do at appropriate points.

Each of the study units follows a common format. The first item is an introduction to the subject matter of the unit and how a particular unit is integrated with the other units and the course as a whole. Next is a set of learning objectives. These objectives let you know what you should be able to do by the time you have completed the unit.

You should use these objectives to guide your study. When you have finished the unit you must re-check whether you have achieved the objectives. If you make a habit of doing this, you will significantly improve your chances of passing the course and getting the best grade.

The main body of the unit guides you through the required reading from other sources. This will usually be either from your set books or from a readings section.

Self-assessments are interspersed throughout the units, and answers are given at the end of the units. Working through these tests will help you achieve the objectives of the unit and prepare you for the assignments and the examination. You should do each self-assessment exercises as you come to it in the study unit. Also, ensure to master some major historical dates and events during the course of studying the material.

If you run into any trouble, consult your tutor. Remember that your tutor's job is to help you. When you need help, don't hesitate to call and ask your tutor to provide it. The following is a practical strategy for working through the course:

1. Read this Course Guide thoroughly.
2. Organise a study schedule. Refer to the `Course overview' for more details. Note the time you are expected to spend on each unit and how the assignments relate to the units. Important information, e.g. details of your tutorials, and the date of the first day of the semester is available from study centre. You need to gather together all this information in one place, such as your diary or a wall calendar. Whatever method you choose to use, you should decide on and write in your own dates for working breach unit.
3. Once you have created your own study schedule, do everything you can to stick to it. The major reason that students fail is that they get behind with their course work. If you get into difficulties with your schedule, let your tutor know before it is too late for help.
4. Turn to Unit 1 and read the introduction and the objectives for the unit.
5. Assemble the study materials. Information about what you need for a unit is given in the `Overview' at the beginning of each unit. You will also need both the study unit you are working on and one of your set books on your desk at the same time.
6. Work through the unit. The content of the unit itself has been arranged to provide a sequence for you to follow. As you work through the unit you will be instructed to read sections from your set books or other articles. Use the unit to guide your reading.
7. Up-to-date course information will be continuously delivered to you at the study centre.
8. Work before the relevant due date (about 4 weeks before due dates), get the Assignment File for the next required assignment. Keep in mind that you will learn a lot by doing the assignments

carefully. They have been designed to help you meet the objectives of the course and, therefore, will help you pass the exam. Submit all assignments no later than the due date.

9. Review the objectives for each study unit to confirm that you have achieved them. If you feel unsure about any of the objectives, review the study material or consult your tutor.
10. When you are confident that you have achieved a unit's objectives, you can then start on the next unit. Proceed unit by unit through the course and try to space your study so that you keep yourself on schedule.
11. When you have submitted an assignment to your tutor for marking do not wait for its return `before starting on the next units. Keep to your schedule. When the assignment is returned, pay particular attention to your tutor's comments, both on the tutor-marked assignment form and also written on the assignment. Consult your tutor as soon as possible if you have any questions or problems.
12. After completing the last unit, review the course and prepare yourself for the final examination. Check that you have achieved the unit objectives (listed at the beginning of each unit) and the course objectives (listed in this Course Guide).

TUTORS AND TUTORIALS

There are some hours of tutorials (two-hour session) provided in support of this course. You will be notified of the dates, times and location of these tutorials. Together with the name and phone number of your tutor, as soon as you are allocated a tutorial group.

Your tutor will evaluate and comment on your assignments, keep a close watch on your progress and on any difficulties you might encounter during the course. You must mail your tutor-marked assignments to your tutor well before the due date (at least two working days are required). They will be marked by your tutor and returned to you as soon as possible.
Do not hesitate to contact your tutor by telephone, e-mail, or discussion board if you need help. The following might be circumstances in which you would find help necessary. Contact your tutor if you:

- do not understand any part of the study units or the assigned readings
- have difficulty with the self-assessment exercises
- have a question or problem with an assignment, with your tutor's comments on an assignment or with the grading of an assignment.

You should try your best to attend the tutorials. This is the only chance to have face to face contact with your tutor and to ask questions which are answered instantly. You can raise any problem encountered in the course of your study. To gain the maximum benefit from course tutorials, prepare a question list before attending them. You will learn a lot from participating in discussions actively.

SUMMARY

On successful completion of the course, you would have developed sufficient critical thinking skills with the material necessary for efficient and effective discussion on issues related to soil survey and land evaluation; you will also be able to proffer solutions to problems with soil classification in the field.

We wish you success in the course and hope that you will find it exciting.

MAIN COURSE

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MODULE 1 DEFINITION, DESCRIPTION, PURPOSE, METHODS, KINDS AND USERS OF SOIL SURVEY

UNIT 1 DEFINITION AND DESCRIPTION OF SOIL SURVEY

CONTENTS

1.0 INTRODUCTION

Soil survey is a systematic study of the soil of an area including classification and mapping of the properties and the distribution of various soil units. Systematic soil survey has been carried out for over one hundred years. As in other applied sciences, conceptual and technological advances are making soil survey more reliable, cheaper and useful. Soil survey is of great significance for any nation to provide an inventory of the national soil resource so that public policies may be more wisely planned and executed. They form an important aspect in worldwide programmes for developing rational land use plans. The basic objective of soil surveys is the same for all kinds of land, but the number of map units, their composition, and the detail of mapping vary with the complexity of the soil patterns and the specific needs of the users. Thus, a soil survey is designed for the soils and the soil-related problems of the area. Soil surveys increase general knowledge about soils and serve practical purposes. They provide soil information about specific geographic areas needed for regional or local land use plans. These plans include resource conservation for farms and ranches, development of reclamation projects, forest management, engineering projects, as well as other purposes.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- examine fully the definitions of soil survey
- explain the concept of soil survey.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Soil survey is a systematic study of the soil of an area including classification and mapping of the properties and the distribution of various soil units.
ii. Soil Survey is a systematic examination, description, classification, and mapping of the soils in a given area.
iii. Soil survey is of great significance for any nation to provide an inventory of the national soil resource so that public policies may be more wisely planned and executed.
iv. Soil survey is designed for the soils and the soil-related problems of the area.
v. Soil surveys increase general knowledge about soils and serve practical purposes.

3.2 Definition of Soil Survey

According to Brady and Weil (1996), soil survey is “a systematic examination, description, classification, and mapping of the soils in a given area.” Soil survey (soil mapping) is the process of classifying **soil types** and other soil properties in a given area and geo-encoding such information. Soil survey is a systematic study of the soil of an area including classification and mapping of the properties and the distribution of various soil units.

Sources of information in soil survey

Soil survey applies the principles of **soil science,** and draws information heavily from:

- Geomorphology
- Theories of soil formation
- Physical geography
- Analysis of vegetation
- Land use patterns

  Also, Sources of primary data for the soil survey are usually by:
- Field sampling
- Remote sensing.

Remote sensing principally uses **aerial photography,** but **LiDAR** and other digital techniques are steadily gaining popularity. In the past, a soil scientist would take hard-copies of aerial photography, topo-sheets, and mapping keys into the field with them. Today, a growing number of soil scientists bring a **ruggedised tablet computer** and GPS into the field with them. The tablet may be loaded with digital aerial photos, LiDAR, topography, soil geodatabases, mapping keys, and more.

3.3 Description of Soil Survey

A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of taxonomy, plots the boundaries of the soils on a map, stores soil property information in an organised database, and makes predictions about the suitability and limitations of each soil for multiple uses as well as their likely response to management systems. The information collected in a soil survey helps in the development of land use plans and can be used to evaluate and predict the effects of land use on the environment.

Soil survey, soil mapping, is the process of classifying **soil types** and other soil properties in a given area and geo-encoding such information.

The term **soil survey** may also be used to describe the published results. In the United States, these surveys were once published in book form for individual counties by the National Cooperative Soil Survey. Today, soil surveys are no longer published in book form; they are published to the web and accessed on NRCS Web Soil Survey where a person can create a custom soil survey. This allows for rapid flow of the latest soil information to the user. In the past it could take years to publish a paper soil survey. Today it takes only moments for changes to go live to the public. Also, the most current soil survey data is made available on the Download Soils Data tab at NRCS Web Soil Survey for high end GIS users such as professional consulting companies and universities.

4.0 CONCLUSION

Soil surveys increase general knowledge about soils and serve practical purposes. They provide soil information about specific geographic areas needed for regional or local land use plans. These plans include resource conservation for farms and ranches, development of reclamation projects, forest management, engineering projects, as well as other purposes.

5.0 SUMMARY

Soil survey, soil mapping, is the process of classifying soil types and other soil properties in a given area and geo-encoding such information. The information in a soil survey can be used by farmers and ranchers to help determine whether a particular soil type is suited for crops or livestock and what type of soil management might be required. An architect or engineer might use the engineering properties of a soil to determine whether it is suitable for a certain type of construction. A homeowner may even use the information for maintaining or constructing their garden, yard, or home.

6.0 TUTOR-MARKED ASSIGNMENT

1. Give three definitions of soil survey.
2. Mention four sources of information for a soil survey.
3. Briefly describe soil survey.
4. Who are the users of soil survey information?
5. Outline two major sources of primary data in soil survey.

7.0 REFERENCES/FURTHER READING

Brady, M.C. & Weil, R. R. (1996). *The Nature and Properties of Soils.* (11th ed.). New Jersey: Prentice-Hall.

Soil Survey Staff (2017). “Soil Survey Manual.” United States Department of Agriculture.

UNIT 2 THE PRINCIPLES AND PURPOSE OF SOIL SURVEY

CONTENTS

1.0 INTRODUCTION

In any country that has developed a soil survey report or soil map, the control of soil surveys is usually the responsibility of an agency such as the Ministry of Agriculture.

A Memorandum of Understanding is reached between the controlling agency and other agencies that may have interest in the conduct of surveys or may wish to participate in a given soil survey. The publication of soil survey reports, including maps, in a standard series guides against the loss or misplacement of important soil survey information and usually a part of the soil survey programme. The practical purpose of soil survey is to enable more numerous, more accurate and more useful predictions to be made for specific purposes than could have been made otherwise i.e., in the absence of location-specific information about soils. To carry out a soil map, the units to be mapped are usually properly defined. Mapping may be carried out directly if the purpose of the survey is narrowly specific while soil properties relevant to the purpose are known. If, however, the purpose is broad, then the soils are usually classified and mapped according to observable properties such as morphology, while other properties are measured as representative sample of each morphological group.

Steps that will enhance the achievement of the purpose of soil survey are:

- determine the pattern of the soil cover

- divide this pattern into relatively homogeneous units
- map the distribution of these units, so enabling the soil properties over any area to be predicted
- characterise the mapped units in such a way that useful statements can be made about their land use potential and response to changes in management.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss the principles of soil survey
- explain the purpose of soil survey.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. There is a need to expand the work of the laboratory so that certain investigations of special importance to the soil survey can be made.
ii. In the face of conflicts over potential land use, soil surveys at various levels may be needed to provide pertinent information about the comparative suitability of the kinds of soils for farming, range, forestry, housing
iii. Priorities for soil survey areas require consideration of factors such as the acuteness of the need for soils information
iv. Training of local personnel at various levels to carry out all phases of soil surveys should be regarded as a continuing part of the long-term programme.
v. The purpose of soil survey is both fundamental and applied.

3.2 The Principles of Soil Survey

1. **Draws heavily from soil properties:** Soil survey works usually include clay mineralogy and certain phases of soil chemistry and physics, as well as information on improved methods for the dispersion of tropical clays; the cation exchange capacity of clay fractions; the mineralogy of soil horizons; the infiltration, movement, and availability of water in different kinds of soils; thin sections and the behaviour of nutrients.

2. **Provision of vital information**: In the face of conflicts over potential land use, soil surveys at various levels may be needed to provide pertinent information about the comparative suitability of the kinds of soils for farming, range, forestry, housing, etc. It may be advisable to contract for some of this work with outside sources, as long as the standards of mapping adopted by the Soil Survey Unit are followed so that the survey will contribute to the long-range soil survey programme.
3. **Need for soil information:** Priorities for soil survey areas require consideration of factors such as the acuteness of the need for soils information, the benefits to be derived, the number of people involved and their ability to make direct use of the information, and the problems faced by the soil survey team. It is suggested that the responsibility for decisions on these priorities be assigned to the proposed Land Use Committee.
4. **Training:** Training of local personnel at various levels to carry out all phases of soil surveys should be regarded as a continuing part of the long-term programme. This can be achieved through fellowships and attendance of soil conferences.
5. **Approximations:** The 7th approximation scheme of soil classification appears to be the most satisfactory system of soil classification to use because the categories are defined precisely, and yet there is flexibility to permit a change if they are needed.
6. **Correlations:** The results of fertiliser applications need to be correlated with the kinds of soil on which they were made so that the information will have wider application through the use of the subsequent soil maps.

3.3 The Purpose of Soil Survey

The practical purpose of soil survey is to enable more numerous and accurate prediction to be made about soils. In order to achieve the purpose of soil survey, it is necessary to know the type and patterns of soil cover as well as determine its types in a relatively homogenous unit. This will guarantee the proper mapping of the distribution of the units and accurate prediction of soil properties of the studied soils. The mapped soils will also be adequately characterised in such a way that useful statements can be made about the potentials of such soils in terms of land use and response to any change in management. The purpose of soil survey is both fundamental and applied.

Fundamental

Soil surveys help in expanding our knowledge and understanding of different soils, as regards their properties, genesis, and classification for sustainable development are concerned.

Applied

Soil surveys and soil maps for the sole purpose of making predictions about the behaviour of different soils for agriculture, forestry, engineering, urban development, recreation, etc. The following are the applied purpose of soil survey:

i. Transferring technology by correlating the characteristics of soils of known behavior and predicting their adaptability to various use and productivity under set of management practices. These predictions can also be used to make practical recommendations for the management of degraded soils.
ii. Providing information needed for developing optimum land use plans and for bringing new areas under irrigation and drainage networks. They also help in evaluating suitability of soils for irrigation and or agricultural crops and a variety of other uses.
iii. Delineating the degraded soils, such as saline alkali, waterlogged or flood prone, water and wind eroded and so-called wastelands and in suggesting soil and water conservation measures, to ameliorate these soils.
iv. Land settlement, rehabilitation, tax appraisal, locating and designing highways, airports and other engineering structures and in public sanitation's works.
v. Delineating disease-infested areas and may provide indirect help in controlling the diseases, for instance, delineating schistosomiasis disease infested areas in south east Asia. The zinc deficiency in human beings, especially children, has been related to its deficiency is sandy soils of Punjab (India).
vi. In short, soil surveys add to the growing wealth of knowledge about the soils of a country for developing and optimising land use of an area.

Soil survey report will help the pedologist in the following areas:

i. To classify soils into well-defined mapping units i.e. soil series, phases etc.
ii. To shows their distribution in the field on the map.
iii. To find out the best use of soils.
iv. To predict their performance under different management practices i.e. yields of crops under different management practices.

3.3.1 Special-Purpose and General-Purpose Soil Surveys

Special purpose surveys: for a single well-defined objective. The classic example is an irrigation project. Another example is conservation-oriented farm planning. The advantage of a special-purpose survey is that we know the properties of interest for the special purpose and can concentrate on mapping these, so that the mapping is more rapid and can be done with less-skilled mappers (i.e., not just trained pedologists). But, we may not record properties that are vital for other uses. Example: Brazilian system for directly mapping the physical environment.

General purpose surveys: provide the basis for a variety of interpretations for various kinds of uses, present and future, including some we can't anticipate now. The advantage is that the survey can be re-used for many purposes. The disadvantage is that the survey isn't ideal for any purpose; also we may not anticipate future needs. Example: 'general purpose' surveys pre-1970 applied to ground-water contamination studies. The trend has been towards general-purpose surveys, sponsored on a 'speculative' basis coordinated by a national mapping agency (e.g., in the USA, the Soil Conservation Service has formed a National Cooperative Soil Survey). However, in countries with less resources and immediate needs, the special purpose survey prevails.

4.0 CONCLUSION

Soil survey works usually include clay mineralogy and certain phases of soil chemistry and physics, as well as information on improved methods for the dispersion of tropical clays; the cation exchange capacity of clay fractions; the mineralogy of soil horizons; the infiltration, movement, and availability of water in different kinds of soils; The purpose of soil survey is both fundamental and applied. Special purpose surveys are for a single well-defined objective. General purpose surveys provide the basis for a variety of interpretations for various kinds of uses, present and future, including some we can't anticipate now.

5.0 SUMMARY

In the face of conflicts over potential land use, soil surveys at various levels may be needed to provide pertinent information about the comparative suitability of the kinds of soils for farming, range, forestry, housing. Priorities for soil survey areas require consideration of factors such as the acuteness of the need for soils information. Training of local personnel at various levels to carry out all phases of soil surveys should be regarded as a continuing part of the long-term programme. The purposes of soil surveys are both fundamental and applied.

1.0 TUTOR-MARKED ASSIGNMENT

1. Discuss briefly five principles of soil survey.
2. Briefly explain five applied uses of soil survey information.
3. Distinguish between single purpose and general-purposes oil survey.

7.0 REFERENCE/FURTHER READING

Dent, D. & Young, A. (1981). *Soil Survey and Land Evaluation*. London, England: George Allen & Unwin.

UNIT 3 METHODS OF SOIL SURVEYS

CONTENTS

1.0 INTRODUCTION

Soil survey is a complex process of mapping a parcel of landscape. Soil survey is necessary because of variability or changes experienced in soils from time to time. Such changes may be gradual in vertical or horizontal directions. Changes in a particular soil property may not necessarily imply changes in another thereby resulting in an identical combination in a particular landscape. However, there are methods involved is soil survey activities. These methods include pre-field, field and post-field activities.

Pre-Field Preparations: These include, collation and study of existing data of the area i.e. maps, reports, topo-sheets and analytical data, general field reconnaissance, aerial photo assemblage and interpretation, and design and planning of field survey. Field Survey: Activities include, soil mapping operation and land evaluation operation. The soil mapping operation involves identification and classification of the soil types present in the area, and surveying their distribution, leading to the production of a soil map. The land evaluation operation includes field activities for assessing the potentials of the various soils for a range of alternative types of land use, and the identification of possible development hazards.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss pre-field preparation
- conduct field operations
- explain post-field operations.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Pre-field preparations include, collation and study of existing data of the area i.e. maps, reports, topo-sheets and analytical data, general field reconnaissance, aerial photo assemblage and interpretation, and design and planning of field survey.
ii. Field survey activities include, soil mapping operation and land evaluation operation. The soil mapping operation involves identification and classification of the soil types present in the area, and surveying their distribution, leading to the production of a soil map.
iii. Post field operations: Aerial photo interpretation is revised in the light of field observations. The soil samples collected are analysed. The data are also analysed.

3.2 Methods of Soil Survey

3.2.1 Pre-field Preparations

Pre-field preparations include, collation and study of existing data of the area i.e. maps, reports, topo-sheets and analytical data, general field reconnaissance, aerial photo assemblage and interpretation, and design and planning of field survey.

3.2.2 Field Operations

There are two methods of field survey namely: Free survey and grid survey**:**

i. **Free Survey:** In the Free Survey all the available aerial photos and ground evidence to locate profile pits of the most useful and representative sites. The number of the profile pits depends on the requirements of the survey and the complexity of the soil pattern. The free survey is only feasible in “open” areas, in grass or arable regions. The surveyor uses a lot of observable field marks and taking auger borings in relation to every change of vegetation or edaphic features. Aerial photo interpretation will be of immense help in this method.

ii. **Grid Survey**: Here, observations are made at regular intervals along pre-determined traverses in the survey area. This method is especially useful for large scale high intensity detailed surveys and intensive surveys. However, there is no alternative to grid survey for areas under forest or broken topography where accessibility is difficult and areas where adequate aerial photos or topo sheets are not available. It is generally employed in dense forests and swamps where photo interpretation is often of limited usefulness and there is no way of finding one's position except by measurement. A 'rigid grid' pattern of cut traverses is essential with a central baseline, between regularly spaced straight traverses. The grid survey is very tedious, expensive, and time consuming because it takes a lot of time cutting traverses through the forest, chiseling or augering at regular intervals.

Advantages of Grid System

a. Traverses provide access between roads in the dense forests.
b. Sampling points along the traverses can be located and mapped with accuracy.
c. The direction of the traverses can be arranged to cross the topographical 'grain' of the country.
d. The greater part of the field survey can be carried out by soil survey assistants with minimum supervision by the surveyor.
e. The traverse grid provides a uniform sampling point within which it is very unlikely that important soil types will be overlooked.

3.2.2.1Field Observations

Field observations include the following; soil profile observations, which include description of the environment, general information on the soils and brief and detailed profile descriptions. Others include brief descriptions and classification of chisel holes, site descriptions –including vegetation / land-use, slope measurement, drainage and geology. Also, detailed descriptions of modal soil profiles and sampling for laboratory analysis must be carried out. Soil mapping operations involve, identification and classification of the soil types, their distribution and production of a soil map.

3.2.3 Post Field Operations

Aerial photo interpretation is revised in the light of field observations. The soil samples collected are analysed. The data are analysed. The survey report is written. The unit of mapping is usually the soil series.

4.0 CONCLUSION

Soil survey methods include pre-field, field and post-field activities. Pre-field preparations include, collation and study of existing data of the area i.e. maps, reports, topo-sheets and analytical data, general field reconnaissance, aerial photo assemblage and interpretation, and design and planning of field survey. Field Survey activities include, soil mapping operation and land evaluation operation. The soil mapping operation involves identification and classification of the soil types present in the area, and surveying their distribution, leading to the production of a soil map.

5.0 SUMMARY

Pre-field preparations include, collation and study of existing data of the area i.e. maps, reports, topo-sheets and analytical data, general field reconnaissance, aerial photo assemblage and interpretation, and design and planning of field survey. Field Survey activities include, soil mapping operation and land evaluation operation. The soil mapping operation involves identification and classification of the soil types present in the area, and surveying their distribution, leading to the production of a soil map. Post field operations entail revision of aerial photo interpretation in light of field observations, soil samples collection and analysis. The data are also analysed.

6.0 TUTOR-MARKED ASSIGNMENT

1. What are the pre-field preparations, field and post-field operations in soil survey?
2. Explain in details, free and grid surveys.
3. What are the advantages of grid survey?
4. What are the observations in the field during soul survey activities?

7.0 REFERENCES/FURTHER READING

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054242 [Accessed 22 August 2016].

Hudson, B.D. (1992). "The Soil Survey as a Paradigm-Based Science." *Soil Science Society of America* 56:836-841.

Schoeneberger, P.J., & Wysocki. D.A. (2012). Geomorphic Description System, version 4.2. USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Soil Survey Division Staff. (1993). Soil survey manual. U.S. Department of Agriculture Handbook 18. Natural Resources Conservation Service.

Soil Survey Staff. (2014). *Keys to Soil Taxonomy*. (12th ed.). USDA Natural Resources Conservation Service.

U.S. Department of Agriculture, Natural Resources Conservation Service. National Soil Survey Handbook.

UNIT 4 KINDS OF SOIL SURVEYS REORTS

CONTENTS

1.0 INTRODUCTION

Soil survey can be classified based on purpose of the survey, regularity of observation and scale of mapping. Soil survey can be special purpose or general purpose when it is classified based on purpose of survey. When soil survey is classified based on the regularity of observation, three kinds of soil survey are recognised namely: free survey, rigid grid and flexible grid surveys. When soil survey classification is based on scale of published map, we have seven kinds of soil survey namely; compilation, integrated survey, exploratory survey, reconnaissance survey, semi-detailed survey, detailed and intensive surveys.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- differentiate various classes of soil survey
- identify kinds of soil survey.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Soil survey are generally classified based on purpose of soil survey, regularity of observation and scale of mapping.
ii. Three kinds of soil survey based on regularity of observation include free survey, rigid grid and flexible grid surveys.

iii. Based on scale of published map, we have seven kinds of soil survey namely: compilation, integrated survey, exploratory survey, reconnaissance survey, semi-detailed survey, detailed and intensive surveys.

3.2 Kinds of Soil Survey

Soil survey has been classified based on:

1. **Purpose:** This could be special purpose or general purpose. Whereas special purpose soil survey is done for specific purpose in mind e.g. is survey for irrigation or survey for guava plantation, general purpose soil survey is done mainly to add to the already existing inventory of soil information.
2. **Regularity of observation:** In regularity of observation, the following kinds of soil survey are obtained:
   - i. Free survey: In this kind, there is no rigid pattern of observation
   - ii. Rigid grid survey: Examinations of soil properties are done at regular or predetermined interval.
   - iii. Flexible grid survey: This is a combination of both free survey and rigid grid survey.
3. **Scale of mapping:** we have seven kinds of soil survey in this category namely:
   - i. Exploratory Survey: These are the kind of soil survey meant to identify forms of development that are physically possible within large regions of the country. Scale is usually 1: 2,000,000 – 1:1,500,000
   - ii. Compilation: These are soil maps produced in abstraction from other soil surveys with a scale of usually 1:1,000,000 or smaller. The National Soil Map of Nigeria belongs to this category
   - iii. Reconnaissance Survey: These are mostly based on remote sensing especially aerial photo imagery. Scale is usually 1: 250,000 although smaller scales have been used.
   - iv. Integrated survey: this is known as land system survey which is based on mapping the total physical environments. Landforms are mapping units. Scale is 1:250,000 or smaller.
   - v. Semi-detailed survey: In this type of survey, we have a combination of remote sensing and field work with scales varying between 1:50,000 to 1:100,000.
   - vi. Detailed survey: This is carried out through field examination with pre-determined numbers of observations points or spacing. Scale varies between 1: 10,000 to 1: 25,000.

vii. Intensive survey: Intensive survey usually involves rigid grid approach i.e. number of observations points and spacing of observation are pre-determined. Scale of mapping varies from 1:1000 to 1: 10,000 (Soretire et al., 2012).

3.2.1 Procedure for a Detailed Soil Survey

i. Soils are grouped into units possessing certain common physical properties and also morphological properties, which can be readily recognised in the field.
ii. Physical and morphological properties are texture, structure, colour, pH, carbonate, natural vegetation, slope, erosion, depth of soil, natural vegetation etc.
iii. The soil units are usually defined on the basis of the above-mentioned characteristics of the surface soil, soil depth, slope and erosion and the soil profile. The soil units are the soil series. Cadastral (village) maps are the base maps (Scale 1: 10,000 to 1: 5,000).
iv. Select a convenient starting point like a bench mark, or building or pond, or anything in the field and identify the same on the cadastral map (1: 10,000 to 1:5000).
v. The Soil surveyor moves up or down the slope because usually the soil properties change in that direction.
vi. Start walking down the slope from the starting point and continue observing the natural vegetation, slope of the land/soil erosion, soil depth, soil colour, texture, by feeling the Soil; pH with the help of universal indicator; and carbonate with the help of dilute acid at an interval of about 100 to 200 metres.
vii. As you are walking down the slope and studying these properties, you suddenly find that a number of soil characteristics change. For example, slope erosion, soil depth, colour, texture etc. Then, follow the line of change in the soil properties and demarcate it. This is the boundary between the soil units A and B.
viii. Resume walking down (Traversing) the slope till you again find that number of soil characteristics change. Follow the line of change of soil properties between the soil units B and C and demarcate it on the field. In a similar way, find out and demarcate the boundaries between soil units C and D, D, and E and so on.
ix. Then dig profiles in each of the soil units A, B, C, D and E the number of profiles depend on the relative area of the soil units.
x. Study profiles, the characteristics of which become the basis of identifying soil series. If the characteristics of the profile in soil units A, B, C, D and E are different then the soil units A, B, C, D and E become the soil series A, B, C, D and E. Then a soil survey report is

written, describing the soil series and providing other useful information about the area.

4.0 CONCLUSION

Purpose of soil survey has to do with special purpose or general purpose. Whereas special purpose soil survey is done for specific purpose in mind general purpose soil survey is done mainly to add to the already existing inventory of soil information. Three kinds of soil survey based on regularity of observation include free survey, rigid grid and flexible grid surveys. When soil survey classification is based on scale of published map, we have seven kinds of soil survey namely; compilation, integrated survey, exploratory survey, reconnaissance survey, semi-detailed survey, detailed and intensive surveys.

5.0 SUMMARY

Soil survey has been classified based on: Purpose could be special purpose or general purpose. Regularity of observation include free survey, rigid grid and flexible grid surveys while based on scale of published map, we have seven kinds of soil survey namely: compilation, integrated survey, exploratory survey, reconnaissance survey, semi-detailed survey, detailed and intensive surveys.

6.0 TUTOR-MARKED ASSIGNMENT

1. Classify soil survey based on purpose, regularity of observation and scale of published map.
2. Mention and briefly explain seven kinds of soil survey based on scale of mapping.
3. State the procedures involved in detailed soil survey.
4. Carefully explain the method of soil survey.

7.0 **REFERENCES/FURTHER READING**

Soretire, A.A., Azeez, J.O., Ajiboye, G.A. & Busari, M.A. (2012).” Principles of soil Science.”

Uniaab.edu.ng/opencourseware/principleofsoilscience.pdf

UNIT 5 USERS OF SOIL SURVEYS

CONTENTS

1.0 INTRODUCTION

The usefulness of soil survey depends on two major factors; the accuracy with which soil properties are mapped and the relevance of those properties to the purpose of the survey. The usefulness of any particular purpose depends on the degree of correlation between soil properties that are relevant to the purpose on which the map is based. Soil characteristics that can be measured by hand through observable changes are easier and cheaper to map compared to those that required laboratory analysis. Soil survey information can be used by the following; farmers, agricultural advisory staff, research workers, foresters, planning agencies, development organizations, engineers and private investors.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- identify those that use soil survey information
- discuss the different uses of soil survey information.

3.0 MAIN CONTENT

3.1 Users of Soil Survey

1. **Farmers:** In practice, most farmers make little or no use of soil survey information as they may already have a better knowledge of their soils compared to whatever any soil surveyor may have to offer. The view

of farmers on their own soils are strongly oriented towards significant management characteristics such as:

i. Texture (heavy and light land when ploughed).
ii. Drainage ability (wet lands).
iii. Nutrient retention (hungry soil).
iv. Structural condition of top soil (tilt and heart).

Arable farming is a kind of land use in which soil survey is mostly directed and it is expected that mains users are farmers. The use of soil survey in arable farming is very necessary especially with the introduction of new technology (e.g. sprinkler irrigation) or when use of new parcel of land is to be considered. In either of these situations, mistakes may be very costly and can be averted in advance by means of a soil survey information.

2. **Researchers**: Agricultural research work should be related to the climatic and soil condition for which it is carried out. This is practiced in an applied research such as fertiliser response and crop variety trials as well as other kinds of field experimentation like disease resistance.
3. **Agricultural advisers (Extension agents)**: Extension agents are key users of soil survey information in many countries of the world, e.g. is Agricultural Development and Advisory Services (ADAS) in Britain. In developed countries, soil survey organizations work with extension agents in order to satisfy their needs. Advisory staff conduct experiments from one farm to another as well as introduction of new innovations derived from research.
4. **Forestry workers:** Forestry is one of the major uses of rural lands and often under the government regulations. There are many analogies with the needs of arable farming such as; tree species, like crops may vary in their soil preferences as well as tolerances. A very important feature is the long-term nature of forestry, therefor making the initial matching of species to site very critical. Soil survey is the basis for layout once a forest reserve is acquired. This will enable proper planning, planting and management.
5. **Planning Agencies:** Planners are concerned with decisions over changes between kinds of use, such as rough grazing to forestry and arable to urban. This is in contrast to the task of farmers, foresters and agriculturalist who only operate within the context of a limited range of uses. Considering the constraints at which land use changes are made in developed countries, there is need to access suitability of land for specific purposes. For large changes in land use, it is required that the environmental impact assessment be developed which will include an appraisal of soils and their likely response to proposed changes.

6. **Development organisations:** In developing countries, the call for soil survey comes from the agencies responsible for rural land development. Some international organisations such as World Bank, Food and Agricultural Organisations (FAO), national overseas aid organizations as well as national and sometimes regional government agencies use soil survey information as basis for developmental activities.
7. **Engineers:** Although the use of soil survey information by engineers is new, it is gradually becoming widely known. Soil survey information guide engineers in aspects of road alignments, foundations and in sewage disposal facilities. It has also been established that some key engineering properties relating to several constructions are soil type related. Such properties are; shear strength, plasticity, shrink – swell characteristics as well as corrosivity to steel and concretes.
8. **Private investors:** Banks and other financial organisations use soil survey information as basis for granting loan facility to private investors (farmers etc.). Although sometimes such credit agencies prefer using an on-the-spot access or usually highly experienced person, whose judgement may be more trusted by the agency.

4.0 CONCLUSION

Soil survey information is used widely, farmers, extension agents, engineers all use soil survey information. In developing countries, the call for soil survey comes from the agencies responsible for rural land development. Some international organisations such as World Bank, Food and Agricultural Organisations (FAO), national overseas aid organisations as well as national and sometimes regional government agencies use soil survey information as basis for developmental activities.

5.0 SUMMARY

Users of soil survey information include; Researchers, foresters, farmers, engineers, extension workers, planning agencies, development organisations and private sectors. In practice, most farmers make little or no use of soil survey information as they may already have a better knowledge of their soils compared to whatever any soil surveyor may have to offer. However, the use of soil survey in arable farming is very necessary especially with the introduction of new technology (e.g. sprinkler irrigation) or when use of new parcel of land is to be considered. In either of these situations, mistakes may be very costly and can be averted in advance by means of a soil survey information.

TUTOR-MARKED ASSIGNMENT

1. How does soil survey information benefit engineers and forestry workers?
2. Who are the key users of soil survey information?
3. Discuss in details how soil survey information could be used by development organisations in developing countries.

7.0 REFERENCE/FURTHER READING

Dent, D. & Young, A. (1981). *Soil Survey and Land Evaluation*. London, England: George Allen & Unwin.

MODULE 2 SOIL MAPS, MAPPING PROCESSES AND MAPPING UNITS

UNIT 1 SOIL MAPPING

CONTENTS

1.0 INTRODUCTION

Soil mapping is the process of delineating natural bodies of soils, classifying and grouping the delineated soils into map units, and capturing soil property information for interpreting and depicting soil spatial distribution on a map. The soils and miscellaneous areas (e.g., rock outcrop) in a survey area are in an orderly pattern that is related to the geology, landforms, topography, climate, and natural vegetation. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. Soil scientists delineate these repeating patterns of landform segments, or natural bodies, on a map. Through observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they formed. Thus, during mapping, these models enable the soil scientist to predict with considerable accuracy the kind of soil or miscellaneous area on the landscape (Hudson, 1992).

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss what soil mapping is all about.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Soil mapping is the process of delineating natural bodies of soils, classifying and grouping the delineated soils into map units, and capturing soil property information for interpreting and depicting soil spatial distribution on a map.
ii. Soil scientists delineate the repeating patterns of landform segments, or natural bodies, on a map.
iii. Through observation of the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they formed.
iv. During mapping, these models enable the soil scientist to predict with considerable accuracy the kind of soil or miscellaneous area on the landscape.

3.2 Soil Mapping

Soil mapping can be defined as the process of delineating natural bodies of soils, classifying and grouping the delineated soils into map units, and capturing soil property information for interpreting and depicting soil spatial distribution on a map. The repetitive patterns imprinted in soils by the soil-forming factors can be observed at scales ranging from continental to microscopic. These patterns are the basis for soil identification and mapping at different scales. A system of terminology, definitions, and operations can be ascribed to the various scales. Hierarchical systems of classes and subclasses are established to produce groupings at the different scales. Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. Some boundaries are sharp, where soils change over a few meters, while others are more gradual. Soil scientists can observe only a limited number of pedions. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil and to determine their boundaries.

4.0 CONCLUSION

The different kinds of soil used to name soil map units have sets of interrelated properties that characteristic of soil as a natural body. This definition is intended to exclude maps showing the distribution of a single soil property such as texture, slope, or depth, alone or in limited combinations; maps that show the distribution of soil qualities such as productivity or erodibility; and maps of soil-forming factors, such as climate, topography, vegetation, or geologic material. A soil map delineates areas occupied by different kinds of soil, each of which has a unique set of interrelated properties characteristic of the material from which it formed, its environment, and its history. The soils mapped by the NCSS are identified by names that serve as references to a national system of soil taxonomy.

5.0 SUMMARY

Soil mapping can be defined as the process of delineating natural bodies of soils, classifying and grouping the delineated soils into map units, and capturing soil property information for interpreting and depicting soil spatial distribution on a map. Soil scientists delineate these repeating patterns of landform segments, or natural bodies, on a map. Through observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they formed. Thus, during mapping, these models enable the soil scientist to predict with considerable accuracy the kind of soil or miscellaneous area on the landscape.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is soil mapping?
2. Explain in details what you understand by soil mapping.
3. Explain how soil scientist develop the concepts and models on how specific segments of landforms are formed.

7.0 REFERENCES/FURTHER READING

Hudson, B.D. (1992). “The Soil Survey as a Paradigm-Based Science.” *Soil Science Society of America* 56:836-841.

USDA Natural Resources Conservation Service. http//www.nrcs.usda.gov

UNIT 2 TYPES OF SOIL MAPS

CONTENTS

1.0 INTRODUCTION

In most cases the results of both soil surveys and studies derived from them are expressed in the form of maps indicating the distribution of different recognized units and their relationships. Pedological and non-pedological soil maps include a vast variety of forms, but these can be distinguished by the density and precision of their detail, their scale, and their legend (Aubert and Tavernier, 1972).

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- identify different kinds of maps as a function of the density and precision of detail contained in their information
- state different kinds of maps as a function of scale
- discuss different kinds of maps as a function of their objectives.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Maps could be as a function of density and precision of detail of their information.
ii. There are three levels of cartography distinguished on the basis of precision, as the above-mentioned type of map is rarely encountered.
iii. A common classification of soil maps is as a function of their field scale.

iv. Maps may be created as a function of their objectives.

3.2 Types of Soil Maps

A. Maps as a function of the density and precision

In regions where essentially no valuable surveys of terrestrial resources exist, maps of the "probable" distribution of principal soil types expected as a function of existing information on soil formative factors (geologic deposits, climate, topography, and even vegetation), can be compiled. These maps do not have definite significance except at the scale of synthesis (1:1,000,000 to 1:5,000,000), or at medium scales (1:200,000 to 1:500,000).There are three levels of cartography distinguished on the basis of precision:

i. **Reconnaissance maps:** These are based on observations and results obtained from traverses conducted throughout the study region and on known elements of factors of formation, as well as relationships which have been established during the course of the investigation between the observed soils and those diverse factors in particular, at the end of the study of the toposequences formed over the principal parent rocks of the area. The soil map of France at the scale of 1: 1,000,000 conforms to this definition, at least for the majority of the country.
ii. **Semi-detailed maps:** Such surveys are carried out using traditional procedures, but the precision of observation, at least theoretically, corresponds to one observation of the map.
iii. **Detailed maps:** These maps are the result of very precise, detailed studies. The level of precision necessary for this category is minimally four observations for eachcm2 of the map. Such limits of precision are very theoretical, and are hard to apply to practical situations since calculations of the gain in precision are difficult (the coefficient by which it would be necessary to divide the preceding recommendations or multiply the envisaged surfaces for a known point) due to the use of aerial photography and additional satellite imagery. The use of these modem techniques permits greater rapidity and more detail in establishing the limits between the map units, it certainly needs to be supported by numerous traverses and observations of the soils.

B. Maps as a function of scale

Another common habit is the classification of soil maps as a function of their field scale. However, it should be remembered that field work is often undertaken at a scale that is at least double, and preferably quadruple to, that at which the map is published. (For example, in France the field scale is 1:25,000 for a 1: 100,000published map). Classification on this basis has different potential possibilities and significance for the use of these documents.

i. **Small scale maps:** Maps at the scale of 1:1,000,000 or smaller permit general interpretations. As such they are of great didactic value since they permit the performance of interesting geographical studies of soils in either diverse regions or on several continents, and allow useful extrapolations about the consequences of land use, in particular agronomic use. According to our conception with respect to the French classification system, the legends of such maps can include classification levels as low as subgroups with their associated phases, and can even distinguish those families which have particular importance.

ii. **Medium scale maps:** Scales of 1:50,000 or 1:100,000 are correlated with maps designed for regional planning. These in effect serve as a base for prospective work. In France, those at 1:100,000 have been retained simply because of the time and effort invested; those at 1:50,000 are more interesting in terms of their applications. In tropical countries a scale of 1:200,000 as in the soil map of Bossangoa (Boulvert, 1974) or 1:500,000 in the map of Upper Volta (Fauck, 1977), is more commonly utilized. In the legend of these maps the soil families as distinguished by the lithographic nature of the parent material can be indicated, even as can be soil series that generally correspond to significant gradations of soil depth for the land use, especially if it is principally agricultural.

iii. **Large scale maps:** At scales larger than 1:50,000, the soil map permits practical applications for local development planning and area development. Soil series, and even phases of those characterized by different erosion intensities or internal drainage conditions, are distinguished on the legends of these maps. Even if these two general methods of soil map classification are clearly different, their results nevertheless partially overlap. For example, maps at a scale of 1: 1,000,000or at smaller scale are in general types of reconnaissance maps if they are not really derived from a synthesis of more detailed maps, such as those at the 1:200,000 or1: 100,000 scales. Similarly, maps at larger scales are not always reconnaissance maps; rather they are more often detailed maps.

C. **Maps as a function of their objectives**

i. **Pedological maps:** Theoretically, for pedological maps, the kinds of maps and legends follow the rules of the precision and level of information, as a function of their scale as given in the beginning of the second part of this paper. The legend is linked as narrowly as possible to a soil classification system, as for example, the morphogenetic (soils map of France) or morphological (soil map of the U. S.) classification systems.

ii. **Regional planning maps:** In the last several years, it has become increasingly more apparent that representation of the milieu at a medium scale (1: 100,000 or 1:200,000) is insufficient as a basis for regional planning. The global characterization of the evolution of diverse soil types, their distribution, and even their relationships with various factors will not suffice for a general description of the milieu for expressing the general possibility of its use. Thus, various authors have attempted to accomplish the objective at this level by presenting maps that are both pedological and morphogenetic.

Without remaining at the initial stage of French soil maps where geomorphological descriptions do not appear except in the form of accessory maps at a smaller scale, nor proceeding to the morphogenetic maps in which soil characteristics appear only in a secondary form, the methodology of Beaudou and Chatelin (1976) can be followed: A description of the pedological regions, followed by pedological soil landscapes, and finally functional segments or elements of toposequences and caten as of soils. Eschenbrenner and Badare (1975) used schematic drawings to describe and explain morphogenetic landscapes of the northern Ivory Coast.

In this method, the landscapes are defined by the presence of characteristic morphological elements: inselbergs, residual relief, buttes (which are generally cupped with ironstone), the remains of plateaus, derived forms more or less flattened or convex with, an appearance of the slopes of lower bottoms, and nick-point values. Landscapes are also defined by the relative importance of soils at the level of the subgroup and their associated phases, and even of the families. Maps of grouped morpho-pedological landscapes have been constructed at the scale of 1:200,000; but each of them is supplemented by a pedological detailed map, at the scale of 1:50,000, which is representative of a typical landscape, and by corresponding air photos.

iii. **Maps of agronomic application:** As has been previously stated, maps of agronomic applications can be very different, both in their detail and scale, but they must be based on a soils map established on an identical or larger scale.

- Maps of soil resources are established at smaller scales (such as the 1:500,000map of Upper Volta), and they are analytical in nature. They include delineation of agro-climatic zones and emphasize texture, primarily that of the surface horizon, but also that of the lower horizon to the extent that it affects plant performance. Taxonomic units are indicated with respect to the principal kinds of improvements proposed for various characteristic features: drainage conditions, actual water consumption, organic matter content, exchangeable bases, physical properties (particularly unfavorable ones), and the presence of toxic elements. Some subunits are defined by the association of different component units in a zone or "spot" of the soils map, as this had been indicated in the units of the pedological map. In northern climatic zones, cultivatable lands have been separated into areas suitable for dryland and irrigated agriculture and rangelands. On the map itself, a table was compiled that indicated the order of the units and subunits as assembled on the pedological map, and these units were given values characteristic of the various land uses for each of the retained fertility factors.

- At medium and detailed scales (1:100,000) or larger, synthesized maps of optimum agricultural utilization or suitability for cultivation are assembled. The legend includes units of "universal agricultural value" and the principal possible uses as a function of the soil characteristics themselves (their type of evolution, parent material. depth, etc.) and also as a function of their environment, slope, degree of erosion, etc. The most interesting system, as previously mentioned, indicates for each unit of land the relative fertility for each of the principal kinds of use or possible cultivation groupings, and the principal for seen improvements. It is of course indispensable that these documents be prepared with collaboration of an agronomist.
- An example is given by the management maps compiled for the high-plateau steppes of Algeria which were prepared by Pouget (1977) in collaboration with geomorphologists, botanists, and agronomists. The maps include recommendations and for seen management and- the potential yield of forages.
- Maps of cultivation constraints have been rarely established by French pedologists, as many of the previous map types include in their taxonomic description's constraints such as "utilizable depth" or various other unfavorable physical properties. However, maps have been made for the northern Cameroons by P. Brabant that analyze depth, texture, profile differentiation, insufficiency or excess of available water, and degree and danger of erosion. They have also been made in France by the "Organization for the Management of the Hills of Gascogne." The limiting factors are primarily the slope and the depth of usable land, and extreme textures, the excess of calcareous materials and any fertility or chemical insufficiencies.

i. In France, purely thematic maps are also established at very detailed scales with regard to drainage operations (various working groups of INRA), or for particular irrigated cultivations (Organization for the Management of Lower-Rhône Languedoc). The maps compiled at very small scales (1:1,000,000 or 1:5,000,000) concerning the dangers of desert formation and the degradation of soils.

4.0 CONCLUSION

In regions, where essentially no valuable surveys of terrestrial resources exist, maps of the “probable” distribution of principal soil types expected as a function of existing information on soil formative factors (geologic deposits, climate, topography, and even vegetation), can be compiled. Another common habit is the classification of soil maps as a function of their field scale. However, it should be remembered that field work is often undertaken at a scale that is at least double, and preferably quadruple to, that at which the map is published. (For example, in France the field scale is 1:25,000 for a 1: 100,000 published map). maps of agronomic applications can be very different, both in their detail and scale, but they must be based on a soils map established on an identical or larger scale.

5.0 SUMMARY

Maps could be as a function of density and precision of detail of their information. There are three levels of cartography distinguished on the basis of precision, as the above-mentioned type of map is rarely encountered. A common classification of soil maps is as a function of their field scale and maps may also be created as a function of their objectives.

6.0 TUTOR-MARKED ASSIGNMENT

1. Classify soil maps under the following headings:
   i. Maps based on density and precision
   ii. Maps based on scale
   iii. Maps based on their objectives
2. Explain in details, map of agronomic applications.

7.0 REFERENCES/FURTHER READING

Aubert, G. (1977). "Carte des sols Salésd'afrique (scale 1:5,000,000)." In: *Managing Saline Water for Irrigation. Proc*. Texas: Int. Soc. Soil Sci. p. 598-604.

Aubert G. & Tavernier, R. (1972). "Soil survey." In: *Committee on Tropical Soils (ed.) Soils of the Humid Tropics.* Washington, DC: National Academy of Sciences p. 17-44

Beaudoua, G. & Chatelin Y. (1976). Methodologie de la représentation des volumes pédologiques. O.R.S.T.O.M., Adiopodoumé, Côte d'Ivoire.

Eschenbrennev, R. & Badarello, L. (1975) Carte des paysagesmorphodédologique 1/200,000. Odienne O.R.S.T.O.M., Adiopodoumé, Côte d'Ivoire.

UNIT 3 MAPPING UNIT

CONTENTS

1.0 INTRODUCTION

A soil mapping unit can be defined as a collection of soil delineations (on the map) that comprise similar soils or soil combinations (depending on the scale of the survey and the intricacy of the soil pattern) Soil mapping units are designed to efficiently deliver soil information to meet the need of user and for effective management and land use decisions. Mapping units can appear as individual areas (i.e., polygons), points, or lines on a map. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. Each individual area on the map is a **delineation**. A map unit is a collection of areas defined and named the same in terms of their soil components, miscellaneous areas, or both (components and miscellaneous areas are described below). Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. A map unit description is a written characterization of the component within a map unit and the relationship of one map unit to another. A delineation of a map unit generally contains the dominant components in the map unit name, but it may not always contain a representative of each kind of inclusion. A dominant component is represented in a delineation by a part of a polypedon, a complete polypedon, or several polypedons.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss what mapping unit is all about
- identify different types of mapping units.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. A soil mapping unit can be defined as a collection of soil delineations (on the map) that comprise similar soils or soil combinations.
ii. Soil mapping units are designed to efficiently deliver soil information to meet the need of user and for effective management and land use decisions.
iii. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map.
iv. A few delineations of some map units may not contain any of the dominant components named in the map unit description, but contain very similar soils.
v. The kinds of map units used in a survey depend primarily on the purposes of the survey and the pattern of the soils and miscellaneous areas in the landscape.
vi. It must be remembered that soil interpretations are made for areas of land and the most useful map units are those that group similarities.

3.2 Mapping Unit

A map unit is a collection of areas defined and named the same in terms of their soil components or miscellaneous areas or both. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. Map units consist of one or more components. An individual component of a map unit represents the collection of polypedons or parts of polypedons that are members of the taxon or a kind of miscellaneous area. Classes of miscellaneous areas are treated the same as soil taxa in soil surveys. A taxonomic unit description describes the ranges in soil properties exhibited in the polypedon for the maps in a survey area that are referenced by that taxonomic unit.

Soil boundaries can seldom be shown with complete accuracy on soil maps, hence parts and pieces of adjacent polypedons are inadvertently included or excluded from delineations. A few delineations of some map units may not contain any of the dominant components named in the map unit description, but contain very similar soils. In most survey areas there are a few soils that occur as mappable bodies, but they have very limited total extent. They are normally included with other map units, if, for all practical purposes, interpretations are the same.

Aggregated data capture the ranges of various physical and chemical properties of soil map units as a whole and individual soil map unit components. They include the descriptions of each soil map unit and map unit component; the detailed physical, chemical, and morphological attributes of each soil; and descriptions of the relationship of one soil map unit to another on the landscape. Aggregated soil property data generally are the data used to generate interpretive ratings for each map unit and its components.

3.2.1 Types of Mapping Units

The following are types of mapping units:

- Single Mapping Unit **(Consociation):** A mapping unit dominated by a single soil series and containing less than 25% inclusions of minor soils.

a) Compound Mapping Units

  i. **Association:** A mapping unit consisting of two or more soil taxa (series) geographically associated in a characteristic recurring pattern. It contains less than 25% inclusions of minor soils.
  ii. **Complex:** Similar to association but the constituent soil taxa occur in such an intricate pattern or are so small in area that it is not possible to map them separate, even at the scale of the sample area survey. The pattern and proportions of soil taxa are somewhat similar in all areas. A complex contains less than 25% inclusions of minor soils.
  iii. **Undifferentiated:** A mapping unit consisting of two or more soil taxa e.g. series that are not consistently associated geographically but are included in the map unit because use and management are the same or very similar. Soil taxa occur in variable proportions in various soil delineations representing the mapping unit.

3.3 Aggregated Data in Soil Map Units

Aggregated data are developed by putting together the various pieces of point data that have been collected during the soil survey and referenced to a particular soil map unit or map unit component. Values for a particular soil property are commonly expressed as a range. Depending on mapping scale, map unit design, and the level of specificity of data needed for the purpose of the soil survey, the upper and lower limits and, in most cases, a representative value (RV) of the range of each soil property need to be stored in the database (e.g., clay content ranges from 18 to 27%, with an RV of

22%). The representative value is the value most likely to be found for a particular soil property and is useful in computerized interpretive models.

The RV can be determined by summarising the values recorded on the individual pieces of point data. Tacit knowledge from individual soil mappers can be used to augment recorded point data measurements.

The physical, chemical, and morphological properties of the soils included in the aggregated data generally are most or all of those that are included in the point data. They should include any properties that are used to generate interpretive ratings. Values for many physical and chemical soil properties of a particular soil map unit or map unit component commonly vary from one topographic position to another, or from one geographic location to another, within a particular map unit or even a single delineation of a map unit. Properties can also vary from one time of the year to another, from year to year, and from one land use and/or management system to another. The database must have the capability to record this variability.

Aggregated data may represent map units that cover a particular geographic area at different map scales, for example, 1:12,000 or 1:24,000 and also 1:100,000 or 1:250,000. The differences in scale may represent a "detailed" soil map of the area and a "generalized" soil map of the same area. Map unit design and the respective map unit components will generally differ between the larger (e.g., 1:24,000) and smaller (e.g., 1:250,000) map scales.

4.0 CONCLUSION

Mapping units are conceived during the aerial-photo interpretation stage when API units are delineated on the basis of supposedly soil-related characteristics of the photo stereo-image. The API units are subsequently transformed into regular soil mapping units during the reconnaissance and sample area surveys. Soil mapping units comprise soils or soil combinations which in turn represent series concepts (by meeting the specific requirements of these concepts). In the literature such defined concepts are often referred to as taxonomic units, taxonomic classes or, shortly, taxa as they all belong to a larger taxonomic framework developed for soil classification purposes.

5.0 SUMMARY

A delineation of a map unit generally contains the dominant components in the map unit name, but it may not always contain a representative of each kind of inclusion. A dominant component is represented in a delineation by a part of a polypedon, a complete polypedon, or several polypedons. A part of a polypedon is represented when the phase criteria, such as a slope, requires that a polypedon be divided. A complete polypedon is present when there are no phase criteria that require the subdivision of the polypedon or the features exhibited by the individual polypedon do not cross the limits of the phase. Several polypedons of a component may be represented if the map unit consists of two or more dominant components and the pattern is such that at least one component is not continuous but occurs as an isolated body or polypedon. Similarly, each inclusion in a delineation is represented by a part of a polypedon, a complete polypedon, or several polypedons. Their extent, however, is small relative to the extent of the dominant component(s). It is important that all major soils of the area are presented in the various mapping units in a way that their geographic setting in relation to the overall soil pattern is clearly shown. This is one of the main reasons why the structure of the soil map legend is based on physiography and lithology.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define a mapping unit.
2. Give the two major types of mapping units.
3. Explain the following terms as relate to mapping units:

   i. Consociation
   ii. Association
   iii. Complexes
   iv. Undifferentiated

7.0 REFERENCE/FURTHER READING

Soil survey staff (2017). Soil Survey Manual. United States Department of Agriculture.

UNIT 4 REMOTE SENSING

CONTENTS

1.0 INTRODUCTION

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object. The advancement of remote sensing technology is key in conducting efficient soil surveys and soil mapping. Recent technological advances in satellite remote sensing have helped to overcome the limitation of conventional soil survey, thus providing a new outlook for soil survey and mapping. Remote sensing has proved to be an important part of soil survey and mapping. Soil properties that have been measured using remote sensing approaches include mineralogy, texture, soil iron, soil moisture, soil organic carbon, soil salinity and carbonate content. In sparsely vegetated areas, successful use of space borne, airborne and in situ measurements using optical, passive and active microwave instruments has been reported. In densely vegetated areas however, soil data acquisition typically relied on indirect retrievals using soil indicators, such as plant functional groups, productivity changes, and Ellenberg indicator values. Optical remote sensing helps in the mapping of properties like land cover, land type, vegetation and soil moisture. Thermal infrared remote sensing is commonly used to estimate moisture and salinity. Visual image interpretation technique helps in the identification and mapping of soil elements like land type, vegetation, land use, slope and relief. Microwave remote sensing is a new and effective technique for mapping of soil moisture and salinity which is being commonly used today. Hyperspectral remote sensing is another recent method which is applied in soil salinity mapping as well as identification and mapping of minerals in the soil.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss what remote sensing is all about
- explain different remote sensing methods for soil survey and mapping.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object.
ii. Recent technological advances in satellite remote sensing have helped to overcome the limitation of conventional soil survey, thus providing a new outlook for soil survey and mapping.
iii. Soil properties that have been measured using remote sensing approaches include mineralogy, texture, soil iron, soil moisture, soil organic carbon, soil salinity and carbonate content.
iv. Optical remote sensing helps in the mapping of properties like land cover, land type, vegetation and soil moisture.
v. Thermal infrared remote sensing is commonly used to estimate moisture and salinity. Visual image interpretation technique helps in the identification and mapping of soil elements like land type, vegetation, land use, slope and relief.
vi. Microwave remote sensing is a new and effective technique for mapping of soil moisture and salinity which is being commonly used today.
vii. Hyperspectral remote sensing is another recent method which is applied in soil salinity mapping as well as identification and mapping of minerals in the soil.

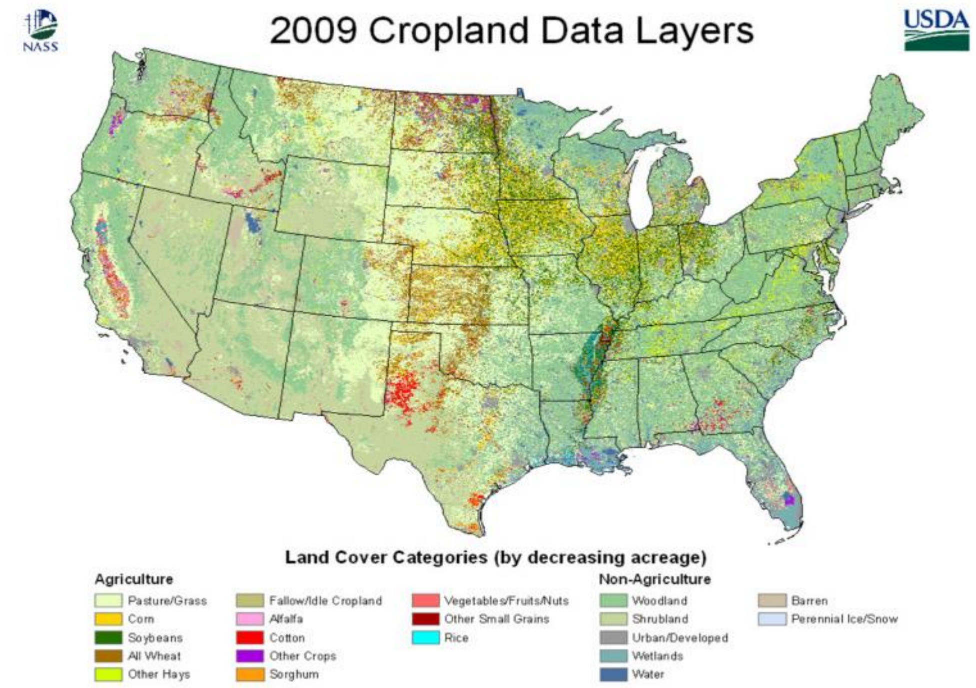

Fig. 1: 2009 Cropland Data Layers, Released January 11, 2010
Source: (FAO, 2010)

3.2 Different Remote Sensing Methods in Soil Survey and Mapping

1. Optical Remote Sensing

The surface features reflected on satellite image provide enough information to accurately delineate the boundaries which is accomplished effectively through systematic interpretation of satellite imageries. Optical remote sensing has been used to monitor various properties of soil like land cover, land type, vegetation and even soil moisture. Optical remote sensing provides a quantitative measure of surface reflectance, that is, the reflected radiation of the sun from the Earth's surface, which is related to some soil properties. Organic matter, particle size and moisture content influence soil reflectance primarily through a change in average surface reflectance, and produce only broad spectral expression (Irons et al., 1989). Optical remote sensing is the most commonly used for soil moisture estimation. Liu et al. (2003) analyzed 18 different soils that represent a large range of permanent soil characteristics and investigated the potential of estimating soil moisture from reflectance measurements in the solar domain.

2. Thermal Infrared Remote Sensing

The thermal infrared remote sensing is commonly used to estimate moisture and salinity. Thermal infrared remote sensing measures the thermal emission of the Earth with an electromagnetic wavelength region between 3.5 and 14μm (Curran, 1985). The moisture content is mainly measured by the thermal inertia method and the temperature/vegetation index method (Wang and Qu, 2009). Thermal infrared remote sensing is also commonly used to detect salt-affected areas from the relationship between crop water stress and temperatures of the crop canopy (Metternicht and Zinck, 2003). Although thermal infrared remote sensing has many scopes, the potential use of thermal systems for soil monitoring appears to be little investigated.

For the reflected solar radiation, the most important characteristics of a soil that determine its reflectance properties according to Sunita (2016) are:

i. **Moisture:** Increasing soil moisture content decreases the reflectance in the water absorption bands but also in the remaining bands due to the internal reflections within the water film covering the soil particles; thus wet soils appear darker (less reflective) than dry soils.
ii. **Organic matter:** Increasing organic matter content gives darker (less reflective) soils.
iii. **Texture:** Sandy soils are more reflective than clay soils.
iv. **Surface roughness:** Decreases in surface roughness slightly increase reflection: an example is the development of soil crust.
v. **Iron content:** Increasing the content of iron oxide corresponds for many soils to a change in colour towards their characteristic brick-red colour, which implies an increased reflection ion in the red and a decrease in green.

Some of the following problems can occur while mapping Soil from thermal remotely sensed data:

i. Identifying, categorising and mapping soils can be a complex procedure which in many cases is based on soil properties that are not even visible to the naked eye and require field or laboratory analyses (e.g. pH).
ii. Soil is a complex three-dimensional body. The majority of remote sensing systems only characterise the surface or, in

optimum conditions, shallow depths of soils. In many cases, the surface characteristics may not be representative of the deeper soil body (e.g. soil organic carbon concentration decreases with depth).

iii. Soil properties can vary dramatically both spatially and temporally within a small area.

iv. The upper surface can be subject to frequent alteration by tillage, precipitation, erosion, crusting and other surface processes.

v. Vegetation coverage obscures most soils for most or all the time. Soil subjected to arable cultivation will be exposed after ploughing. Soil under natural vegetation may never be exposed.

vi. The signal recorded by sensor is the result of a combination of several soil properties (which are frequently interlinked). Such mixtures often mask the signal from a feature under investigation.

vii. The spectral resolution of sensors is not suitable for mapping soil characteristics (i.e. not covering diagnostic regions of the spectrum, focused on observing vegetation).

3. Visual Image Interpretation

Visual interpretation is based on shape, size, tone, shadow, texture, pattern, site and association. This has the advantage of being relatively simple and inexpensive. Soils are surveyed and mapped, following a three tier approach, comprising interpretation of remote sensing imagery and/or aerial photograph (Mulder, 1987), field survey (including laboratory analysis of soil samples) and cartography. This technique helps in the identification and mapping of soil elements like land type, vegetation, land use, slope and relief. Interpretation of aerial photographs have also been used in soil salinity mapping, especially colour-infrared photographs in which barren saline soils (in white) and salt-stressed crops (in reddish brown) can be easily discriminated from other soil surface and vegetation features (Rao and Venkataratnam, 1991).

1. Microwave Remote Sensing

Microwave remote sensing is an effective technique for mapping of soil moisture and salinity, with advantages for all-weather observations and solid physics. It presents advantages in special soil conditions, such as salt-affected areas (Taylor et al., 1996), sandy coastal and desert zones, waterlogged areas, and places with irregular micro-topography such as puffy crusts and cloddy surfaces. There are two methods of microwave sensing - active microwave sensing and passive microwave sensing. Great progress has been made in mapping regional soil moisture with active microwave sensors. In active microwave methods, a microwave pulse is sent and received. The power of the received signal is compared with which was sent to determine the backscattering coefficient of the surface, which has been shown to be sensitive to soil moisture (Wang and Qu, 2009). The most common imaging active microwave configuration is the synthetic aperture radar (SAR), which transmits a series of pulses as the radar antenna traverses the. Active sensors, although having the capability to provide high spatial resolution in the order of tens of meters, have a poor resolution in time with repeat time excess of 1 month.

On the other hand, the space borne passive systems can provide spatial resolutions only in the order of tens of kilometres but with a higher temporal resolution. Passive microwave remote sensors can be used to monitor surface soil moisture over land surfaces (Wigneron et al., 2004). These sensors measure the intensity of microwave emission from the soil, which is proportional to the brightness temperature, a product of the surface temperature and emissivity (Wang and Qu, 2009). Because of the differential behaviour of the real and imaginary parts of the dielectric constant of soil, microwaves also are efficient in detecting soil salinity. While the real part is independent of soil salinity and alkalinity, the imaginary part is highly sensitive to variations in soil electrical conductivity, but with no bearing on variations in alkalinity. This allows the separation of saline soils from others.

2. Hyperspectral Remote Sensing

Recent developments in hyperspectral remote sensing offer the potential of significantly improving data input to predictive soil models. The key characteristic of hyperspectral imagery data is the high spectral resolution that is provided over a large and continuous wavelength region. Each pixel in a hyperspectral image is associated with hundreds of data points that represent the spectral signature of the materials within the spatial area of the pixel. The result is a three-dimensional data set that has two axes of spatial information and one axis of spectral information. The high resolution of hyperspectral imagery makes it possible to uniquely identify different materials at the earth's surface. The large number of spectral bands permits direct identification of minerals in surface soils. Clark and Swayze (1996) mapped over 30 minerals using hyperspectral sensor, Airborne

Visible/Infrared Imaging Spectrometer (AVIRIS) at Cuprites, Nevada. AVIRIS measures a contiguous spectrum in the visible and near-infrared, and thereby better characterize atmospheric and surface properties (Rimjhim et al., 2013).

3. Airborne topographic Lidar

Light Detection and Ranging (lidar) is an emerging geospatial technology that is improving our characterization of terrestrial landscapes. Advantages over other forms of remotely sensed data include spatial data collected in 3D, geo-referenced during acquisition, and ability to classify 3D elements within point clouds into user-defined surface features and above-surface features (Renslow, 2012). Improved representations of the Earth's surface, surface feature structure, and reflectance intensity allow broad use of lidar technology for mapping terrain derivatives and landscape conditions critical for soil investigations. High horizontal and vertical accuracy allow mapping of terrain features that contribute to our knowledge of soil properties and dynamic processes across multiple scales. At a suitable resolution, lidar helps to identify subtle topographic controls on soil variability traditionally missed at coarser scales. Topography controls water redistribution on the landscape, which in turn controls pedogenesis over geologic time and subsequent soil distribution across a landscape. These scientific concepts are not new to soil resource inventories. However, data such as lidar and the other aforementioned tools provide spatially explicit representations of soils and soil processes in a quantifiable format. Digital soil mapping processes quantify and capture soil patterns determined by topography, parent materials and other soil forming factors (McBratney et al., 2003) and this information in a digital format for computer-based applications (Sunita, 2016).

3.3 Components of Remote Sensing

The major critical component for any remote sensing program is reliable ground truth information. Without ground data to identify land cover categories, to train the classifier and validate the output image products, it is impossible to run a defensible program that provides reliable results. Ground truth is mentioned first, because it must be seriously considered before initiating plans for any remote sensing application. Secondly, a source of satellite imagery is required. There are many sources of satellite imagery which vary considerably in cost, as well as, spatial, temporal, spectral and radiometric resolution. Finding an imagery source that also provides a guarantee of future continuity is an important consideration, since once a program has been researched and implemented, it becomes more difficult to transition to another satellite. Thirdly, using remotely sensed data requires a sizable investment in Information Technology (IT) resources. However, with the speed of computers continuing to increase and the price of disc storage on the decline this has become much less of a hindrance.

3.3.1 Ground Truth

NASS has two sources of field level crop information for ground truth, its own June Area Survey (JAS) and the USDA Farm Service Agency (FSA). NASS collects the June Area Survey (JAS)segment data and the FSA collects CLU polygon data. The scope of the FSA CLU program is comprehensive including all states and extensive coverage of major crops. The program is run at the county level in over 2,300 FSA county offices. There are two important differences between JAS and FSA data, as ground truth, in the CDL program. First, the JAS data requires manual digitization of individual segments by NASS staff or cooperators while the FSA data does not. The individual polygon boundaries of the JAS segments are regularly digitized to support the survey but the individual fields within each segment require additional digitization. The FSA CLU polygon data are digitized and crop specific attribute data collected in the FSA county offices as part of a standardized GIS layer that collects information on all fields in FSA programs on a near real time basis for compliance and administration purposes (Mueller et al., 2009). A second difference is that the coverage of major crops provided by the FSA are more comprehensive than the 150 – 400 one square mile area segments included in the JAS data, approximating full coverage in major speculative states.

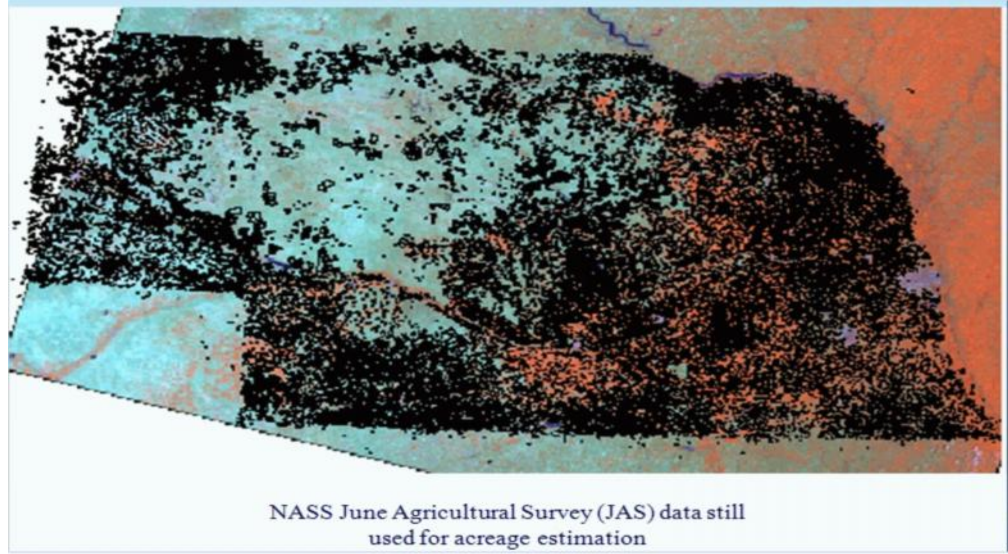

Fig. 2: FSA CLU polygon data overlaying an Advanced Wide Field Sensor image

However, there are several shortcomings to using the FSA data. First, approximately fifty percent of CLU polygons include more than one crop type per CLU while JAS segments are digitized to the field (Craig, 2005). In order to use the FSA data, CLUs with mixed crop types, except certain double crops such as winter wheat followed by soybeans, are excluded from the ground truth. Second, specialty crops are not well represented in the FSA data leading to a bias toward "program crops", for which farmers received subsidies. Third, not all CLU polygons are attributed each year (Mueller et al., 2009).

Fortunately, these shortcomings are greatly overshadowed by the sheer volume of crop data available from the FSA CLU program. Being a comprehensive agricultural data set that requires minimal preparation and can be updated multiple times during the growing season greatly outweighs the disadvantages. Using the FSA CLU and 578 attribute data for training has dramatically increased the volume and timeliness of available ground truth and thereby increased the scope, efficiency and accuracy of the operational CDL program.

3.3.2 Imagery

In the late 1990s, NASS used both Landsat TM and ETM+ data with a 30 metre spatial resolution in CDL production. The Landsat sensors have a 185 km swath; seven spectral bands including a visible blue, visible green, visible red, near infrared red (NIR), two mid infrared (MIR) bands and a thermal band; a 16-day repeat and 8 bit quantisation. The synchronisation of the two sensors to achieve an 8day repeat cycle was appropriate for acquiring crop information during the growing season. Lands at data were purchased and made available to NASS via the USDA's Foreign Agricultural Service (FAS), which established the satellite image archive (SIA) for the purpose of coordinated purchases of satellite imagery for the entire Department of Agriculture (Craig, 2009).

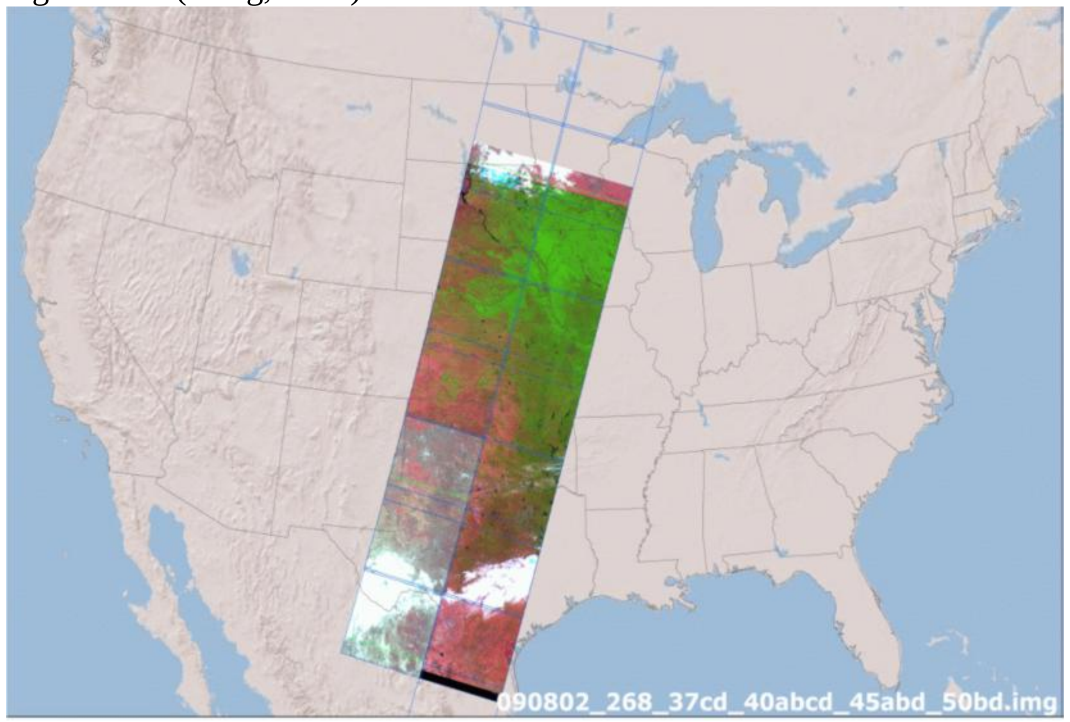

Fig. 3: IRS Resources at 1 – Advanced Wide Field Sensor (AWiFS) Imagery acquired on August 2, 2009. Acquisition descriptions include path/row/quad information. The brightly colored quads are those used in CDL processing.

On May 31, 2003, the Landsat 7 ETM+ sensor experienced an anomaly in its scan line corrector. At the time, the imagery was considered unusable by NASS and the CDL program experienced a 50% reduction in the inventory of available satellite imagery. In 2004 the USDA purchased imagery, for evaluation purposes, from the Indian Remote Sensing Satellite (IRS)RESOURCESAT-1 launched in October of 2003. The moderate spatial resolution (56 meter) Advanced Wide Field Sensor (AWiFS) data were selected for evaluation as a substitute for Landsat imagery in CDL production. NASS conducted investigations to assess the effectiveness of AWiFS data for crop acreage estimation including: Nebraska, 2004 (Boryan and Craig, 2005); Arkansas (Delta Region); Nebraska, 2005 and Coincident Studies, (Arkansas, Illinois, Iowa) 2005 (NASS, 2006; Seffrin, 2007;

Johnson, 2008) after which time NASS decided along with its partner, FAS, to purchase AWiFS data exclusively for the USDA's SIA, International Productions Assessment Unit.

In 2006, NASS began using AWiFS data as the primary source of imagery. The AWiFS sensor offers a moderate spatial resolution (56 meter); a large swath width (720 km), appropriate spectral characteristics for agriculture monitoring and a rapid revisit (5-day repeat) capability. The 56 metre spatial resolution, though coarser than Landsat's 30-meters is sufficient for the accurate identification of large homogenous crop fields (NASS, 2006). Additionally, the full swath width of 720 kilometers, when using both camera A and B acquisitions, provides an excellent opportunity for large area coverage with single day acquisitions. AWiFS offers four spectral bands that closely resemble the most useful of Landsat 5 TM and Landsat 7 ETM+. The sensor acquires data in the visible green, visible red, near infrared (NIR) and short wave infrared (SWIR) bands. The 5-day temporal resolution of AWiFS is a significant improvement from the 16-day revisit of Landsat 5 TM providing the opportunity for abundant nearly cloud free imagery collected throughout the growing season. From the 2006 - 2008 growing seasons, AWiFS was collected from April 1 through the month of October.

Acquisitions were excluded based on a 50% cloud cover criteria. Fortunately, with new software a large volume of satellite imagery and ancillary data could be used in the classification process. In 2006, Moderate Resolution Imaging Spectroradiometer Data (MODIS) 16-day Normalized Difference Vegetative Index (NDVI) composites began to be used in the classification process. With its250 meter spatial resolution, MODIS could not replace AWiFS but was useful when collected during the late fall over specific states where the winter wheat crop was beginning to emerge. In 2009, NASS regularly supplemented AWiFS data with Level 1T (terrain corrected) Landsat 5TM and Landsat 7 ETM+ data for CDL production, as the entire USGS Landsat Data Archive became available for public consumption, at no charge (USGS, 2005). The Landsat data were downloaded from Glovis (http://glovis.usgs.gov). Post processing steps included converting the data from GeoTIFF to ERDAS Imagine image (.img) format, re-projecting from Universal Transverse Mercator (UTM) to Albers, resampling from 30 to 56 meters using cubic convolution (CC) resampling method, and mosaicing same day acquisitions.

During the 2009 CDL season, AWiFS experienced technical problems including an on-board data recorder failure and degraded solar panel capacity. Further, increased competition from international customers reduced the availability of AWiFS data for purchase over the U.S. by the

FAS archive. Fortunately, the freely available Landsat data were available for use as a source of supplemental imagery. The CDL program would not have been able to meet all program deadlines, as well as, expand its scope to include the forty-eight conterminous states without the use of Landsat data.

3.3.3 Software and IT infrastructure

3.3.3.1 Remote Sensing Classification Software

In 2004, transitioning the CDL program from research to operational status appeared to be in the realm of possibility. Changes including new imagery, ground truth, image processing and estimation software were required. Already in place was the FSA CLU data which provided an expansive source of agricultural ground truth and required no in-house digitization, a significant advance. Additionally, the JAS segment boundaries could still be used as an independent data source for regression modeling. Also available were the AWiFS data which showed promise for large area coverage at a five-day repeat cycle. The next step was the identification of commercial remote sensing software that could perform the functions of Peditor, NASS' original in-house remote sensing maximum classifier and estimation software. NASS evaluated ERDAS Imagine, Definiens' eCognition and Rulequest Research's See5 decision tree software. The remote sensing software selected needed to be affordable, efficient and accurate. See5 came highly recommended by EROS Data Center researchers and was used to produce the National Land Cover Database (NLCD) for 2001 and was found to be the most appropriate as a replacement for the Peditor maximum likelihood classifier (Homer., et al., 2004; 2007).

See5 was the remote sensing classification software used by NASS since 2006 and was the primary driver of the expansion of the CDL program. The most important factor was the time required to produce a state wide CDL. Once the See5 method was fully developed, an experienced analyst could produce a state wide CDL, after all preprocessing of ground truth, imagery, and ancillary data was complete, within several days. It required one to several months for the same analyst, using the Peditor method, to produce a state wide CDL product. The difference is in large part because See5 is able to generate a state wide CDL in one process incorporating all input data. Although Peditor was an excellent classifier, there were a number of limitations that made the classification process more time consuming. Peditor operated by creating multiple smaller classifications. The intersection of Landsat scenes defined "analysis districts" (AD). A separate classification would be generated for each analysis district. Using the Peditor method, some states required as many as twelve separate analysis districts which in turn required running twelve separate classifications to produce a state wide CDL. The individual classifications were merged to create the state wide CDL.

With See5, even though by definition it classifies the intersection of inputs, there is a technique to get around this obstacle so that the entire state or region can be classified in one process. All input data including imagery and ancillary data must be set to a specific map extent when created.

Consequently, even though all of the imagery does not cover, for example the entire state of Nebraska if all of the inputs are set to this specific map extent then See5 categorizes all land cover within this region. This is a tremendous time saver. It takes additional time preparing the input data, but the time saved in the classification phase is significant.

Additionally, See 5 provides options which improve the quality and accuracy of the CDL products. These options include allowing for the ingestion of an abundance of satellite imagery and other non-parametric data sources; incorporating a boosting algorithm in which the classifier reviews the results multiple times to refine or "prune" the decision tree; tolerating image noise, such as clouds haze or even gaps in the imagery and generating confidence layers which corresponded to the resulting classifications. Lastly the NLCD 2001 can be used with See5 for training on non-agricultural categories and can be combined with the agricultural training to create a complete training set for the state or region.

In 2009, NASS used AWiFS, MODIS, Landsat TM and ETM+ data to produce the CDL products. Imagery was acquired from the fall of 2008 until late September 2009. Using imagery collected over the entire growing season facilitated the separation of crop phenologies and the accurate identification of cropland. In some instances, over a particular area six or more satellite scenes acquired throughout the growing season were used to classify the land cover. This was extremely useful when attempting to identify double crops such as winter wheat followed by soybeans or crops with similar phenologies. Peditor could only ingest a maximum of two scenes of a study area. This was a significant limitation.

Non parametric data sets such as the USGS Digital Elevation Model (DEM), USGS percent canopy layer, and USGS percent impervious layer were used from 2007 – 2009 to help identify non-agricultural categories and separate them from crops. The DEM is most useful in regions with significant topographic variation. Further, crops are most often grown in areas of low topographic relief. For example, in Mississippi, Louisiana and Missouri a significant percentage of the agriculture grown in the region is located in the

low lying portion of the delta. The percent canopy layers help identify the forested areas and the percent impervious layers helps identify urban infrastructure. Theseraster layers could not be used with Peditor.
Boosting or bagging, in which the classifier reviews the results multiple times to refine or “prune” the decision tree, was available with See5. This was shown to improve accuracy in the literature (Quinlan, J., 1996). In 2009, ten boosts were generally run to refine the CDL classification.

Boosting was not available with Peditor. The NLCD 2001 is currently used for training for non-agricultural categories. The NLCD 2001was released in 2006 at which time; NASS began using it for non-agricultural sampling.

When using Peditor, an analyst would have to manually create non-agricultural ground truth. “Extra signatures” were created for clouds, water, grass, trees, wetlands and many other non-agricultural categories, a very time consuming process. Additionally, these “extra signatures’ were created for each individual classification or analysis district with Peditor. A tremendous advantage of See5 and improvement in operational efficiency was its tolerance of image noise such as clouds, haze and the scan gaps in the Landsat 7 ETM+ data. As long as there was an abundance of clear imagery overlaying the same location as the image noise, the software seemingly ignored the bad data. When using Peditor, “extra signatures” would have to be created for all analysis districts ADs in which clouds were evident.

3.3.3.2 RSP to ESRI ArcGIS

Starting in 2006 when the FSA CLU data became the primary source of ground truth for the CDL program, the switch was made from Remote Sensing Program (RSP) to ESRI’s ArcGIS software. ArcGIS was the clear choice as USDA has an enterprise software license and many staff members trained in its use. The preparation of the FSA CLU data was dramatically more efficient when using ArcGIS than it was with RSP. Models were written in ArcGIS to merge the original county FSA CLU shape files into statewide shape files. The shape files were then “cleaned, re-projected to Albers Conical Area (Albers) and buffered inward 30.0 – 56.0 meters. All of these steps, which were relatively time consuming for 48states, were completed on the CLU polygon data in 2009, prior to the crop season. All of these processes could not be performed with RSP which was primarily used for digitizing and editing crop attribute information. The JAS segment data required approximately one month, during the crop season, for digitising in the FOs and two weeks for editing by a CDL analyst.

Once the FSA CLU polygons were linked to the FSA 578 attribute data, ArcGIS models were used to exclude non matching CLUs, separate CLUs into training and validation data sets, and rasterize the shape files for use in See5. The ArcGIS models dramatically improved the efficiency of the process whereby the most current ground truth could be used prior to in season deadlines. ESRI's ArcGIS was an important contributor improving the efficiency and quantity of the ground truth available for use in producing CDLs.

3.3.3.3 Peditor to SAS

From 1997 to 2005, Peditor performed all of the functions of both a remote sensing classification and estimation software. Once the decision was made to transition from Peditor to See5, new estimation software was required. SAS was selected as it was widely used within NASS and had the statistical analysis capabilities that NASS required. In 2006, the regression estimator in Peditor was well developed and documented (Day, 2002). Consequently, the identical programs written and run in Peditor were transitioned to SAS.

By 2007, SAS was able to increase the efficiency of estimation modeling and help transition the CDL program from research to operational status. One of the most important advantages of SAS was the ability to interactively review the regression analysis results in IML Workshop (called Stat Studio in SAS 9.2). This made the process of removing outliers and rerunning the regression modeling less labour intensive for statisticians. Second, the original format of JAS segment data was formatted in SAS and made the data easier to use. Third, results tables in SAS were output in .pdf files and Excel files that were easier for NASS headquarters statisticians to import and analyse than the earlier tables generated in Peditor. Another important advantage that occurred during the transition from Peditor to See5 and SAS was the ability to run estimates for the entire state at one time.

1.0 CONCLUSION

The advancement of remote sensing technology is key in conducting efficient soil surveys and soil mapping. Recent technological advances in satellite remote sensing have helped to overcome the limitation of conventional soil survey, thereby providing a new outlook for soil survey and mapping. Remote sensing has proved to be an important part of soil survey and mapping. Soil properties that have been measured using remote sensing approaches include mineralogy, texture, soil iron, soil moisture, soil organic carbon, soil salinity and carbonate content.

5.0 SUMMARY

Optical remote sensing helps in the mapping of properties like land cover, land type, vegetation and soil moisture. Thermal infrared remote sensing is commonly used to estimate moisture and salinity. Visual image interpretation technique helps in the identification and mapping of soil elements like land type, vegetation, land use, slope and relief. Microwave remote sensing is a new and effective technique for mapping of soil moisture and salinity which is being commonly used today. Hyperspectral remote sensing is another recent method which is applied in soil salinity mapping as well as identification and mapping of minerals in the soil.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is remote sensing?
2. List and briefly explain three key components of remote sensing.
3. Mention and explain the different remote sensing methods used in soil survey and mapping.
4. What are the important characteristics of soils that determine their reflectance properties?
5. Give five problems which may occur while mapping Soil from thermal remotely sensed data.

7.0 REFERENCES/FURTHER READING

Clark, R.N. & Swayze, G.A. (1996). “Evolution in Imaging Spectroscopy Analysis and Sensor Signal-to-Noise: An Examination of How Far We Have Come.” Summaries of the sixth annual JPL airborne Earth science workshop. 4–8 March 1996. AVIRIS Workshop, Vol. 1, 5.

Craig, M. (2005). "Using FSA Administrative Data in the NASS Cropland Data Layer" Draft as of 9/7/2005; write-up of FSA data used for Nebraska 2002-2004 research; circulated administratively only in NASS; NASS/RDD/GIB/SARS Fairfax, VA 2005.

Curran, P.J. (1985). *Principles of Remote Sensing*. UK: Longman Scientific and Technical.

Day, C.D. (2002) "A Compilation of PEDITOR Estimation Formulas". RDD Research Paper RDD-02- 03, USDA, NASS, Washington, D.C. January, 2002.

Homer, C., Huang, C. Yang, L. Wylie, B. & Coan, M. (2004). “Development of a 2001, National Land Cover Database for the United States”, *Photogrammetric Engineering & Remote Sensing*. Vol. 70, No. 7, pp 829-840, July 2004.

Homer, C. et al. (2007). “Completion of the 2001 National Land Cover Database for the Conterminous United States”, Photogrammetric *Engineering & Remote Sensing*. Vol. 73, No. 4, pp. 337-341, April 2007.

http://www.fao.org/fileadmin/templates/ess/documents/meetings_and_workshops/ICAS5/PDF/ICASV_2.1_048_Paper_Bailey.pdf

Irons, J. R., Weismiller, R.A. & Petersen, G.W. (1989) ‘Soil reflectance.” In G.Asrar (Ed.). *Theory and Applications of Optical Remote Sensing*. New York: John Wiley and Sons, 66–106.

Jeffrey, T. B. & Claire, G. B. (2010). Remote Sensing Applications in Agriculture at the USDA National Agricultural Statistics Service

Johnson, D. M. (2008). “A comparison of coincident Landsat-5 TM and Resourcesat-1 AWiFS Imagery for Classifying Croplands.” *Photogrammetric Engineering and Remote Sensing*. Vol 74, No 11 November 2008.

Liu, W., Baret, F., Gu, X., Zhang, B., Tong, Q. & Zheng, L. (2003). “Evaluation of Methods for Soil Surface Moisture Estimation from Reflectance Data.” *International journal of remote sensing*, 24(10): 2069–2083.

McBratney, A.B., Mendonsa-Santos, M .L. & Minasny, B. (2003). *On digital soil mapping.* Geoderma, 117,pp 3-52.

Metternicht, G.I. & Zinck, J.A. (2003). “Remote Sensing of Soil Salinity: Potentials and Constraints.” *Available at www.elsevier.com/locate/rse*.

Mueller, R., Boryan, C. & Seffrin, R. (2009). Data Partnership Synergy: The Cropland Data Layer. August ’09 GMU conf http://www.geoinformatics2009.org/

Mulders. (1987). "Remote Sensing in Soil Science Development in Soil Science." *Elsevier*. Amsterdam.

NASS (2006). Assessment of TM and AWiFS Imagery for Cropland Classification: Three Case Studies. http://www.pecad.fas.usda.gov/pdfs/2006/NASS_AWiFS_TM_CDL_comparison_Final.pdf >Accessed, February 10, 2010.

Photogrammetry & Remote Sensing. Bethesda Maryland, 528p.

Quinlan, J. (1996). Bagging, Boosting, and C4.5, *Proceedings of the Thirteenth National Conference on Artificial Intelligence*. Portland, Oregon: American Association for Artificial Intelligence Press. pp. 725 – 730.

Rao, B.R.M. & Venkataratnam, L. (1991). "Monitoring of Salt-Affected Soils: A Case Study Using Aerial Photographs, Salyut-7 Space Photographs, and Lands at TM Data." *Geocarto International*, 6, 5–11.

Renslow, M.S. (Ed). (2012), Manual of Airborne Topographic Lidar, Am. Soc.

Rimjhim K., Sushmita B. & Malaya C. (2013). "Application of Remote Sensing in Soil Mapping - A Review." https://www.researchgate.net/publication/309034749. pp 60 – 66.

Seffrin, R. (2007). "Evaluating the Accuracy of 2005 Multitemporal TM and AWiFS Imagery for Cropland Classification of Nebraska." Proceedings of the ASPRS 2007 Annual Conference, Tampa Florida, May 7-11, 2007.

Sunita, S. (2016). "Remote sensing applications in soil survey and mapping: A Review." *International Journal of Geomatics and Geosciences* Vol. 7, No 2. Pp 192 – 203.

Taylor, G.R., Mah, A.H., Kruse, F.A., Kierein-Young, K.S., Hewson, R.D. & Bennett, B.A. (1996). "Characterisation of Saline Soils Using Airborne Radar Imagery." *Remote Sensing of Environment*, 57, 127–142.

USGS Newsroom (2005). "Orthorectified Landsat Digital Data Now Available from the USGS".

Wang, L. & Qu, J. J. (2009). "Satellite Remote Sensing Applications for Surface Soil Moisture Monitoring: A Review." *Front. Earth Sci.*, 3(2): 237–247.

Wigneron, J.P., et al. (2004). "Soil Moisture Retrievals from Biangular L-Band Passive Microwave Observations." *Geoscience and Remote Sensing Letters*, IEEE, 1: 277–281.

UNIT 5 PHOTOGRAPHS IN SOIL SURVEY

CONTENTS

1.0 INTRODUCTION

Photographs are a significant component of soil survey data collection and documentation. They can illustrate important things about an individual soil or a soil catena in soil survey reports, scientific journals, textbooks, and periodicals. They can be included in any electronic presentation of soil survey data to end users. Good photographs provide records and reference sources of basic soil information. Taking photographs needs to be planned early in the soil survey. Features such as buildings, rivers, roads, railroads, lakes, and field boundaries, and many kinds of vegetation can be recognized on aerial photographs and serve as location aids. Cultural features commonly are the easiest features to recognize on aerial photos, but they generally do not coincide precisely with differences in soils, except in areas with significant anthropogenic alteration or human interference. Relief can be perceived by stereoscopic study. Relief features are helpful in locating many soil boundaries on the map. Topographic maps also provide insight to relief, slope, and aspect. Relief also identifies many kinds of landforms commonly related to kinds of soil. Many landforms (e.g., terraces, flood plains, sand dunes, kames, and eskers) can be identified and delineated reliably according to their shapes, relative heights, and slopes. Their relationship to streams and other landforms provides additional clues. The soil scientist must understand geomorphology to take full advantage of photo interpretation. Accurate soil maps cannot be produced solely by interpretation of aerial photographs. Time and place influence the clues visible on the photographs. Human activities have changed patterns of vegetation and confounded their relationships to soil patterns. The clues must be correlated with soil attributes and verified in the field.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss the importance of use of photos in soil survey and mapping
- explain what aerial photography is all about
- identify different types of photographs in soil survey and mapping.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Photographs are a viable mapping base in soil survey.
ii. Aerial Photography provide important clues about kinds of soil from the shape and color of the surface and the vegetation.
iii. The relationships between patterns of soil and patterns of images on photographs for an area can be determined. These relationships can be used to predict the location of soil boundaries and the kinds of soil within them.
iv. The soil scientist must understand geomorphology to take full advantage of photo interpretation.

3.2 Photographs

Aerial photographs were used as the mapping base in most soil survey areas in the United States during the 20th century. Conventional panchromatic (black and white) photography, color photography, and infrared photography were used for remote sensing and as base maps for the soil survey.

Information on the applicability of each type of base map and how the older map products were used is covered in the 1993 *Soil Survey Manual* (Soil Survey Staff, 1993). Even in the current digital age, the use of aerial photographs remains an effective means of mapping soils in areas where suitable digital imagery and data layers or the required skills, resources, or support for digital mapping techniques are not available. Aerial photographs are still a viable mapping base in soil survey. They provide important clues about kinds of soil from the shape and color of the surface and the vegetation.

The relationships between patterns of soil and patterns of images on photographs for an area can be determined. These relationships can be used to predict the location of soil boundaries and the kinds of soil within them. Aerial photographs using spectral bands not visible to the eye, such as colour infrared, enable subtle differences in plant communities to be observed. Other spectral bands in the infrared are useful in distinguishing differences in mineralogy and moisture on the soil surface and also have better cloud penetration. These data must be interpreted by relating the visual pattern on the photographs to soil characteristics found by inspection on the ground.

3.2.1 Contemporary Approach

Digital imagery has replaced photographs as the mapping base in 21st century soil survey. The ability to overlay multiple imagery resources for comparisons, the ability to quickly adjust scale, and the use of raster-based soil maps have increased the speed of delivering soil survey products as well as the variety of products available. Customised soil survey products are enhanced by the choice of background imagery (e.g., colour imagery and topographic imagery) used to display soil survey information.

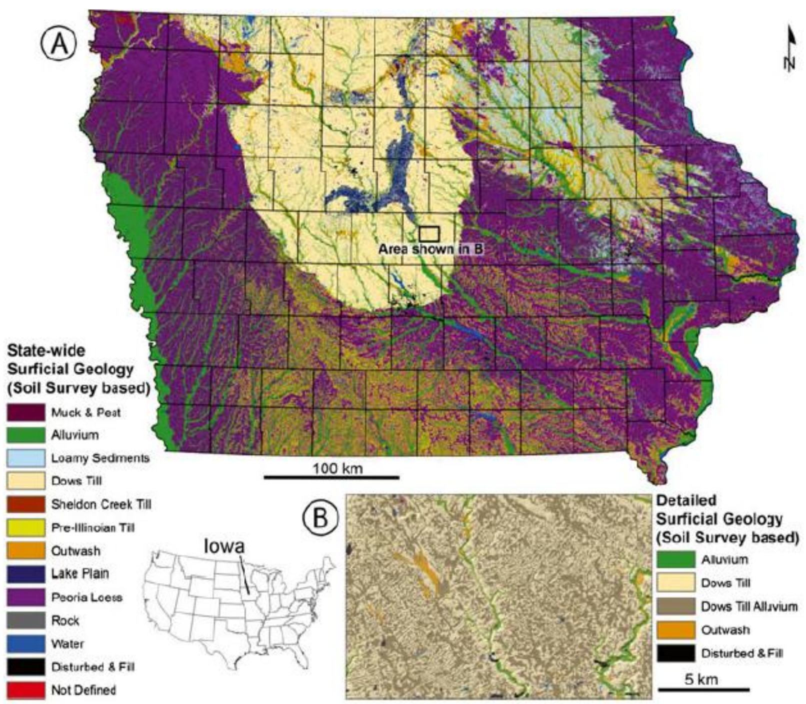

Fig 4: Surficial geology maps for Iowa, USA, based on digital soil survey maps and interpretation of official soil series descriptions. After Miller and Burras (2015). (**a**) Although the same soil series in different counties are technically different soil map units, they are still constrained by definitions set in the official series description.

3.2.2 Uses of Photos and Imageries

i. Photographs that include a scale are useful in estimating volume, area, or size distribution.
ii. The comparison of coarse fragments in a soil against photographs of known quantities of coarse fragments improves the reliability of estimates.
iii. Similar photographic standards can be used to estimate volume or size of nodules and concretions, mottles, roots, pores, and rock fragments.
iv. Photographic standards can be used in estimating area or the special arrangement of surface features and land use.

3.2.3 Equipment for Field Use to Obtain Good Photos

i. **A good-quality camera is important in obtaining high-quality photos.** Digital cameras are the general norm today. A digital camera allows the image file, along with its respective metadata, to be stored in a database file system for later use. The camera needs to provide resolution greater than 8 megapixels (at least 16 megapixels is preferred) to produce high-quality images. The ability to vary the aperture and exposure time settings is desirable. Many of the larger point-and-shoot cameras and 35-mm single-lens reflex digital cameras are adequate.
ii. **A tripod is generally necessary**, especially at shutter speeds below 1/50 second. It reduces camera movement and enables the photographer to concentrate on composition and focus. A flash is needed in some poorly lighted situations or to eliminate shadows.
iii. **A scale that indicates horizon depth or thickness is important.** A scale that does not contrast greatly with the soil, such as an unvarnished and unpainted wood rule or a brown or khaki colored cloth tape that is 5 cm by 2 m works well. Large black or yellow figures at 50-cm intervals, large ticks at 10-cm intervals, and small ticks at 5-cm intervals complete the scale. A perfectly vertical scale increases the quality of the photo, in contrast to a tilted scale.
iv. **A small spatula, kitchen fork**, or narrow-bladed knife is useful in dressing the soil profile. Paint brushes of various widths and a tire

pump can help clean dust from peds. A sprayer can be used to moisten the profile when necessary before a snapshot is taken.

3.2.4 Photographing Soil Profiles

To be able to obtain a high-quality photographs of soil profiles, careful planning is essential. The procedure for photographing soil profiles are as follows:

1. **Good Exposure to source of light:** A representative site is selected on a vertical cut face or in an area where a pit can be dug large enough for adequate lighting of all horizons and for the camera to be 1.5 to 2.5 m from the profile. The pit or cut face should be oriented so that the maximum amount of light will strike the prepared face at the proper angle when photographed. Better images are generally obtained when the soil profile is either in full sun or full shade. Subtle differences in soil color are often more apparent on cloudy days than in full sun. Direct exposure to full sunlight often results in a washed out image.
2. **Significant contrast in structure and colour of horizons:** The profile needs to be properly prepared to bring out significant contrast in structure and color between the soil horizons. Beginning at the top, fragments of the soil can be broken off with a spatula, kitchen fork, or small knife to eliminate digging marks and expose the natural soil structure. Dust and small fragments can be brushed or blown away. Moistening the whole profile or part of it with a hand sprayer helps to obtain uniform moisture content and contrast.
3. **Capture several shots varying aperture settings:** Every profile should be photographed three or four times with different aperture settings, angles of light, and exposure times.
4. **Use notes to describe the profiles and locations clearly:** Notes should be made immediately after each photograph is taken to record location and date, complete description of the subject, time of day, amount and angle of light, camera setting, method of preparing the profile, and other facts that are not evident in the photograph. Besides increasing the ways the photograph can be used, good notes provide information for improving technique. If possible, a landscape photograph should accompany the soil profile photograph.

3.2.5 Photographing Landscapes

Landscape photographs illustrate important relationships between soils and geomorphology, vegetation, land use as well as management. They should be clear and in sharp focus and have good contrast. Photographs representative of the area being mapped are the most useful.

Procedures that will ensure quality landscape photographing include the following:

1. **Lighting:** The most important thing in landscape photography is lighting. The best pictures are made at the time of day and during the time of year when the sun lights the scene from the side. The shadows created by this lighting separate parts of the landscape and give the picture depth. If the sun is at a low angle to the horizon, shadows are generally amplified and give an image more contrast and depth. Photographs taken at midday or with direct front lighting can lack tonal gradation and, therefore, appear flat. Photographs taken on overcast days can have the same problem. A small aperture should be used to gain maximum depth of focus.
2. **The photo composition:** A good photograph has only one primary point of interest. Objects that clutter the photograph (e.g., utility poles, poorly maintained roads and fences, signs, and vehicles) detract from the main subject. The point of interest should not be in the center of the photograph. The "rule of thirds" for composition is useful when looking at the scene through the viewfinder. The image area can be visualized as divided into thirds both horizontally and vertically. The center of interest should be one of the four points where these lines intersect.
3. Sky should make up less than one-third of the image.
4. The camera should be kept level with the horizon. In addition,
5. landscape photographs should be taken from a variety of angles (e.g., from a kneeling position, on a ladder, on top of a car or low building, etc.).

3.2.6 Close-Up Photography

Many soil features, such as peds, pores, roots, rock fragments, krotovinas, redoximorphic features, concretions, and organisms, can be photographed at close range. The minimum focusing distance for most cameras used in the field allows small features to be photographed. Many cameras have a built-in macro focus feature that enables focusing within a few inches. Macro lenses are available for most 35-mm cameras. Close-up attachments for conventional lenses are also available. As with landscape photography, the lighting angle is important. Direct front lighting tends to blend texture, separation, and contrast in the photograph. Photographing clay films and other minute soil features requires special equipment and techniques of photomicrography that are outside the range of this manual.

Metadata

For each photograph, metadata should be recorded, including:

a. the date of the photo
b. the geographic location
c. a description (caption) of what the image is intended to show
d. and a reference to the map unit(s)
e. soil components of the area.

4.0 CONCLUSION

Good photographs provide records and reference sources of basic soil information. Taking photographs needs to be planned early in the soil survey. Features such as buildings, rivers, roads, railroads, lakes, and field boundaries, and many kinds of vegetation can be recognised on aerial photographs and serve as location aids. Cultural features commonly are the easiest features to recognise on aerial photos, but they generally do not coincide precisely with differences in soils, except in areas with significant anthropogenic alteration or human interference.

5.0 SUMMARY

Digital imagery has replaced photographs as the mapping base in 21st century soil survey. The ability to overlay multiple imagery resources for comparisons, the ability to quickly adjust scale, and the use of raster-based soil maps have increased the speed of delivering soil survey products as well as the variety of products available. Customised soil survey products are enhanced by the choice of background imagery (e.g., colour imagery and topographic imagery) used to display soil survey information.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the term “photos” and “digital imageries” as they relate to soil survey.
2. Mention four uses of photos and imageries to soil users.
3. Mention and briefly explain the five procedures involved in photographing a soil profile.
4. Mention five procedures involved in photographing a landscape.
5. List the metadata that should be recorded after each photograph.

7.0 REFERENCES/FURTHER READING

Soil Survey Division Staff (1993). "Soil Survey Manual." U.S. Department of Agriculture Handbook 18. Natural Resources Conservation Service.

MODULE 3 SOIL MORPHOLOGICAL INVESTIGATIONS

UNIT 1 SOIL MORPHOLOGY

1.0 INTRODUCTION

Soil Morphology is the field observable attributes of the soil within the various soil horizons and the description of the kind and arrangement of the horizons. It deals with the form and arrangement of soil features. Soil morphology is carried out using a standard profile pit by an experienced pedologist (soil surveyor). Parameters usually investigated in soil morphological investigations include: Depth intervals of horizons or layers (measured from the top of the mineral horizons), Horizon boundary characteristics, soil colour, soil texture, soil structure, pores, consistence, roots, pH, effervescence, special features such as coatings, nodules, and concretions.

Micromorphology is using micro-morphological techniques (e.g. thin sections) and measurements in the laboratory. Field morphology is the study of soil morphological features in the field by thorough observation, description and interpretation. Observations may be refined with the aid of a hand lens. Simple tests are also used in the field to record salient chemical properties (e.g. pH, presence or carbonates). In addition, field observations and measurement may be refined through a range of laboratory analytical procedures that include more sophisticated evaluation of chemical, biological and physical attributes.

However, the quality of field description and sampling ultimately defines the utility of any subsequent laboratory analyses. A keen eye that can discern specific features and their relationship to adjoining features coupled with well-calibrated fingers that can distinguish among relative differences in physical properties of soil material are essential and can only be acquired and maintained through practice, In this course we will focus on morphology.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss morphological and micro-morphological properties of the soil
- identify these properties in the field.

3.0 MAIN CONTENT

3.1 Soil Morphology

Field morphology begins with *in situ* (field) examination of a soil profile, Field descriptions are organised by subdividing, in vertical exposure of the soil (soil profile) into reasonably distinct layers or horizons that differ appreciably from the horizons immediately above and below in one or more of the soil features listed below. The delineation of horizons is necessarily a somewhat subjective processes because changes in soil attributes are often gradational rather than abrupt. Thus, obvious boundaries between horizons are not always apparent and their assignment may require integrated assessment of changes in several attributes before a sensible and defensible delineation can he made. Knowledge of similar soils and a well-defined rationale for the purpose of the description helps considerably in development of systematic criteria for criteria for defining and delineating horizons.

1.0 CONCLUSION

In many soils, differences are expressed by horizonation that lies approximately parallel to the land surface, which in turn reflects vertical partitioning in the type and intensity of the various processes that influence soil development. However, there are many exceptions to this preferred horizontal organisation. Differences between horizons generally reflect the type and intensity of processes that have caused changes in the soil. Ideally, we should always try in our descriptions to maintain a link between process and morphology.

1.0 SUMMARY

Properties of each horizon are described in the following order: Depth intervals of horizons or layers (measured from the top of the mineral horizons), horizon boundary characteristics, colour, texture, structure, pores, consistence, roots, pH, effervescence, special features such as coatings, nodules, and concretions. Also, about $^{1}/_{2}$ kg or 500g of soil should be taken from each horizon. Sampling should start from the last horizon to avoid contamination of the horizon. Properly labeled and taken to a standard laboratory for analysis.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is soil field morphology?
2. Name five morphological properties of soil.
3. What is soil micro-morphology?
4. What are the precautions to take during sampling using a profile pit?

7.0 REFERENCE/FURTHER READING

Buol, S.W., Hole, F.D., McCracken, R.J., & Southard, R.J. (1997). *Soil Genesis and Classification.* Iowa State University Press.

UNIT 2 HORIZONS AND BOUNDARIES OF SOIL

CONTENTS

1.0 INTRODUCTION

As you observe a soil profile pit or a roadside cut, you will see various layers in the soil. These layers are called **soil horizons,** whereas the arrangement of these horizons in a soil is known as a **soil profile**. A pedologists or an experienced soil scientist, observe and describe soil profiles and soil horizons to classify and interpret the soil for various uses. Soil horizons differ in a number of easily seen soil properties such as color, texture, structure, and thickness. Other properties may be less visible. Properties, such as chemical and mineral content, consistence, and reaction require special laboratory tests. The distinction between a mineral and an organic horizon is by the organic carbon content. Layers which contain > 20 % organic carbon and are not water saturated for periods more than a few days are classed as organic soil material. If a layer is saturated for a longer period, it is considered to be organic soil material if it has:

- ≥12 % organic carbon and no clay, or
- ≥18 % organic carbon and ≥ 60 % clay, or
- 12 – 18 % organic carbon and 0 – 60 % clay.

These properties are used to define types of soil horizons.

Soil generally consists of visually and texturally distinct layers, which can be summarised as follows from top to bottom:

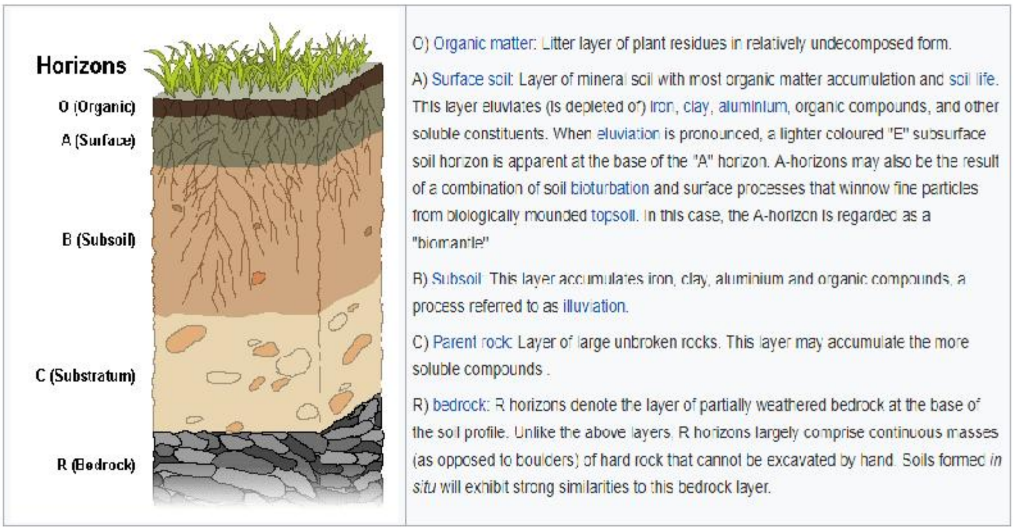

Fig.5: A Soil Profile Revealing the Different Horizons
Source: Wikipedia

There are master horizons (Surface horizons) and are designated by capital letters, such as O, A, E, B, C, and R., Sub surface horizons and transitional Horizons.

1.0 OBJECTIVES

By the end of this unit, you will be able to:

- identify surface diagnostic (master) horizons
- explain subordinate distinctions with master horizons
- identify transitional horizons
- discuss and identify subsurface horizons.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Master horizons (major horizons) are designated by capital letters, such as O, A, E, B, C, and R.

ii. Some O layers may be undecomposed or partially decomposed litter, such as leaves, twigs, moss, and lichens, that has been decomposed on the surface; they are either on the top of either mineral or organic soils. Other O layers, are organic materials that were deposited in saturated environments and have undergone decomposition.

iii. A horizons are mineral horizons that formed at the surface or below an O layer, that exhibition obliteration of all or much of the original rock or depositional structure (in the case of transported materials).

iv. B Horizons have some features such as; An illuvial concentration of silicate clay, iron, aluminum, carbonates, gypsum, or humus; Removal of carbonates; A residual concentration of sesquioxides or silicate clays, alone or mixed, that has formed by means other than solution and removal of carbonates or more soluble salts; Coatings of sesquioxides adequate to give darker, stronger, or redder colors than overlying and underlying horizons but without apparent illuviation of iron.

v. C Horizons are mineral horizons that are little altered by soil forming processes. They lack properties of O, A, E, or B horizons.

vi. Transitional horizons are layers or the soil between two master horizons designated as AB, BA, EB, BE. The first letter indicates the material of greatest volume in the transitional horizon. E.g. A/B, B/A, E/B or B/E.

3.2 Soil Horizon and Boundaries

3.2.1 Soil Master Horizons

i. **O horizons:** They are dominated by organic material. Some O layers consist of undecomposed or partially decomposed litter, such as leaves, twigs, moss, and lichens, that has been decomposed on the surface; they may be on the top of either mineral or organic soils. Other O layers, are organic materials that were deposited in saturated environments and have undergone decomposition. The mineral fraction of these layers is small and generally less than half the weight of the total mass. In the case of organic soils (peal, muck) they may compose the entire soil profile. Organic rich horizons which are formed by the translocation of organic matter within the mineral material are not designated as O horizons.

ii. **A horizons:** Mineral horizons that formed at the surface or below an O layer, that exhibition obliteration of all or much of the original rock or depositional structure (in the case of transported materials). A horizons show one or more of the following:

- An accumulation of humified organic matter intimately mixed with the mineral fraction and not dominated by characteristic properties or the E or B horizon or,

- Properties resulting from cultivation, pasturing or other similar kinds of disturbance.

iii. **E horizons:** Mineral horizons in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles and lighter colors. The horizons exhibit obliteration of all or much of the original rock structure.

iv. **B horizons:** Horizons in which the dominant features (s) is one or more of the following:

- An illuvial concentration of silicate clay, iron, aluminum, carbonates, gypsum, or humus
- Removal of carbonates
- A residual concentration of sesquioxides or silicate clays, alone or mixed, that has formed by means other than solution and removal of carbonates or more soluble salts
- Coatings of sesquioxides adequate to give darker, stronger, or redder colors than overlying and underlying horizons but without apparent illuviation of iron.
- An alteration of material from its original condition that obliterates original rock structure, that form silicate clay, liberates oxides, or both, and that forms a granular, blocky, or prismatic structure.
- Any combination of these.

v. **C horizons:** Mineral horizons that are little altered by soil forming processes. They lack properties of O, A, E, or B horizons. The designated C is also used for saprolite, sediments, or bedrock not hard enough to qualify for R. the material designated as C may be like or unlike the material from the A, E, and B horizons are thought to have formed.

vi. **R Layers:** Consolidated bedrock (hard bedrock), such as granite, basalt, quarzite, sandstone, or limestone. Small cracks, partially or totally filled with soil material and occupied by roots, me frequently present in the R layers.

Subordinate Distinctions within Master Horizons (Letter Suffixes)

Lower case letters are used to designate specific features within master horizons. They are listed in alphabetical order below:

a Highly decomposed organic material. The ‘a’ is used only with the O master horizon (Oa). The rubbed fiber content < l7 % of the volume.

b Buried genetic horizon. It is not used in organic soils or to identify a buried O master horizon.

c Concretions of hard non-concretionary nodules. This symbol is used only for iron, aluminum, manganese, or titanium cemented nodules or concretions.

d Physical root restriction. It is used to indicate natural occurring or humanly induced layers such as basal till, plow pans, and other mechanical compacted zones. Roots do not enter except along facture planes.

e Organic material of intermediate decomposition. This symbol is only used in combination with an O master horizon with rubbed fiber content between 17 – 40 % of the volume.

d Frozen soil. The horizon must contain permanent ice.

g Gleying: This symbol is used in B and C horizons to indicate low chroma color (< = 2), caused by reduction of iron in stagnant saturated conditions. The iron may or may not be present in the ferrous form (Fe^{2+}). The g is used to indicate either total gleying or the presence of gleying in a mottled pattern. It is not used in E horizons, which are commonly of low chroma, or in C horizons where the low chroma colors are inherited form the parent material and no evidence of saturation is apparent.

h illuvial accumulation of organic matter: Used only in B horizon. The h indicates an accumulation of illuvial, amorphous, dispersible organic matter with or without sequioxide component. If the sequioxide component contains enough iron so that the color value and chroma exceed 3 additionally a s is used (hs). The organoosequioxide complexes may coat sand and silt particles, of occur as discrete pellets, or fill voids and cement the horizon (use of m).

i Slightly decomposed organic material. Used only in Combination with an O master horizon to designate that the rubbed fiber content is > 40 % or the volume.

k Accumulation of carbonates, usually calcium carbonate. Used with B and C horizons.

m Cementation or induration: Used with any master horizon, except R, where > 90 % of the horizon is cemented and roots penetrate only through cracks. Tire cementing material is identified by the appropriate letter.

km: carbonate

- **qm:** silica
- **sm:** iron
- **ym:** gypsum
- **kqm:** both lime and silica
- **zm:** salts more soluble than gypsum

vii. **n:** Accumulation of sodium: This symbol is used on any master horizon showing morphological properties indicative of high levels of exchangeable sodium.

viii. **o:** Residual accumulation of sesquioxides.

ix. **p:** Tillage or other cultivation disturbance (e.g. plowing, hoeing, discing). This symbol is only used in combination with the master horizon A or O.

x. **q.** Accumulation of silica: This symbol is used with any master horizon, except R, where secondary silica has accumulated.

xi. **r:** Weathered soft bedrock: This symbol is only used in combination with the master C horizon. It designate saprolite or dense till that is hard enough that roofs only penetrate along cracks, but which is soft enough that it can be dug with a spade or shovel.

xii. **s:** illuvial accumulation or sesquioxides and organic matter. This symbol is only used in combination with B horizons. It indicates the presence or illuvial iron oxides. It is often used in conjunction with h when the color is = < 3 (chroma and value).

xiii. **ss:** Presence of slicken sides. They are formed by shear failure as clay material swell upon wetting. Their presence is an indicator of vertic characteristics.

xiv. **t:** Accumulation of silicate clay: The presence of silicate clay forming coats on ped faces, in pores, or on bridges between sand-sized material grains. The clay coats may be either formed by illuviation or concentrated by migration within the horizon. Usually used ill combination with B horizons, but it may be used in C or R horizons also.

xv. **v:** Plinthite: This symbol is used in B and C horizons that are humus poor and iron rich. The 5 material usually has reticulate mottling of reds, yellows and gray colors.

xvi. **w:** Development of color and structure. This symbol is used for B horizons that. have developed structure or color different, usually redder than that of the A or C horizons, but do not have apparent illuvial accumulations.

xvii. **x:** Fragipan character: This symbol is used to designate genetically developed firmness, brittleness, or high bulk density in B or C horizons. No cementing agent is evident.

xviii. **y:** Accumulation of gypsum. This symbol is used in B and C horizons to indicated genetically accumulated gypsum.

xix. **z:** Accumulation of salts more soluble than: gypsum. This symbol is used in combination with B and C horizons.

Note: Arabic numerals can be added as suffixes to the horizon designations to identify subdivisions within horizons. For example, Btl - Bt2 - Bt3 indicated three subsamples of the Bt horizon.

3.2.2 Transitional Horizons

Transitional horizons are layers or the soil between two master horizons. There are two types of transitional horizons:

Horizons dominated by properties of one master horizon that also have subordinate properties of an adjacent master horizon. The designation is by two master horizon capital letters:

- The first letter indicates the dominant master horizon characteristics
- The second letter indicated the subordinate characteristics

For example, an AB horizon indicates a transitional horizon between the A and B horizon, but one that is more like the A horizon than the B horizon. An AB or BA designation can be used as a surface horizon if the master A horizon is believed to have been removed by erosion.

➢ Separate components of two master horizons me recognizable in the horizon and at least one of the component materials is surrounded by the others. The designation is by two capital letters with a slash in between. The first letter designates the material of greatest volume in the transitional horizon. For example, A/B, B/A, E/B or B/E.

3.2.3 Diagnostic Subsurface Horizons

The accumulation of substances such as silica, iron, aluminum, carbonate, and other salts can result in cementer layers, which change the physical, chemical, and biological behavior of the soil. For example, a cemented layer retards percolation, and restrict root activity. Furthermore, the availability of nutrients for plant growth is reduced, i.e., the cation exchange capacity is reduced. There are accumulations in the soil which show the enrichment of one substance and / or the depletion of another substance. This can be expressed by **diagnostic subsurface horizons**, which are listed in alphabetically order below. It should be stressed that some characteristics can be measured only in the laboratory and not in the field.

i. **Agric horizon:** This is formed directly under the plow layer and has silt, clay, and humus accumulated as thick, dark lamallae.

ii. **Albic horizon:**Typically this is a light-colored E horizon with the color value > = 5 (dry) or > = 4 (moist).

iii. **Argillic horizon**: It is formed by illuviation of clay (generally a B horizon, where the accumulation of clay is denoted by a lower case 't') and illuviation argillans are usually observable unless there is evidence of stress cutans. Requirements to meet an argillic horizon are:

- 1/10 as thick as all overlying horizons
- > = 1.2 times more clay than horizon above, or:
- lf eluvial layer < 15 % clay, then > = 3 % more clay, or:
- If eluvial layer > 40 % clay, then > = 8 % more clay.

iv. **Calcic horizon:** This layer has a secondary accumulation or carbonates, usually of calcium or magnesium. Requirements:

- > = 15 cm thick
- > = 5 % carbonate than an underlying layer

v. **Cambic horizon:** This subsurface often shows weak indication of either an argillic or spodic horizon, but not enough to qualify as either. H may be conceptually regarded as a signature of early stages of soil development, i.e. soil structure or color development. Requirements:

- Texture: loamy very fine sand or finer texture
- Formation of soil structure
- Development of soil color

vi. **Duripan:** It is a subsurface horizon cemented by illuvial silica. Air-dry fragments from more than 50 % of the horizon do not slake in water or HCl but do slake in hot concentrated KOH.

vii. **Fragipan:** These subsoil layers are of high bulk density, brittle when moist, and very hard when dry. They do not soften on welling, but can be broken in the hands. Air-dry fragments slake when immersed in water. Fragipan genesis as outlined in Soil Taxonomy is largely dependent all physical processes and requires a forest vegetation and minimal physical disturbance. Desiccation and shrinking cause development of a network of polygonal cracks in the zone of fragipan formation. Subsequent rewetting washes very fine sand, silt, and clay-sized particles from the overlying horizons into the cracks. Upon wetting, the added materials and plant roots growing into the cracks result in compression or the interprism materials. Close packing and binding of the matrix material with clay is responsible for the hard consistence of the dry prisms. Iron is usually concentrated along the bleached boundaries of the prisms. It has also been postulated that clay and sequioxides cements to be binding agents in fragipans.

viii. **Glossic horizon:** It occurs usually between an overlying albic horizon and an underlying argillic, kandic, or natric horizon or fragipan. Requirements:

- > = 5 cm thick
- Albic material between 15 % to 85 %, rest: material like the underlying horizon

ix. **Kandic horizon**: It is composed of low activity clays, which are accumulated at its upper boundary. Clay skins mayor may not be present It is considered that clay translocation is involved in the process of kandic formation, however, clay skills may be subsequently disrupted or destroyed by physical and chemical weathering, or they may have formed in situ. Requirements:

- Within a distance of < 15 cm at its upper boundary the clay content increases by > 1.2 times
- Abrupt or clear textural boundary to the upper horizon
- A pH 7: low-activity days with CEC of < = I6 cmol/kg and ECEC (effective CEC) of < = 12 cmol/kg

x. **Natric horizon:** It is a subsurface horizon with accumulations of clay minerals and sodium. Requirements:

- Same as argillic horizon
- Prismatic or columnar structure
- > 15 % of the CEC is saturated with Na^+,or :
- More exchangeable Na^+ plus Mg^{2+} than Ca^{2+}

xi. **Oxic horizon:** Requirements:

- > = 30 cm thick
- Texture: sandy loam or finer
- At pH 7: CEC of < = I6 cmol/kg and ECEC of' < = 12 cmol/kg (i.e., a high content or 1:1 type clay minerals).
- Clay content is more gradual than required by the kandic horizon
- < 10 % weatherable minerals in the sand
- < 5 % weatherable minerals by volume rock structure (i.e., indicative of a very strongly weathered material)

xii. **Petrocalcic horizon:** It is an indurated calcic horizon. Requirements:

- At least 1/2 of a dry fragment breaks down when immersed in acid but does not break down when immersed in water.

xiii. **Petrogypsic horizon:** This is a strongly cemented gypsic horizon. Dry fragments will not slake in H_2O.

xiv. **Placic horizon:** This is a dark reddish brown to black pan or iron and/or manganese. Requirements:

- 2 – 10 cm thick
- It has to lie within 50 cm of the soil surface
- Boundary: wavy
- Slowly permeable

xv. **Salic horizon:** This is all subsurface horizon accumulated by secondary soluble salts. Requirements:

- > = 15 cm thick
- Enrichment of secondary soluble salts such (hat electrical conductivity exceeds 30 dS/m more than 90 days each year

xvi. **Sombric horizon:** Formed by illuviation or humus (dark brown to black color) but not of aluminum or sodium. Requirements:

- At pH 7: base saturation < 50 %
- Not under an albic horizon
- Free-draining horizon

xvii. **Spodic horizon:** This horizon has an illuvial accumulation of sequioxides and/or organic matter. There are many specific limitations dealing with aluminum, iron, and organic matter content, and clay ratios, depending on whether the overlying horizon is virgin or cultivated.

xviii. Sulfuric horizon: this is a very acid mineral or organic soil horizon. Requirements:

- pH < 3.5
- Mottles are present (yellow color: jarosite)

3.3 Boundary

The boundary between the horizons can be described considering the distinctness and topography. **Distinctness** refers to the degree of contrast between two adjoining horizons and the thickness of the transition between them. **Topography** refers to the shape or degree of irregularity of the boundary.

Table 1: Classification of Horizon Boundaries

Distinctness	**Abbreviation**	**Cm**
Abrupt	A	< 2
Clear	C	2 – 5
Gradual	G	5 – 15
Diffuse	D	> 15
Topography	**Abbreviation**	**Description**
Smooth	S	Nearly a plane
Wavy	W	Waves wider than deep
Irregular	I	Depth greater than width
Broken	B	Discontinuous

4.0 CONCLUSION

A **soil horizon** is a layer parallel to the soil surface, whose physical characteristics differ from the layers above and beneath. Each soil type usually has three or four horizons. Horizons are defined in most cases by obvious physical features, mainly colour and texture. There are master horizons (Surface horizons) and are designated by capital letters, such as O, A, E, B, C, and R., Diagnostic Sub surface and Transitional Horizons. Soil horizons are identified in the field by careful observation of a standard soil profile pit. The experience of the observer will go a long way in ensuring accuracy of obtained results.

5.0 SUMMARY

- O- Horizon (Organic matter): Litter layer of plant residues in relatively undecomposed form.
- A-Horizons (Surface soil): Layer of mineral soil with most organic matter accumulation and soil life. This layer eluviates (is depleted of) iron, clay, aluminum, organic compounds, and other soluble constituents. When eluviation is pronounced, a lighter coloured "E" subsurface soil horizon is apparent at the base of the "A" horizon. A-horizons may also be the result of a combination of soil bioturbation and surface processes that winnow fine particles from biologically mounded topsoil. In this case, the A-horizon is regarded as a "biomantle".
- B-Horizon (Subsoil): This layer accumulates iron, clay, aluminum and organic compounds, a process referred to as illuviation.

- C-Horizon (Parent rock): Layer of large unbroken rocks. This layer may accumulate the more soluble compounds.
- R-Layer (bedrock): R horizons denote the layer of partially weathered bedrock at the base of the soil profile. Unlike the above layers, R horizons largely comprise continuous masses (as opposed to boulders) of hard rock that cannot be excavated by hand. Soils formed *in situ* will exhibit strong similarities to this bedrock layer.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain what the letters; O, A, E, B, C, and R associated with master horizons stand for.
2. What do you understand by transitional horizons?
3. Briefly explain what you know about subsurface diagnostic horizons.
4. List and briefly explain 10 distinctive features (letter suffixes) that can be used to describe master horizon.

7.0 REFERENCE/FURTHER READING

https://en.wikipedia.org/wiki/Soil_horizon

UNIT 3 SOIL COLOUR

CONTENTS

1.0 INTRODUCTION

Among other soil physico-chemical properties, soil color, texture, structure, and consistence are used to distinguish and identify soil horizons (layers) and to group soils according to the soil classification system called *Soil Taxonomy*. Color development and distribution of color within a soil profile are part of weathering. As rocks containing iron or manganese weather, the elements oxidize. Iron forms small crystals with a yellow or red color; organic matter decomposes into black humus, and manganese forms black mineral deposits. Colour is also affected by the environment: aerobic environments produce sweeping vistas of uniform or subtly changing color, and anaerobic (lacking oxygen), wet environments disrupt color flow with complex, often intriguing patterns and points of accent. With depth below the soil surface, colors usually become lighter, yellower, or redder. The Munsell System allows for direct comparison of soils anywhere in the world.

The system has three components: hue (a specific color), value (lightness and darkness), and chroma (color intensity) that are arranged in books of color chips. Soil is held next to the chips to find a visual match and assigned the corresponding Munsell notation. For example, a brown soil may be noted as: hue value/chroma (10YR 5/3). With a soil color book with Munsell notations, a science student or teacher can visually connect soil colors with natural environments of the area, and students can learn to read and record the color, scientifically. Soil colour by Munsell notation is one of many standard methods used to describe soils for soil survey. Munsell color notations can be used to define an archeological site or to make comparisons in a criminal investigation. Even carpet manufacturers use Munsell soil colors to match carpet colors to local soils so that the carpet will not show the dirt (soil) tracked into the house.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- examine how colour is impacted on the soil during soil forming processes
- discuss how to use soil colour to determine the soil horizon boundaries in a standard profile pit.
- explain how to use the Munsell colour chart to determine soil colours.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Colour reflects an integration of chemical, biological and physical transformations and translocations that have occurred within a soil.
ii. Soil organic matter imparts a dark brown to black color to the soil.
iii. Subsoil color reflects more strongly in most soils the imprint of physico-chemical processes.
iv. Colors associated with minerals inherited from parent materials may also influence color in horizons that have not been extensively weathered.
v. Soil color can provide information about subsoil drainage and the soil moisture conditions of soils.
vi. Through the use of the Munsell Soil Color Charts, practitioners from a wide range of professions can share reliable and consistent information about the color of soils at a particular site with colleagues anywhere around the world.
vii. The system of Munsell colour chart has three components: hue (a specific color), value (lightness and darkness), and chroma (color intensity) that are arranged in books of color chips.

3.2 Soil Colour

Colour reflects an integration of chemical, biological and physical transformations and translocations that have occurred within a soil. In general, colour of surface horizons reflects a strong imprint of biological processes, notably those influenced by the ecological origin of soil organic matter (SOM). Soil organic matter imparts a dark brown to black colour to the soil. Generally, the higher the organic, matter content of the soil, the darker the soil. A bright-light color can be related to an eluvial horizon, where sequioxides, carbonates and/or clay minerals have been leached out.

Subsoil colour reflects more strongly in most soils the imprint of physico-chemical processes. In particular, the redox status of Fe and to a lesser extent Mn, strongly influence the wide variation found in subsoil color. Soil color can provide information about subsoil drainage and the soil moisture conditions of soils. In well aerated soils, Fe^{3+} is present which give soil a yellow or redish colour. In more poorly drained soils (anaerobic conditions) iron compounds are reduced and the neutral gray colors of Fe^{2+} or bluish-green colours of iron sulfides, iron carbonates, or iron phosphates are visible.

A black colour in the subsoil can be related to all accumulation of manganese. In arid and semi-arid environments, the influence of soluble salts (carbon ales, sulfates, chlorides etc.) may impart a strong influence on soil color. For example, in arid or sub-humid regions, surface soils may be white due to evaporation of water and soluble salts.

Colours associated with minerals inherited from parent materials may also influence colour in horizons that have not been extensively weathered. For example, light gray or nearly while colours is sometimes inherited from parent material, such as marl or quartz. Parent material, such as basalt, can imprints a black colour to the subsoil horizons.

Table 2: Soil Colours Associated with Soil Attributes

Soil Colour	Soil Attribute	Environmental Conditions
Brown to black (surface horizon)	Accumulation of Organic matter (OM), humus	low temperature, high annual precipitation amounts, soils high in soil moisture, and /or litter from coniferous trees favor an accumulation of OM
Black(subsurface horizon)	Accumulation of manganese Parent material (e.g. basalt)	
Bright-light	Eluvial horizon (E horizon)	In environments where precipitation > evapotranspiration there is leaching of sequioxides, carbonates, and silicate clays.

		The eluviated horizons consist mainly of silica.
Yellow to reddish	Fe^{3+} (oxidized iron)	Well-aerated soils
Gray, bluish-green	Fe^{2+} (reduces iron)	Poorly drained soils (e.g. subsurface layer with a high bulk density causes water logging, or a very fine textured soil where permeability is very low), anaerobic environmental conditions.
White to gray	Accumulation of salts	In arid or sub-humid environments where the evapotranspiration > precipitation there is an upward movement of water and soluble salts in the soil.
White to gray	Parent material: marl, quartz.	

Soil colour is usually registered by comparison of a standard colour chart (Munsell Book or Colours). The Munsell notations distinguish three characteristics of the colour, Hue, value, and chroma.

i. **Hue:** It is the dominant spectral color, i.e., whether the hue is pure color such as yellow, red, green, or a mixture of pure colours.
ii. **Value:** It describes the degree of lightness or brightness of the hue reflected in the property or the gray color that is being added to the hue.
iii. **Chroma:** It is the amount of a particular hue added to a gray or the relative purity of the hue.

3.3 The Munsell Soil Colour Chart

The Munsell Soil Colour Charts is an affordable way to evaluate the type of soil that is present within a given area. The book is set up to allow users to make soil color evaluations in the field quickly and easily. The soil classification system that has been developed around the Munsell colour system is an established and accepted process to assign a soil type. This classification system has been used in the United States for more than 55 years to aid in the management and stewardship of natural resources. Through the use of the Munsell Soil Colour Charts, practitioners from a wide range of professions can share reliable and consistent information about the color of soils at a particular site with colleagues anywhere around the world.

The Munsell Soil Colour Charts are used by a variety of industries and professions such as universities and high schools, forestry, forensics, environmental and soil science, building and contracting, landscaping, real estate, health departments, geology and archaeology.

The following pages are included in the Munsell Soil Colour Charts: Munsell 10R Soil Chart, Munsell 10YR Soil Chart, Munsell 2.5Y Soil Chart, Munsell 2.5YR Soil Chart, Munsell 5Y Soil Chart, Munsell 5YR Soil Chart, Munsell 7.5YR Soil, 10Y - 5GY Colors - Olive greens Soil Chart, Gley 1 & 2 (2 - Separate Charts) Soil Charts, Munsell 5R Individual Soil Chart, Munsell 7.5R Individual Soil Chart, White Page, 7.5R, 10YR, & 2.5Y.

Fig. 6a: Munsell Soil Color Chart

Fig. 6b: Soil Scientist using Munsell Colour Chart to detect soil colour

The soil colours are given in the order: hue, value, and chroma. For example, 2.5YR 4/2 describes the hue 2.5YR, dark-grayish brown with a value 4 and a chroma of 2. It should be stressed that soil colour is dependent on soil moisture, hence if soil color is recorded also the soil moisture conditions have to be described (e.g. soil color dry, soil colour wet). In the upper mid-west and other humid areas, colours are conventionally recorded moist. This convention may differ in other climatic regimes.

Many soils have a dominant soil color. Other soils, where soil forming factors vary seasonally (e.g. wet in winter, dry in summer) lend to exhibit a mixture of two or more colors. When several colors are present the term **mottling or redoximorphic features (RMF)** is used. In such a case, several soil colours have to be recorded, where the dominant colour is first, following by a description of the abundance, size, and contrast of the other colours in the mottled pattern. Mottling/RMFs are described by three characteristics: contrast, abundance, and size of area of each colour.

Redoximorphic features me a colour pattern in a soil due to loss (depletion) or gain (concentration) of pigment compared to the matrix color. H is formed by oxidation I reduction of Fe and/or Mn coupled with their removal and translocation or a soil matrix colour controlled by the presence or Fe^{2+}. RMFs are described separately from other mottles or concentrations! Based on the Field Book for Describing and Sampling Soils (Schoeneberger*et al.*, 1998) RMFs are described in terms of kind, colour and contrast, quantity, size, shape, location, composition and hardness, and boundary. RMFs occur in the soil matrix, all or beneath the surface of peds, and as filled pores, linings of pores, or beneath the surface of pores.

Mottles are areas of color that differ from the matrix color. These colors are commonly lithochromic or lithomorphic attributes retained from the geologic source rather than from pedogenesis. Mottles exclude RMFs and peel & void surface features (e.g. clay films). Based on the Field Book for Describing and Sampling Soils (Schoeneberger*el al.*, 1998) mottles are described in terms of quantity, size, color & contrast, moisture state, and shape. Example: Few, medium, distinct, reddish yellow (7.5YR 7/8), irregular mottles.

However, a variety of other features in a horizon may have colors different from the matrix, such as infillings of animal burrows (krotovinas), clay coatings (argillans) and precipitates of calcium carbonate. In all instances where specific soil features are described, the shape and spatial relationships of the feature (i.e.., where is it located, on a ped face, in the matrix ...) to adjacent features should be described in addition to its color, abundance, size and contrast.

Table 3: RMFs/Mottles in Soils are described in term of Abundance, Size, and Contrast

Abundance	**Abbreviation**	**% of the Exposed Surface**
Few	f	< 2
Common	c	2 – 20
Many	m	20 – 40
Very many	v	> 40
Size	**Abbreviation**	**Diameter (mm)**
Fine	1	< 5 mm
Medium	2	5 – 15 mm
Coarse	3	> 15 mm
Contrast	**Abbreviation**	**Visibility**
Faint	F	Difficult to see, hue, and chroma of matrix and mottles closely related
Distinct	D	Readily seen, matrix and mottles vary 1 – 2 hues and several units in chroma and value
Prominent	P	Conspicuous, matrix and mottles vary several units in hue, value, and chroma

4.0 CONCLUSION

Colour development and distribution of colour within a soil profile are part of weathering. As rocks containing iron or manganese weather, the elements oxidize. Iron forms small crystals with a yellow or red colour; organic matter decomposes into black humus, and manganese forms black mineral deposits. These pigments paint the soil into different colours we observe in the soil. With a soil color book with Munsell notations, a science student or teacher can visually connect soil colours with natural environments of the area, and you can learn to read and record the colour scientifically.

5.0 SUMMARY

The Munsell notations distinguish three characteristics of the colour, hue, value, and chroma. **Hue** is the dominant spectral colour, i.e., whether the hue is pure colour such as yellow, red, green, or a mixture of pure colours. **Value** describes the degree of lightness or brightness of the hue reflected in the property or the gray colour that is being added to the hue. **Chroma** is the amount of a particular hue added to a gray or the relative purity of the hue.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by Redoximorphic features/mottles in soil colour formation?
2. Who can use the Munsell Colour Chart? Briefly describe the Munsell Colour Chart. How is it used?
3. In tabular form, mention soil colours as well as its associated soil attributes.

7.0 REFERENCES/FURTHER READING

Bradv, N.C. & Weil, R.R. (2006). *The Nature and Properties of Soil*. (13^{th} ed.) New Jersey: Prentice Hall Inc.

Schoeneberger, P.J., Wysocki, D. A. Benham, E. C. & Broderson, W. D. (1998). "Field Book for Describing and Sampling Soils." USDA Natural Resources Conservation Service, Lincoln, NE; Online: http//www.statlab.iastate.edu/soils nssc/field_gd/field_gd.htm.

UNIT 4 SOIL TEXTURE

CONTENTS

1.0 INTRODUCTION

Soil is composed of three important primary particles namely; sand (2-0.02 mm), silt (0.02 – 0.002 mm) and clay (<0.002 mm). These particles are usually clustered together to form secondary particles or aggregates. They also bind themselves together alongside organic matter and other minerals in different proportions to form different types of soil such as loamy soil which contains 40% sand, 40% silt and 20% clay. Sand feels gritty between fingers and the particles are generally visible to the naked eyes. Since soil particles are relatively large, their pore spaces between them are wider and promotes faster drainage of water into and out of the soil profile and exchange of gases with the atmosphere. Silt particles are smooth and silky like flour having smaller pores between them and can retain more water for a longer period of time. The clay particles have a larger specific surface area and higher capacity to absorb water and other substances. Clay particles feel sticky or plastic when rubbed in between fingers under moist condition. There are three major methods of determining soil texture of the soil. The feel method, hydrometer method and pipette method. While the feel method is usually employed under field or *in situ* analysis condition, hydrometer and pipette methods are employed in a laboratory analysis. The pipette method has been proven to be most accurate.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss what soil texture is all about

- explain the importance of soil texture to soil fertility and productivity
- use the textural triangle to find out the texture of any given soil.

3.0 MAIN CONTENT

3.1 Soil Textural Classification

Texture refers to the amount of sand, silt, and clay in a soil sample. The distribution of particle sizes determines the soil texture, which can be assessed in the field or by a particle-size analysis in the laboratory. A field analysis is carried out in the following way: a small soil sample is taken, water is added to the sample, it is kneaded between the fingers and thumb until the aggregates are broken down. The guidelines to determine the particle class are as following:

i. **Sand:** Sand particles are large enough to grate against each other and they can be detected by sight. Sand shows no stickiness or plasticity when wet.
ii. **Silt:** Grains cannot be detected by feel, but their presence makes the soil feel smooth and soapy and only very slightly sticky.
iii. **Clay:** A characteristic of clay is the stickiness. If the soil sample can he rolled easily and the sample is sticky and plastic when wet (or hard and cloddy when dry) it indicates a high clay content. Note that a high organic matter content tends to smoothen the soil and can influence the feeling for clay.

Table 4: Soil Texture Classes

Soil Texture	Abbreviation
Gravel	G
Very Coarse sand	Vcos
Coarse sand	Cos
Sand	S
Fine sand	Fs
Very fine sand	Vfs
Loamy coarse sand	Lcos
Loamy sand	Ls
Loamy fine sand	Lfs
Sandy loam	Sl
Fine sandy loam	Fsl
Very fine sandy loam	Vfsl
Gravelly sandy loam	Gsl
Loam	L

Gravelly loam	Gl
Stony loam	Stl
Silt	Si
Silt loam	Sil
Clay loam	Cl
Silty clay loam	Sicl
Sandy clay loam	Scl
Stony clay loam	Stcl
Silty clay	Sic
Clay	c

A variety of systems are used to define the size ranges of particles, where the ranges of sand, silt and clay that define a particle class differs among countries. In the U.S. the soil texture is classified based on the U.S.D.A. system. The classification or particle sizes are as follow:

i. Sand (2-0.02 mm),
ii. Silt (0.02 – 0.002 mm) and
iii. Clay (<0.002 mm)

Soil texture in the field is determined using a texture triangle (Figure 9). For example, a particle size distribution of 33 % clay, 33 % silt, and 33 % sand would result in the soil texture class 'clay loam'.

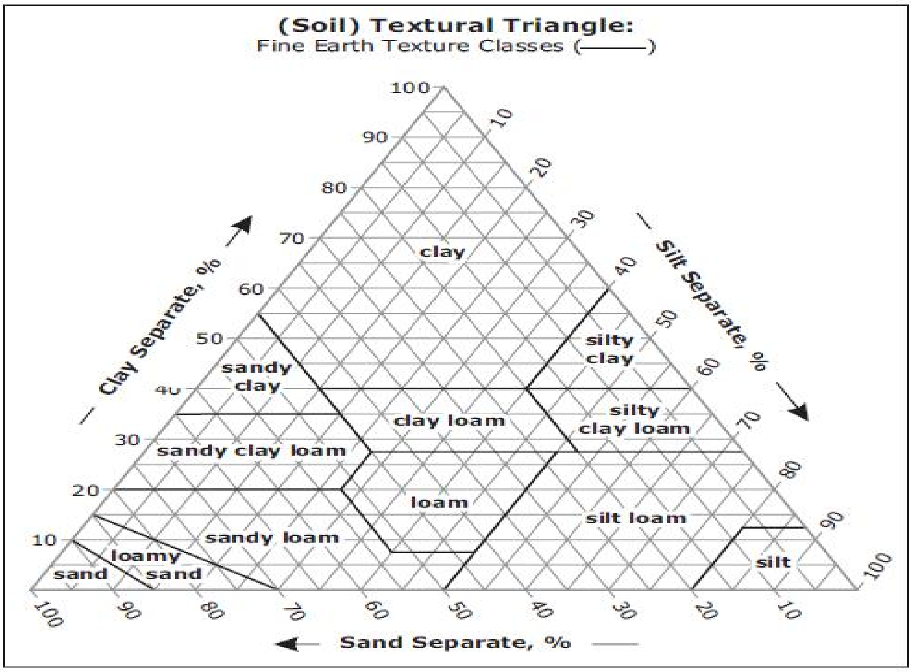

Fig. 7: Triangular Diagram of Soil Textural Classes (USDA Triangle)

Particles greater than 2 mm are removed from a textural soil classification. The presence of larger particles is recognised by the use of modifiers added to the textural class (e.g. gravelly, cobbly, stony) (Table 5 and 6).

Table 5: Terms for Rock Fragments

Shape and Size (mm)	**Adjective**
Spherical and Cubelike:	xxx
2 – 75	Gravelly
2 – 5	Fine gravelly
5 – 20	Medium gravelly
20 – 75	Coarse gravelly
75 – 250	Cobbly
250 – 600	Stony
> 600	Bouldery
Flat:	
2 – 150	Channery
150 – 380	Flaggy
380 – 600	Stony
> 600	Bouldery

Table 6: Modifier for Rock Fragments

Rock Fragments by Volume (%)	**Adjectival Modifier**
< 15	No modifier
15 – 30	Gravelly loam
30 – 60	Very flaggy loam
> 60	Extremely bouldery loam

3.2 Significance of Soil Texture

The fine and medium-textured soils (e.g. clay loams, silly clay loams, sandy silt loams) are favorable from an agricultural viewpoint because of their high available retention of water and exchangeable nutrients. In fine pores the water is strongly adsorbed in pores but not available for plants, i.e. cohesion and adhesion water occupy the micropore space and they are retained in soil by' forces that exceed gravity. In medium-sized pores the available water content is high, whereas in macropores water is more weakly held and percolation is high (gravitational water). In silty soils the distribution of macropores, medium-sized, and fine pores is optimal relating to available water content.

3.3 Importance of Soil Texture

a. The structure of the soil is an important parameter in determining the physical fertility of the soil which is a function of texture. The fine textured soil has a more stable structure with plenty of micro-pores which helps retain more water and less air in the soil, but coarse textured soils have more macro-pores which allows water pass through it very fast.
b. The finer textured soil retains more nutrients on their surfaces through adsorption thereby reducing losses by leaching. The cation exchange capacity of the soil which is a very important tool in determining the availability of nutrients to plants is a function of texture.
c. The workability of the soil is a function of soil texture. The heavier or lighter a texture is will determine the amount of energy required to cultivate the soil.
d. Most soil physical and chemical properties of the soil are a function of soil texture, either directly or indirectly
e. Soils with finer particles gets waterlogged during excessive rains or irrigation and leads to aeration stress to plants with the result that they are not able to take up water and nutrients which are present in the soil in sufficient amounts

3.4 How Textures Relates with Soil Fertility

i. Soil fertility is maintained through various chemical reactions in the soil, which are influenced by microorganisms. These tend to grow and colonize particles surfaces. Microbial reactions are therefore greatly affected by the specific surface area.
ii. The fertility of soil is a function of moisture, fine textured soils, which retain more water for longer period of time, are more fertile than the coarse textured soils. Soils with appreciable amount of primary particles are more fertile.
iii. The retention of nutrients and water on the surface of solids is a function of surface area of the minerals. The leaching of nutrients also is a function of soil texture.
iv. The greater the surface area of a soil, the greater the rate of release of plant nutrients.

Table 7: Pore size distribution in soils different in Texture (Scheffer*et al.*, 1989)

Soil Different in Texture	Pore Volume (%)	Macropores (%)	Medium-Size Pores (%)	Mivropores (%)
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)

4.0 CONCLUSION

As we know, coarse-textured soils permit rapid infiltration because of the predominance of large pores, while the infiltration rates of finer-textured soils are smaller because of the predominance of micropores. Other factors, like the compaction of the soil, management practices, vegetation, saturation of the soil have also a significant impact on infiltration and have to be considered. Soil texture has an impact on soil temperature. Fine-textured soils hold more water than coarse-textured. soils, which considering the differences in the specific heat capacity results in a slow response of warming up of fine-textured soils compared to coarse-textured soils.

5.0 SUMMARY

Many important chemical and biological properties of soil particles are functions of particle size and hence surface area. That is to say, with decreasing particle size the surface area increases. For example, the adsorption of cations (nutrients) or the microbial activity is dependent on surface area.

6.0 TUTOR-MARKED ASSIGNMENT

1. State the three methods of texture determination, give the one normally during filed activities.
2. What are the three main components of texture? How do they affect soil moisture retention?
3. Mention five importance of texture to agricultural productivity.
4. How can you determine sand, silt and clay by feel method in the field?

7.0 REFERENCES/FURTHER READING

Scheffer F. & Sehachtschabel P. (1989). Lehrbuch der Bodenkunde. Enke - Verlag Stuttgart.

https://www.scribd.com/doc/26537848/importa

UNIT 5 SOIL STRUCTURE

CONTENTS

1.0 INTRODUCTION

Structure refers to the arrangement of soil particles. Soil structure is the product of processes that aggregate, cement, compact or unconsolidated soil material. The peds are separated from the adjoining peds by surfaces of weakness. To describe structure in a soil profile it is best to examine the profile standing some meters apart to recognize larger structural units (e.g. prisms). The next step is to study the structure by removing soil material for more detailed inspection. It should be stressed that soil moisture affects the expression of soil structure. The classification of soil structure considers the grade, form, and size of particles. Soil structure describes the arrangement of the solid parts of soil and of the pore spaces located between them. It is determined by how individual soil granules clump, bind together and aggregate, resulting in the arrangement of solid pores between them. Soil structure has a major influence on water and air movement, biological activity, root growth and emergence of seedling.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- classify structure into grade, form and sizes
- discuss how structure is formed in the soil and its influence on biological activities, root growth, water and air movement.

3.0 MAIN CONTENT

3.1 Soil Structure

Soil structure is a physical condition that is distinct from that of the initial material from which it formed, and can be related to processes of soil formation. Soil structure is measured in grade, form and size. The grade describes the distinctiveness of the peds (differential between cohesion within peds and adhesion between peds). It relates to the degree of aggregation or the development of soil structure. In the field a classification of grade is based on a finger test (durability of peds) or a crushing of a soil sample.

The form is classified on the basis of the shape of peds, such as spheroidal, platy, blocky, or prismatic. A granular or crumb structure is often found in A horizons, a platy structure in E horizons, and a blocky, prismatic or columnar structure in Bt horizons. Massive or single-grain structure occurs in very young soils, which are in an initial stage of soil development. Another example where massive or single-grain structure can be identified is on reconstruction sites. There may two or more structural arrangements occur in a given profile. This may be in the form of progressive change in size/type of structural units with depth (e.g. A horizons that exhibit a progressive increase in size of granular peds that grade into sub-angular blocks with increasing depth) or occurrence of larger structural entities (e.g. prisms) that are internally composed of smaller structural units (e.g. blocky peds). In such a case all discernible structures should be recorded (i.e. more rather than less detail).

The size of the particles has to be recorded as well, which is dependent on the form of the peds.

Table 8a: Classification of Soil Structure considering Grade, Size, and Form of Particles

Grade	Abbreviation	Description
Structureless	0	No observable aggregation or no orderly arrangement of natural lines of weakness
Weak	1	Poorly formed indistinct peds
Moderate	2	Well-formed distinct peds, moderately durable and evident, but not distinct in undisturbed soil.
Strong	3	Durable peds that are quite evident in undisplaced soil, adhere weakly to one

		another, withstand displacement, and become separated when soil is disturbed.
Form	**Abbreviation**	**Description**
Granular	Gr	Relatively nonporous, spheroidal peds, not fitted to adjoining peds
Crumb	Cr	Relatively porous, spheroidal peds, not fitted to adjoining peds
Platy	Pl	Peds are plate-like. The particles are arranged about a horizontal plane with limited vertical development. Plates often overlap and impair.
Blocky	Bk	Block-like peds bounded by other peds whose sharp angular faces form the cast for the ped. The peds often break into smaller blocky peds.
Angular Blocky	Abk	Block-like peds bounded by other peds whose sharp angular faces form the cast for the ped
Sub-angular Blocky	Sbk	Block-like peds bounded by other peds whose rounded subangular faces form the cast for the ped
Prismatic	Pr	Column-like peds without rounded caps. Other prismatic caps form the cast for the ped. Some prismatic peds break into smaller blocky peds. In these peds the horizontal development is limited when compared with the vertical
Columnar	Cpr	Column-like peds with rounded caps bounded laterally by other peds that form the cast for the peds. In these peds the horizontal development is limited when compared with the vertical.
Single grain	Sg	Particles show little or no tendency to adhere to other particles. Often associated with very coarse particles.
Massive	M	A massive structure shows little or no tendency to break apart under light pressure into smaller units. Often associated with very fine-textured soils.
Size	**Abbreviation**	
Very fine	Vf	
Fine	F	

Medium	M	
Coarse	C	
Very Coarse	Vc	

Table 8b: Showing Classification of Sizes of structure

Size	**Angular and Subangular Blocky Structure (mm) diameter**	**Granular and Crumb Structure (mm) diameter**	**Platy Structure (mm) diameter**	**Prismatic and Columnar Structure (mm) diameter**
Very fine	< 5	< 1	< 1 (Very thin)	< 10
Fine	5 – 10	1 – 2	1 – 2 (Thin)	10 – 20
Medium	10 – 20	2 – 5	2 – 5	20 – 50
Coarse	20 – 50	5 – 10	5 – 10 (Thick)	50 – 100
Very Coarse	> 50	> 10	> 10 (Very thick)	> 100

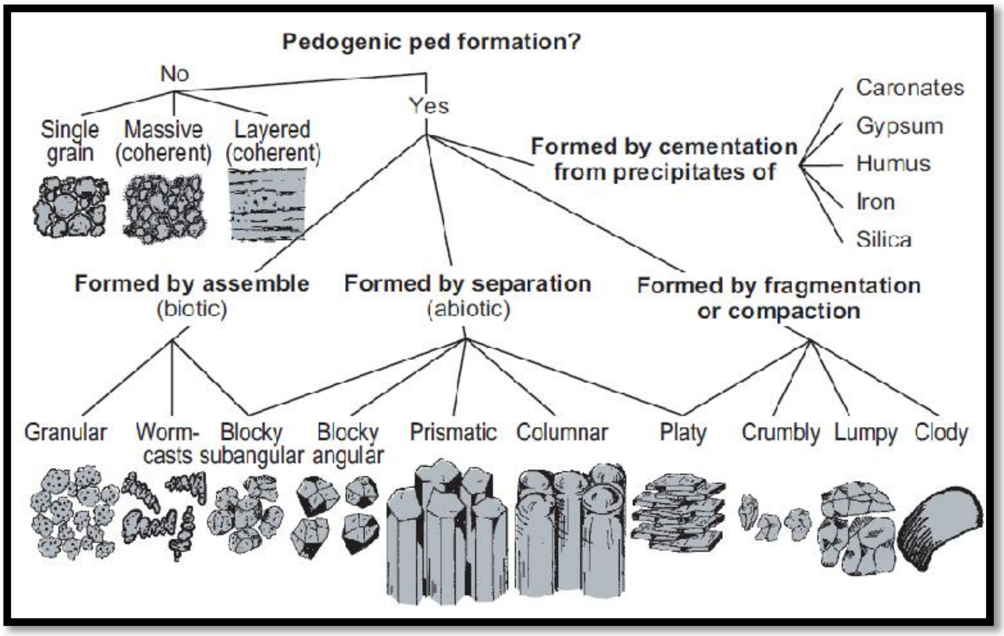

Fig. 8:Soil structure types and their formation
Source: (FAO, 2006)

The three characteristics of soil structure are conventionally written in the order grade, size and shape. For example, weak fine sub-angular blocky structure.

The distribution of different particle sizes in a soil influence the distribution of pores, which can be characterized by their abundance, size and shape.

Table 9: Abundance, Size, and Shape of Pores

Abundance	**Per Unit Area**
Few	< 1
Common	1 – 5
Many	> 5
Size	**Diameter (mm)**
Very fine	< 0.5
Fine	0.5 – 2.0
Medium	2.0 – 5.0
Coarse	> 5.0
Shape	
Vesicular approx, spherical or elliptical	
Tubular approx. cylindrical or elongated	
Irregularly shaped	

3.2 Significance of Soil Structure

i. Soil formation starts with a structureless condition, i.e., the structure is single-grained or massive. Soil development also means development of soil structure, which describes the formation of peds and aggregates. Soil structure forms due to the action of forces (hat push soil particles together. Subsurface structure lends lo be composed of larger structural units than the surface structure. Subsoil structure also tends to have the binding agents on ped surfaces rather than mixed throughout the ped.

ii. Climatically-driven physical processes that result in changes in the amount, distribution and phase (solid, liquid, and vapor) of water exert a major influence on formation of soil structure. Phase changes (shrinking-swelling, freezing-thawing) result in volume changes in the soil, which over time produces distinct aggregations of soil materials.

iii. Physico-chemical processes (e.g., freeze-thaw, wet-dry, clay translocation, formation/removal of pedogenic weathering products) influence soil structure formation throughout the profile. However, the nature and intensity of these processes varies with depth below the ground surface. The structure and hydrological function of plant communities, texture, mineralogy, surface manipulation and topography all serve to modify local climatic effects through their influence on infiltration, storage and evapo-transpiration of water.

iv. Biological processes exert a particularly strong influence on formation of structure in surface horizons. The incorporation of soil organic matter is usually largest in surface horizons. Soil organic matter serves as an agent for building soil aggregates, particularly the polysaccharides appear to be responsible for the formation of peds. Plant roots exert compactive stresses on surrounding soil material, which promotes structure formation. Soil-dwelling animals (e.g., earth worms, gophers) also exert compactive forces, and in some cases (e.g., earth worms) further contribute to structure formation via ingestion/excretion of soil material that includes incorporated organic secretions.

v. CONCLUSION

Aggregation of soil particles can occur in different patterns, leading to the formation of different structures. Soil structure is mostly usually described in terms of grade (degree of aggregation), form (type of aggregates) and class (average size). In some soils, different type of aggregates may be found together and they are then described separately. The characteristics of structure of a soil can be recognized best when the soil is dry or slightly moist. Make sure you use freshly dug profile pit when you are studying the grade, form and size of structure.

4.0 SUMMARY

Soil structure is measured in grade, form and size. The grade describes the distinctiveness of the peds (differential between cohesion within peds and adhesion between peds). The form is classified on the basis of the shape of peds, such as spheroidal, platy, blocky, or prismatic. The size of the particles has to be recorded as well, which is dependent on the form of the peds.

5.0 TUTOR-MARKED ASSIGNMENT

1. What is soil structure?
2. How can you classify the structure of a given soil into grade, form and size?
3. Discuss four significances of structure in agricultural productivity.
4. With the aid of a diagram, sketch four forms of structure you know.

7.0 REFERENCE/FURTHER READING

Foth, H.D. (1984). *Fundamentals in Soil Science*. John Wiley & Sons, Inc.

UNIT 6 SOIL CONSISTENCE, ROOTS, pH AND EFFERVESCENCE AND SPECIAL FEATURES

CONTENTS

1.0 INTRODUCTION

In the course field study of soil or soil morphological study, in addition to all the parameters mentioned in this module as discussed previously, soil consistence, roots, pH and effervescence and special features are also studied. Soil consistence is the strength with which soil materials are held together or the resistance of soil to deformation and rupture; it is measured for wet, moist and dry soil samples. Roots abundance in the different genetic horizons is also measured. This is intended to know the rate of agricultural activities taking place in that soil. The type of plant/crop growing on a particular soil will determine the root density and presence or abundance down the soil profile as one study the soil horizons.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss what soil consistence, roots abundance, pH and effervescence, special features and concentrations stands for in soil morphology study.

3.0 MAIN CONTENT

3.1 Consistence

Consistence refers to the cohesion among soil particles and adhesion of soil to other substances or the resistance of the soil to deformation. Whereas soil structure deals with the arrangement and form of peds, consistence deals with the strength and nature of the forces between particles. Consistence is described for three moisture levels: wet, moist, and dry. The stickiness describes the quality of adhesion to other objects and the plasticity the capability of being molded by hands. Wet consistence is when the moisture content is at or slightly more than field capacity. Moist consistence is a soil moisture content between field capacity and tile permanent wilting point. When recording consistence, it is important to record the moisture status as well. Cementation is also considered when consistence is described in the field. Cementing agents are calcium carbonate, silica, oxides or iron and aluminum.

Table 10: Classification of Consistence (Buol*et al.*, 1997)

Moisture Status	Consistence	Abbreviation	Description
Wet	Non-sticky	Wso	Almost no natural adhesion of soil material to fingers
	Slightly Sticky	Wss	Soil material adheres to only one finger
	Sticky	Ws	Soil material adheres to both fingers
	Very Sticky	Wvs	Soil material strongly adheres to both fingers
	Non-plastic	Wpo	No wire is formable by rolling material between the hands
	Slightly Plastic	Wps	Only short (< 1cm) wires are formed by rolling material between the hands
	Plastic	Wp	Long wires (> 1cm) can be formed and moderate pressure is needed to deform a block of the molded material

	Very Plastic	Wvp	Much pressure is needed to deform a block of the molded material
Moist	Loose	Ml	Soil Material is noncoherent
	Very Friable	Mvfr	Aggregates crush easily between thumb and finger
	Friable	Mfr	Gentle pressure is required to crush aggregates
	Firm	Mfi	Moderate pressure is required to crush aggregates
	Very Firm	Mvfi	Strong pressure is required to crush aggregates
	Extremely Firm	mefi	Aggregates cannot be broken by pressure
Dry	Loose	Dl	
	Soft	Ds	
	Slightly Hard	Dsh	
	Hard	Dh	
	Very Hard	Dvh	
	Extremely Hard	Deh	
Cementation	Weakly cemented	Cw	
	Strongly cemented	Cs	
	Indurated	Ci	

3.2 Roots

Plant roots give evidence of the plant root activity and the penetration. For example, it is important to record if roots only penetrate through cracks, are retarded by waterlogged layers or cemented layers. Other reasons for limited root penetration can be soil compaction or the absence of nutrients. If there is no obstacle to root growth in the soil the roots may he distributed evenly in a soil. It is important to record the quantity and diameter of roots.

Table 11: Classification of Roots

Root Quantity Classes	**Per Unit Area**
Very few	< 0.2
Moderately few	0.2 to 1
Few	< 1
Common	1 to < 5
Many	> = 5
Size Classes of Roots	**Diameter in mm**
Very fine	< 1
Fine	1 – 2
Medium	2 – 5
Coarse	5 – 10
Very Coarse	> 10

3.3 pH and Effervescence

The acidity of a soil can be tested using a simple field test set for fast pH determination. The pH is important for the pH dependent charge of silicates and organic material, therefore for the cation exchange capacity. Furthermore, the pH determines which buffering system is active, i.e. how soils can cope with additional H^+ ions. For example, buffering systems are carbonates, organic matter, silicates, or Iron and Aluminiumoxihydroxides.
Using HCl on a small soil sample the reaction (effervescence) can give clues of the calcium carbon content in the sample.
$2\ HCl + CaCO_3 \leftrightarrow CaCl_2 + H_2CO_3$ (effervescence)

3.4 Special Features

Special features occur is soils which should be recorded additionally. Ped exteriors include clay coats, organic matter coats, silt coats, sand coats, carbonate coats, manganese coats, slickensides, stress surfaces, and clay bridges between sand grains. Ped interiors include concentrations of oxides, nodules, soft accumulations, pseudo-rock fragments, plinthite, and streaks. In particular, concretions are resulting from alternate periods of reducing and oxidizing regimes. Another special feature might be the evidence of animal activity by burrowing animals or high earthworm activity.

3.4.1 Concentrations

Def: Soil features that form by accumulation of material during pedogenesis. Processes involved: Chemical dissolution/precipitation, oxidation and reduction, physical and/or biological removal, transport and accumulation.

Types:

i. **Finely disseminated Materials:** Small precipitates (e.g. salts, carbonates) dispersed throughout the matrix of a horizon concentrations.
ii. **Masses:** Non-cemented bodies of accumulation of various shapes that cannot be removed as discrete units (e.g. crystalline salts).
iii. **Nodules:** Cemented bodies of various shapes that can be removed as discrete units from soil.
iv. **Concretions:** Cemented bodies similar to nodules, except for the presence of visible, concentric layers of material around a point, line or plane.
v. **Crystals:** macro-crystals form of relatively soluble salts (e.g. gypsum, carbonates) that form in situ by precipitation from soil solution.
vi. **Biological Concentrations:** Discrete bodies accumulated by a biological process (e.g. fecal pellets, insect casts).

Ped and Surface Features

These features are coats/films or stress features formed by translocation and deposition, or shrink-swell processes on or along surfaces. They are described in terms of kind, amount, continuity, distinctness, location and color.

Examples: Ferriargillans (Fe^{3+} stained clay films), Mangans (black, thin films of Mn)

4.0 CONCLUSION

Consistence is described for three moisture levels: wet, moist, and dry. The stickiness describes the quality of adhesion to other objects and the plasticity the capability of being molded by hands. Root abundance, pH and effervescence and special features are also studied.

5.0 SUMMARY

Soil consistence, root abundance, pH and effervescence and special features are among the vital morphological properties of soil to be studied in the field.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand be soil consistence and what are the three moisture conditions on which it is determined?

2. Mention and briefly explain six types of concentrations you know under special features of soil.
3. Explain the two major heading upon which soil roots are classified.

7.0 REFERENCE/FURTHER READING

Buol, S.W., Hole, F.D., McCracken, R.J., & Southard, R.J. (1997). *Soil Genesis and Classification.* Iowa State University Press.

MODULE 4 SOIL SAMPLING AND ANALYSIS, SOIL CORRELATIONS, SOIL SURVEY REPORT WRITING, INTERPRETATIONS AND LAND EVALUATION

UNIT 1 SOIL SAMPLING AND ANALYSIS

1.0 INTRODUCTION

The results of even very carefully conducted soil analyses can only be as good as the soil samples themselves. Thus, the efficiency of a soil testing service depends on the care and skill with which soil samples are collected. Non-representative samples constitute the largest single source of error in a soil fertility programme.

The most important phase of soil analysis takes place not in the laboratory but in the field where the soil is sampled. Soils vary from place to place. In view of this, efforts should be made to take the samples in such a way that they are fully representative of the field. Composite sampling can be performed by combining soil from several locations prior to analysis. This is a common procedure, but should be used judiciously to avoid skewing results. This procedure must be done so that government sampling requirements are met. A reference map should be created to record the location and quantity of field samples in order to properly interpret test results. Only 1–10 g of soil is used for each chemical determination and this sample needs to represent as accurately as possible the entire surface 0–22 cm of soil, weighing about 2 million kg/ha.

Soil test commonly refers to the analysis of a soil sample to determine nutrient content, composition, and other characteristics such as the acidity or pH level. This will enable a pedologist to be able to give adequate information in his soil survey report. Note that after soil morphological determinations in the field, every other soil parameter will be determined in a standard soil laboratory. Essential plant nutrients such as N, P, K, Ca, Mg and S are called macronutrients, while Fe, Zn, Cu, Mo, Mn, B and Cl are called micronutrients. Some physical properties such as bulk density, soil texture (pipette or hydrometer method), moisture content and so on are also determined in the laboratory. A soil test can determine fertility, or the expected growth potential of the soil which indicates nutrient deficiencies, potential toxicities from excessive fertility and inhibitions from the presence of non-essential trace minerals. The test is used to mimic the function of roots to assimilate minerals. The expected rate of growth is modeled by the Law of the Maximum.

Tap water or chemicals can change the composition of the soil, and may need to be tested separately. As soil nutrients vary with depth and soil components change with time, the depth and timing of a sample may also affect results.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss soil sampling and its procedures
- explain what soil analysis is all about
- analyse how samples can be handled for a more accurate result.

3.0 MAIN CONTENT

3.1 Important Facts to Know

i. Soil is analysed to determine its ability to supply the necessary plant nutrients to the crop concerned.

ii. Soil analyses are related to potential nutrient uptake, supplementation of plant nutrients through fertilisation and the target yield.
iii. From plant nutrient research programmes that take these factors into account, guidelines that will be valid in a given situation are laid down.
iv. Accurate laboratory result is a function of use of proper sampling procedures and sampling tools.

3.2 Soil Sampling

The methods and procedures for obtaining soil samples vary according to the purpose of the sampling. Analysis of soil samples may be needed for engineering and agricultural purposes. This study guide describes soil sampling for agricultural purposes, i.e. for soil fertility evaluation and fertiliser recommendations for crops. Soil chemistry changes over time, as biological and chemical processes break down or combine compounds over time. These processes change once the soil is removed from its natural ecosystem (flora and fauna that penetrate the sampled area) and environment (temperature, moisture, and solar light/radiation cycles). As a result, the chemical composition analysis accuracy can be improved if the soil is analyzed soon after its extraction — usually within a relative time period of 24 hours Air drying can also preserve the soil sample for many months.

3.2.1 Sampling Tools and Accessories

Depending on the purpose and precision required, the following tools may be needed for taking soil samples:

i. A soil auger – it may be a tube, post-hole or screw-type auger or even a spade for taking sample.
ii. A clean bucket or a tray or a clean cloth – for mixing the soil and Subsampling.
iii. Cloth bags of a specific size.
iv. A copying pencil for markings, and tags for tying cloth bags.
v. Soil sample information sheet.

3.2.2 Selection of a Sampling Unit

i. A visual survey of the field should precede the actual sampling.
ii. Note the variation in slope, colour, texture, management and cropping pattern by traversing the field.
iii. Demarcate the field into uniform portions, each of which must be sampled separately.

iv. Where all these conditions are similar, one field can be treated as a single sampling unit. Such a unit should not exceed 1–2 ha, and it must be an area to which a farmer is willing to give separate attention.
v. The sampling unit is a compromise between expenditure, labour and time on the one hand, and precision on the other.

3.2.3 Standard Sampling Procedures

i. Homogeneous units that are also practical for crop production purposes must be sampled. (Homogeneity is determined by previous crop performance, topography and the soil depth, colour and texture).
ii. A soil sample must represent a homogeneous unit of not more than 50 ha.
iii. Homogeneous units must be numbered clearly and separately.
iv. When taking the sample, all foreign matter (grass, twigs, loose stones) must be removed at the sampling point. In the case of very rocky soils an estimate must be made of the rock percentage per volume.
v. Twenty to 40 samples must be taken at random over the entire area of each homogeneous unit of the land. Conspicuously poor patches, headlands, places were animals gather, et cetera, must be avoided.
vi. The recommended depth for sampling the topsoil is about 20 cm, in other words the 0-20 cm portion of the topsoil is sampled.
vii. Subsoil samples must be taken from the 30-60 cm layer of the profile for dryland cultivation, and at 30-60 and from 60-120 cm for irrigation.
viii. If the land has been ploughed, random samples must be taken from the entire area. If the rows of the previous crop are still visible, the samples must be taken randomly between and in the rows.
ix. To compare results, sampling should be done at more or less the same time of the year every year, or during the same phase of the cultivation programme, but at least once every 3 years.
x. The 20-40 samples from which the final sample is to be compiled must be collected in a clean bag. (Farmers are warned against using salt bags, fertiliser bags or other contaminated containers). Clods must be crushed, foreign matter removed, and the soil must be mixed thoroughly. After spreading the soil in a thin layer, small scoops are taken evenly over the whole depth and area and placed in a clean plastic bag or carton. This final sample, representative of a homogeneous unit, must have a mass of 0.5-1.0 kg.

3.3 Soil Analysis

Soil is the main source of nutrients for crops. Soil also provides support for plant growth in various ways. Knowledge about soil health and its maintenance is critical to sustaining crop productivity. The health of soils can be assessed by the quality and stand of the crops grown on them. However, this is a general assessment made by the farmers. A scientific assessment is possible through detailed physical, chemical and biological analysis of the soils. Essential plant nutrients such as N, P, K, Ca, Mg and S are called macronutrients, while Fe, Zn, Cu, Mo, Mn, B and Cl are called micronutrients. It is necessary to assess the capacity of a soil to supply nutrients in order to supply the remaining amounts of needed plant nutrients (total crop requirement - soil supply). Thus, soil testing laboratories are considered nerve centres for nutrient management and crop production systems.

Soil testing is often performed by commercial labs that offer a variety of tests, targeting groups of compounds and minerals. The advantages associated with local lab is that they are familiar with the chemistry of the soil in the area where the sample was taken. This enables technicians to recommend the tests that are most likely to reveal useful information.

The amount of plant available soil phosphorus is most often measured with a chemical extraction method, and different countries have different standard methods. Just in Europe, more than 10 different soil P tests are currently in use and the results from these tests are not directly comparable with each other *(*Jordan-Meille et al 2012).

Soil testing is used to facilitate fertiliser composition and dosage selection for land employed in both agricultural and horticultural industries.
Prepaid mail-in kits for soil and ground water testing are available to facilitate the packaging and delivery of samples to a laboratory. Similarly, in 2004, laboratories began providing fertilizer recommendations along with the soil composition report.

Lab tests are more accurate and often utilize very precise flow injection technology, though both types are useful. In addition, lab tests frequently include professional interpretation of results and recommendations. Always refer to all proviso statements included in a lab report as they may outline any anomalies, exceptions, and shortcomings in the sampling and/or analytical process/results.

Some laboratories analyze for all 13 mineral nutrients and a dozen non-essential, potentially toxic minerals utilizing the "universal soil extractant" (ammonium bicarbonate DTPA).

3.3.1 Procedure for Analysis of Selected Soil Properties

The following procedures are employed in standard soil laboratories to determine the following soil properties:

i. The particle size distribution is determined by hydrometer method according to the procedures of (Gee and Or, 2002)
ii. Bulk density is measured by core method (Gross man and Reinsch, 2002) and Porosity was computed from bulk density and particle density.
iii. Soil pH is determined potentiometrically in 1:25 soil liquid ratio (Hendershot *et al.*, 1993).
iv. Organic carbon is determined using method described by (Nelson and Sommers, 1982) and the result of organic carbon multiplied by 1.724 to determine the organic matter content.
v. Total available phosphorus is determined using Bray II method (Olsen and Sommers, 1982).
vi. Total Nitrogen is determined using Kjeidal Digestion and Technicon/Auto analyzer method.
vii. Exchangeable bases are determined by extraction of ammonia acetate (NH_4O_{AC}) at pH 7.0 known as extractant in determining calcium, magnesium while sodium and potassium are determined using flame photometer.
viii. The exchangeable acidity is determined using extraction of exchangeable H^+ and $Al^{3+}$with KCl and titrated as outlined by (Mclaren*et al.,* 1994).
ix. The effective cation capacity was estimated by the summation of all the exchangeable base and acidity.

4.0 CONCLUSION

The most important phase of soil analysis takes place not in the laboratory but in the field where the soil is sampled. Soils vary from place to place. In view of this, efforts should be made to take the samples in such a way that they are fully representative of the field. Composite sampling can be performed by combining soil from several locations prior to analysis. This is a common procedure, but should be used judiciously to avoid skewing results.

5.0 SUMMARY

The following estimations are generally carried out in a service-oriented soil testing laboratory: soil texture, soil structure, cation exchange capacity (CEC), soil moisture, water holding capacity, pH, lime requirement, electrical conductivity, gypsum requirement, organic C, total N, mineralisable N, inorganic N, available P, available K, available S, calcium, calcium plus magnesium, micronutrients – available Zn, Cu, Fe, Mn, B and Mo.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by soil sampling?
2. Name five sampling equipment you know.
3. Outline at least six procedures that guarantee effective soil sampling.
4. What do you understand by soil testing or soil analysis?
5. State five procedures used in the laboratory to determine some selected soil properties.

7.0 REFERENCES/FURTHER READING

FAO (2008). “Guides to Laboratory Establishments for Plant Nutrients Analysis.” Fertiliser and plant nutrition bulletin 19.

Gee, G.W., & Or, D. (2002). Particle Size Distribution. In: J.H. Dane & G.C. Topp (Eds). Methods of Soil Analysis Part 4 Physical Methods. *Soil Sci. Soc. Am Book series* No. 5 ASA and SSSA, Madison WI; 225-293.

Grossman, R.B. & Reinsch, T.G. (2002). Bulk Density and Linea Extensibility. In: J.H. Dane & G. C. Topp (Eds). Methods of Soil analysis, Part 4. Physical methods. *Soil Science Society of America Book series* N0. 5 ASA and SSSA Madison, WI.2002; 201-228.

Hendershot, W.H., Lalande, H. & Duqyette, M. (1993). Soil reaction and exchangeable acidity. In: carte M.R. (Ed). Soil sampling and methods of analysis Can. Soc. Soil Sci., Lweis Publisher London, 141-145

Jordan-Meille, L. et al. (2012). "An Overview of Fertiliser P Recommendations in Europe: Soil Testing, Calibration and Fertiliser Recommendations". *Soil Use and Management*. 28 (4): 419–435. *doi*:*10.1111/j.1475-2743.2012.00453.x*. *ISSN 1475-2743*.

Mclean E.O. (1994). Contrasting Concepts in Soil Test Interpretation: Sufficiency Levels of Available Nutrients Versus Basic Cation Saturation Ratios. In: ‘Chemistry in the soil environment’. pp. 41-54. ASA Special Publication No. 40. *American Agronomy Society*.

Nelson, D. W. & Sommers. L. E. (1982). Total Carbon, Organic Carbon and Organic Matter in: Sparks, D. L. (Eds.), Methods of Soil Analysis. Part 3. SSSA Books Series No 5 SSSA Madison.

Olsen, S. R and L. E. Sommers (1982). Phosphorus. In: methods of soil Analysis part 2. Edited by A.L Page; R, H Miller and D.R Keeney. Madison Wl., Am. Soc. Agron. Pp 803-830.

https://en.wikipedia.org/wiki/Soil_test

http://www.arc.agric.za/arc-sgi/Pages/Production%20Systems/Soil-laboratory.aspx

https://uwlab.soils.wisc.edu/about-us/lab-procedures-and-methods/

http://www.fao.org/3/a-i0131e.pdf

UNIT 2 SOIL CORRELATIONS

1.0 INTRODUCTION

The correlation of the soils of a given soil survey area may be stated briefly to be the process whereby each kind of soil is properly recognised, defined, named, and placed in a system of soil classification. This is a most important part of a soil survey programme if the units of mapping are to be consistently identified, delineated, defined, named, and interpreted. This is essential if the soil survey is to function properly in the transfer of the results of experience and research gained from the soils of one locality to those of another, the making of predictions of what will follow from the use of soils in different ways, and what will be the long—term effects of such use.

Soil correlation is a multi-step quality assessment process that ensures accuracy and consistency both within and between soil surveys on both local and regional bases. It involves classifying soils, naming map units, and providing accurate interpretations. The purpose of correlation is to provide consistency in designing and naming map units, provide effective transfer of information to and between users, and allow flexibility between the standards used in soil survey and the variability scientists observe and document geographically. Correlation is a continuous process, from the initial descriptions at the start of mapping through the final manuscript, tables, map development, and certification. It is the responsibility of all survey team members, and the decisions are based primarily on the standards used to create the survey.

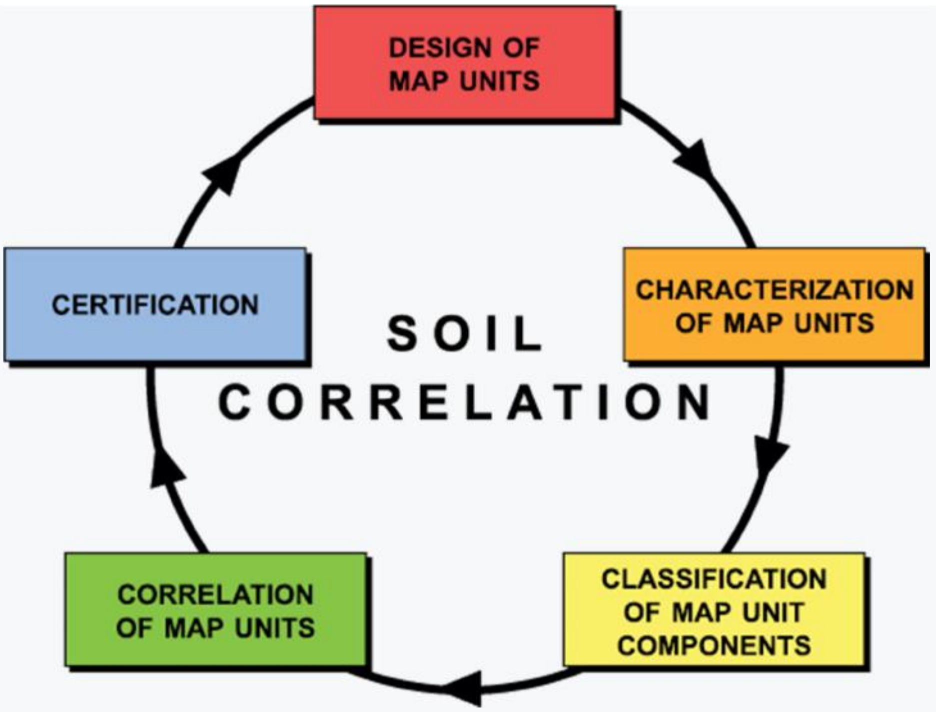

Fig. 9: Diagram that illustrates soil correlation is a continuous process, not a single event. The process is used to facilitate consistent collection, identification, grouping, and transfer of soil information (Soil Survey Staff 2016).

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss what soil correlation is all about
- state why soil correlation is essential to soil survey.

3.0 MAIN CONTENT

3.1 Soil Correlation

Soil correlation is an integral part of soil survey. It is carried out on a continuing basis throughout the course of the project. Soil correlation can be described by the following steps: (1) design of map units, (2) characterisation of map units, (3) classification of map unit components, (4) correlation of map units, and (5) certification.

3.1.1 Design of Map Units

Every soil survey must begin with a clear understanding of the purpose and needs for the project. At a minimum, a project plan must be developed to outline the needs of a soil survey. Preferably, all partners in a survey create a memorandum of understanding and agree to it. These documents outline the scale to be used in making the survey, minimum delineation size for map units, kinds of map units, documentation requirements, and interpretation needs of the soil survey users. Commonly, there is agreement on soil-landscape models to be used and the important soil-forming factors and soil orders known in a project area. These documents are essential to balancing survey detail, survey costs, and time frames for a project. A map unit can be tentatively correlated as soon as it has been accurately described and mapped. Map units in a survey are correlated to ensure consistency in design and level or order of mapping in a survey area.

3.1.2 Characterisation of Map Units

Map unit characterisation includes identifying the kind of components and the kind of map units to use and what data to collect for the soil database. Surveys in high-value, heavily used areas may require that most map units be consociations with components identified to the series level. Surveys in remote areas used primarily for watershed protection or wildlife habitat may only require that map units be complexes and associations with components named for taxonomic categories above the series.

3.1.3 Classification of Map Unit Components

Soil pedons representing the components of the map unit are described and classified to the appropriate taxonomic level (series or higher). In addition to pedon description and classification, laboratory characterisation data are collected, and interpretive features (such as ecological site descriptions) may be developed. The importance of this information cannot be overemphasised. The descriptions and data provide the basic information needed for complete and accurate interpretation. Working from the soil descriptions, supervisory soil scientists can give maximum help to the survey team. Soil taxa (series or higher category) are used to name the components making up the map unit. Soil map unit components are correlated internally to ensure that classification is consistent and that the recorded properties coincide with established taxonomic limits. Property ranges documented for the component that extend slightly beyond the taxonomic ranges are used to document and interpret the map unit component. Laboratory data supports the aggregation or grouping of pedons as well as soil database population.

Pedons described in U.S. surveys use the soil taxonomy system of classification.

3.1.4 Correlation of Map Units

The correlation of map units impacts many subparts of a soil survey. Similar and dissimilar soils should be consistently and objectively evaluated and listed in map unit descriptions and databases to properly account for the complexity in a survey. A system of analysing this information should be developed and followed. Analysis methods might include the use of spatial analysis software or tabular information in databases to identify correct groupings. Taxonomic unit descriptions represent the range in characteristics of the dominant soils in a survey area. Each map unit should reference a typical pedon that describes the range of characteristics for that taxa within the survey. The typical pedon, and commonly the taxonomic unit description, represent only a portion of the full range in characteristics for a given soil series. Soil interpretations and ratings are correlated to ensure that soil suitabilities or limitations are evaluated equitably across the survey.

Correlation ensures consistency within the map unit descriptions, including consistent wording to describe important features and consistent use of performance data among map units having the same use and management.

Map unit correlation also includes the proper documentation of the map unit history. This includes conceptual changes that may occur over the course of a survey project as new areas are identified for use of the same map unit. Current surveys maintain and track this history in a soil database.

3.1.5 Certification

Soil surveys typically have a formal, final correlation document that summarises all correlation decisions within a survey project. This document lists the final versions of map unit and taxonomic legends and explains the reasons for combining soils into map units, any classification anomalies, and any geographical exceptions. An explanation of the correlation of map units and components between adjoining survey areas ensures consistency between surveys. Both initial and update surveys use a similar process to explain correlation decisions and to present new information and data collected to support those decisions. Correlation documents certify that a soil survey product has followed and met the standards used to make a survey. This certification is essential for product delivery. Current delivery of U.S. soil surveys uses the publicly available Web Soil Survey (Soil Survey Staff, 2016).

3.2 Soil Correlation and Classification Systems

A system of classification, whether it be of roads, houses, or natural bodies such as plants, animals, or soils, is an organisation of knowledge so that the properties of the objects can be better remembered, and their relationships understood more easily for a specific objective. Any classification is based on the knowledge of the moment. It is a device made by man for some purpose, and it involves the grouping of objects or things on the basis of common properties.

Systems of soil classification have been developed over the years in a number of countries. It is only natural that they should vary because the experiences of men with soils differ, and hence concepts of the soil and the emphasis to place on individual soil properties and characteristics vary. Perhaps the most outstanding differences in soil classification systems today are those developed by the Russians, French and Americans. While the American effort to develop a system based on soil properties that can be measured and applied objectively has met with favour in parts of the world, there is no one accepted world-wide system of soil classification.

3.2.1 Correlations between Soil Classification Systems

The two most widely used modern soil classification schemes are American Soil Taxonomy, or ST (Soil Survey Staff 2014) and the World Reference Base for Soil Resources, or WRB (IUSS Working Group WRB 2015). After years of intensive worldwide testing and data collection, new versions of the ST and WRB systems have been released. In its current state, ST has a strong hierarchy with six categorical levels, i.e., order, suborder, great group, subgroup, family, and series (Soil Survey Staff 2014), whereas the WRB has a flat hierarchy with only two categorical levels, i.e., reference soil groups and soil units (IUSS Working Group WRB 2015). Rossiter (2001) stated that the reference soil group level of WRB is an intermediate in the conceptual level between ST orders and suborders, while the second-level subdivisions, i.e., soil units, which are defined by combinations of qualifiers, are similar to ST great groups (one qualifier) or subgroups (multiple qualifiers). This has necessitated correlations between the two soil classification systems, to enable scientists communicate properly the subject of classification of soils of any location. The common correlations between the WRB and the Soil Taxonomy are shown in Table 8.

Table 12: Correlation Table of World Reference Base (WRB) with United States Department of Agriculture (USDA) Soil Taxonomy (pp – partial agreement only)

WRB 1998	**USDA Soil Taxonomy**	**WRB 1998**	**USDA Soil Taxonomy**
Histosols	Histosol pp	Phaeozems	Mollisols – Udolls pp
Crysols	Gellisols pp	Gypsisols	Aridisols – Gypsids pp
Anthrosols	Inseptisols pp., plaggepts	Durisols	Aridisols -Durids pp
Leptosols	Entisols, lithic subgroup pp.	Calsisols	Aridisols – Calcids pp
Vertisols	Vertisols	Albeluvisols	Alfisols - Fraglossudalfs
Fluvisols	Entisols – Fluvents	Alisols	Ultisols – Udults pp
Solonchaks	Aridisol - Salorthids	Nitisols	Oxisols – Kandiudults pp Ultisols – Candiudults
Greysols	Inseptisols – Aquepts pp Entisols – Aquepts pp	Acrisols	Ultisols – Kandiudults, Kandiustults
Andosols	Andisols	Luvisols	Alfisols pp
Podzols	Spodosols	Lixisols	Alfisols-Paleustalfs, Kandiustalfs, Kandiudalfs, Kanhaplustalfs pp.
Printhosols	Oxisols-Printhaquox pp.	Umbrisols	Inseptisols pp.
Ferrasols	Oxisolspp.	Cambisols	Inseptisols pp.
Solonetz	Aridisols-Natrargids pp.	Arenosols	Entisols-Plamments pp.
Planosols	Alfisols-Abruptic Albaqualf pp.,	Regosols	Entisols pp.
Chernozems	Mollisols-Ustolls	Kastanozems	Mollisolls-Ustolls, Xerolls pp.

4.0 CONCLUSION

The purpose of correlation is to provide consistency in designing and naming map units, provide effective transfer of information to and between users, and allow flexibility between the standards used in soil survey and the variability scientists observe and document geographically.

5.0 SUMMARY

Correlation is a continuous process, from the initial descriptions at the start of mapping through the final manuscript, tables, map development, and certification. It is the responsibility of all survey team members, and the decisions are based primarily on the standards used to create the survey. Soil correlation is an integral part of soil survey. It is carried out on a continuing basis throughout the course of the project. Soil correlation can be described by the following steps: (1) design of map units, (2) characterisation of map units, (3) classification of map unit components, (4) correlation of map units, and (5) certification.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by soil correlation?
2. Mention and briefly explain the five steps involved in soil correlation.
3. With the aid of a diagram, illustrate soil correlation as a continuous activity.
4. Briefly explain two major classification systems that are usually correlated during soil classification.

7.0 REFERENCES/FURTHER READING

IUSS Working Group WRB, (2015). "International soil classification system for naming soils and creating legends for soil maps." World Soil Resources Reports No. 106., Rome: FAO,

Mohammad, H. S. (2018). "Challenges of Soil Taxonomy and WRB in classifying Soils: Some Examples from Iranian Soils." Bulletin of Geography. Physical Geography Series, No. 14: 63-70 http://dx.doi.org/10.2478/bgeo-2018-0005

Rossiter D.G., (2001). "Principles of Soil Classification." Lecture notes. International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, the Netherlands.

Soil Survey Staff (2014). *Keys to Soil Taxonomy*. (12th ed.). NRCS, USDA, USA

Soil Survey Staff (2016). "Web Soil Survey.) USDA Natural Resources Conservation Service. http://websoilsurvey. nrcs.usda.gov/

UNIT 3 SOIL SURVEY REPORT WRITINGS

1.0 INTRODUCTION

The results of soil surveys are usually published to provide the public with the soil information it needs to make sound decisions about land use and management and to provide a permanent record of what has been learned about soils. The soil survey is the key element in planning both agricultural and nonagricultural uses. Much of the information is spread by soil scientists, conservationists, and other agricultural workers in day-to-day contracts. The United States has chosen to place information assembled in a soil survey is public domain. Computer data banks of basic soil survey data are also public property and are available to workers in soil research and land use management. Technical information about soils for both nontechnical and technical users appears in special reports and professional publications and in bulletins and circulars issued by agricultural experiment stations or other government agencies (Soil Survey Staff 2017).

The major assignment of a soil survey group is to complete the fieldwork and assemble the information for the final publication of a survey. The soil survey work plan, however, should provide reasonable extra time to allow the survey group to satisfy any obligations it may have to collect specific information for particular groups or individuals.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss why soil survey report is very important
- explain how soil survey report is written to benefit all soil users
- examine why soil survey report is kept at the public domain.

3.0 MAIN CONTENT

3.1 Soil Survey Report

Soil survey reports are the primary means for disseminating the information gathered by the National Cooperative Soil Survey in the United States. Soil survey report usually cover a particular part of a State. The area covered by a survey is determined by factors, such as complexity of soils, topography, and the needs of users. Besides the formal soil survey report, special summaries of soils information for the survey area may be required.

Information may be needed before the formal report is finished, or new information may be needed after the report has been released. Special reports are often useful to present information on specific topics. Many people and agencies contribute to the making and publishing of soil survey reports. Local, State, and Federal cooperators may provide funds and personnel for the survey. The central responsibility for coordinating the individual soil surveys, as well as the national soil survey program in the United States, rests with the soil conservation service.

Soil survey publications are distributed widely, although most of the copies of a survey are distributed in the area covered by that survey. Survey reports are distributed by the cooperating agencies and the local conservation district. Publications are also available from Members of Congress. The extension service conducts educational programs about the use of soil surveys.

3.1.1 Where to Find Soil Survey Reports

Published soil surveys are available in:

i. Libraries of most universities and colleges in the United States.
ii. Libraries of many towns and cities.
iii. They are distributed to agricultural colleges.
iv. Ministries of agriculture.
v. Libraries in many other countries.

3.1.2 Contents of Soil Survey Reports

A total of all that were investigated about the soil of an area are usually documented in a soil survey report. Also, other previously identified information is incorporated into the soil survey report. The following are usually documented as stated by (Soil Survey Staff 2017):

i. Map showing the distribution of the different kinds of soils in the area.
ii. Summaries of research that has been done on the effects of soil on plants and engineering practices.
iii. Descriptions, laboratory data, and other information about the properties of the soils.
iv. From the above, basic data interpretations are made about potentials, suitability, and limitations of the soils for crops, pasture, forest, wildlife habitat, recreation, engineering, and any other uses known to be important at the time of the survey.
v. Discussions of land use and management are written to bring out specific relationships to individual soils or groups of soils shown on the map.
vi. The properties, responses to management, and suitability and limitations of each kind of soil are given to enable the public to make full use of the soil map, whether for producing crops or for locating building sites or sources of construction material.
vii. Predictions are made of the behavior of each kind of soil under specified uses and management systems. Predicted yield sunder defined systems of management and use are also provided.
viii. The use of a soil classification system permits eventual development of many useful interpretations beyond those required for the immediate objectives of the survey.
ix. A published soil survey contains instructions for its use, information about how the survey was made, an account of the general nature of the area, a description of the general soil map, a classification of the soils, a discussion of soil formation, references, and a glossary.

The form and content of the publication depends on the nature of the area surveyed, local conditions and needs, and the kinds of uses anticipated. The contents are arranged so that the user can find information as conveniently and rapidly as possible. Data and interpretations are assembled in tables to bring out relationships and contrasts among soils.

3.2 Technical Reports

Some technical soil survey information is used mainly by workers in soil science and in related fields. This information is recorded in technical papers, theses, and dissertations, many of which are published in technical report series and summarised in professional journals.

3.2.1 Soil Survey Investigative Reports

The Soil Survey Investigation Reports, published by the U.S. Department of Agriculture, Soil Conservation Service, makes technical information available from cooperative laboratory and field investigations of soils of the 50 States, Puerto Rico, and the Virgin Islands. Some volumes contain physical, chemical, and mineralogical data from soil laboratories and descriptions of the profiles that were sampled. Others report studies of the genesis of significant soils in a particular area.

Before Soil Survey Investigative Reports were started, laboratory data were distributed in unpublished form to those immediately concerned with specific problems. Some data appeared in technical journals, regional or national technical bulletins, or published soil surveys; however, much of the data was not readily available. Some experiment stations issue summaries of available data on soils within their States. These summaries are issued periodically as data accumulate and are available to those who need it.

3.2.2 Technical Monographs

Monographs summarise the existing data and provide additional data for as nearly complete an understanding of the genesis, morphology, and classification of the subject soils as possible. A technical monograph generally deals with the dominant soils of a comparatively large area, such as a major land resource area. In such areas, the dominant soils are broadly similar in genesis and morphology. Technical monographs differ somewhat in form and content from one area to another. Generally, a monograph contains an introduction that gives pertinent geographic information, a small-scale soil map with explanation, general and detailed description of the soils, laboratory data for soil characterization, and a thorough discussion of the classification of the soils. "The Desert Project Soil Monograph" is an example (Gile and Grossman, 1979).

3.2.3 Scientific Papers

Papers and reports on special studies about soils record the procedures used and the results obtained. For the most part, these papers are presented and distributed at professional meetings. Many of the papers are published in professional journals and similar publications. These papers not only keep soil scientists up-to-date on soils information, but they are also helpful to scientists in other disciplines. Some papers integrate soil data with data of other disciplines and are published in the journals of those fields.

3.3 Other Publications

Soils information appears in publications other than soil survey reports. For example, the Soil Conservation Service has published reports for resource conservation and development projects, river basin studies, flood hazard analyses, and small watershed projects. These reports, as a rule, contain considerable information about the soils of the area covered in the project. A special technical publication, "Soil Classification in the United States," records and partly explains the changing concepts that have guided soil classification through its various stages of development in the United States (Cline, 1979). It assembles the various attempts at classification of soils, emphasising those developed after the system was presented in the 1938 Yearbook of Agriculture.

4.0 CONCLUSION

Soil survey reports are the primary means for disseminating the information gathered by the National Cooperative Soil Survey in the United States. Soil survey report usually cover a particular part of a State. The area covered by a survey is determined by factors, such as complexity of soils, topography, and the needs of users. Besides the formal soil survey report, special summaries of soils information for the survey area may be required. Information may be needed before the formal report is finished, or new information may be needed after the report has been released.

5.0 SUMMARY

The following soil survey reports are usually documented and made available to the public for use; Map showing the distribution of the different kinds of soils in the area, summaries of research that has been done on the effects of soil on plants and engineering practices. Descriptions, laboratory data, and other information about the properties of the soils. Basic data interpretations are made about potentials, suitability, and limitations of the soils for crops, pasture, forest, wildlife habitat, recreation, engineering, and any other uses known to be important at the time of the survey. Discussions of land use and management are written to bring out specific relationships to individual soils or groups of soils shown on the map. The properties, responses to management, and suitability and limitations of each kind of soil are given to enable the public to make full use of the soil map, whether for producing crops or for locating building sites or sources of construction material. Predictions are made of the behavior of each kind of soil under specified uses and management systems. Predicted yields under defined systems of management and use are also provided. The use of a soil classification system permits eventual development of many useful interpretations beyond those required for the immediate objectives of the survey. A published soil survey contains instructions for its use, information about how the survey was made, an account of the general nature of the area, a description of the general soil map, a classification of the soils, a discussion of soil formation, references, and a glossary.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by soil survey reports and where can they be found?
2. Outline 10 information that can be found in a soil survey report.
3. Write short notes on the following:
    a. Technical reports
    b. Soil survey investigative reports
    c. Technical Monographs
    d. Scientific papers

7.0 REFERENCES/FURTHER READING

Cline, M. G. (1979). *Soil classification in the United States*. Ithaca, NY: Dep. of Agronomy Cornell University.

Gile, L. H. & Robert, B. G. (1979). The Desert Project Soil Monograph: Soils and Landscapes of a Desert Region Astride the Rio Grande Valley Near Las Cruces, New Mexico. Washington, DC: USDA. Soil Conserv. Serv.

Soil Survey Staff (2017). “Soil Survey Manual.” United States Department of Agriculture Handbook No. 18.

UNIT 4 SOIL INTERPRETATIONS

1.0 INTRODUCTIONS

Soil Interpretations seek to give meanings to several soil survey reports in a manner that can make the reports useful to its different users. Soil surveys must be based on sound scientific principles and at the same time they must be useful. They must be interpreted in terms of both regional objectives and local needs. They should be regarded as a prerequisite for planning both agricultural and non-agricultural development. The soil descriptions and the soil map form the factual information of a soil survey and have a longer "life" than the interpretations which may be invalidated by changes in social and economic conditions and by the acquisition of the of scientific knowledge.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss the essence of soil survey interpretation
- Understand that soil interpretation is a prerequisite for planning any form of development on the soil.

3.0 MAIN CONTENT

3.1 Soil interpretations

Soil survey information answers a wide range of soil-related questions, such as which crops will grow where and what are the best locations for infrastructure. Soil information can be used alone or as one layer of information in integrated systems that also consider other natural resources, demographics, climate, and ecological and environmental factors in decision making. Historically, soil survey interpretations primarily have been used to provide the public with soil interpretive predictions specific to a land use (Soil Survey, 2017).

3.1.1 Developing a Soil Interpretation

One of the first tasks in developing an interpretation is to create a criteria table of the soil, site, and climatic attributes that are thought to impact the land use. It contains a comprehensive set of criteria for interpreting soils for septic tank absorption fields. Some of the included criteria may not be applicable in some places (e.g., areas of permafrost). Using this example, the soil scientist or group developing an interpretation first determines a list of soil properties that are known, or thought to be, important for septic tank absorption fields. Depth to water table, saturated hydraulic conductivity, depth to bedrock, depth to cemented pan, depth to permafrost, slope, flooding, ponding, fragments > 75 mm, and susceptibility to downslope movement or subsidence are considered important properties. After determining the list of soil properties, the soil scientist or group develops limits for each property and each class. This iterative phase is commonly the most difficult. The initial set of criteria is tested in different areas of the country under a wide variety of soil conditions. Results of the tests may require adjustments to the criteria and retesting. Once the limits are set, they may be arrayed in the table according to degree of severity or importance. Soil interpretations are models for predicting how soils respond under a specific use. They use a set of rules or criteria that are based on the basic soil properties, modeled properties, or classes of properties.

Generally, preparation of interpretations involves the following steps:

4. Assembling information about soils and their landscapes.
5. Deriving inferences, rules, and models for predicting the impact of soil properties on soil behaviour under specific land uses.
6. Integrating these predictions into generalisations for each map unit component.

Soil interpretations provide numerical and descriptive information pertaining to a wide range of soil interpretive predictions. This information can be expressed as classes, indexes, or values with different units of measure. For example, particle-size data can be inferred from soil separates of sand, silt, and clay; USDA texture classes; or unified soil classes.

Generally, soil interpretations are made for specified uses and are reported in the form of:

i. **Limitations:** For limitations, soil properties that limit land use or establish the severity of limitation are typically indicated.
ii. **Suitability:** Soil properties that determine a soil's suitable characteristics may be given.
iii. **Potentials:** Soil interpretations, either as limitations or suitability, may be incorporated into potential ratings along with other resource data and interpretive information.

The interpretive results can be presented in tables or in maps that depict the spatial extent at scales appropriate for a specific application. The predicted practicality of alternative management options can be derived from soil interpretations. For any particular land use, soil responses to management alternatives can be predicted, the kinds of management needed can be identified, and the benefit-to-cost relationship for the management selected can be evaluated.

3.2 Interpretive Soil Properties (Soil Survey Staff 2017)

Soil survey interpretations are provided for specific soil uses. Interpretations for each soil use are based on a set of interpretive soil properties. These properties include site generalities (e.g., slope gradient), measurements on individual horizons (e.g., particle-size distribution), and temporal repetitive characteristics that pertain to the soil as a whole (e.g., depth to free water).
Abbreviated descriptions for many commonly used interpretive soil properties used in the NCSS are explained below. For logical presentation, they are grouped into categories: site, component, and horizon data; physical features or processes; erosion; and corrosivity. Formal classes have been assigned to several interpretive soil properties. These classes generally are not given unless they are used in field morphological descriptions.

3.2.1 Site Data

1. **Climate**
   i. Mean annual air temperature: The mean air temperature for the calendar year.
   ii. Frost-free period: The average length of the longest time period per calendar year that is free of killing frost.
   iii. Mean annual precipitation: The mean annual moisture received per calendar year, including rainfall and solid forms of water.

2. **Landscape**
   i. Slope: The range in slope gradient, in percent.
   ii. Slope aspect: The direction in which the slope faces, in degrees.
   iii. Slope shape: Whether the land surface is convex, concave, or linear in the up-down or across planes.
   iv. Elevation: The height above sea level.
   v. Geomorphic component: The part of the landform the soil occupies (e.g., interfluve, head slope, nose slope, side slope).
   vi. Hillslope position: The position the soil occupies on the landscape (e.g., summit, shoulder, backslope, footslope, toeslope).

3.2.2 Component Data

Field Water Characterisation

i. **Available water capacity (AWC)**: The volume of water that a soil layer retains between the tensions of 10 kPa (sandy soils) or 33 kPa and 1500 kPa. The water is considered to be available to most common agronomic plants. The standard of reference is the water retention difference (Soil Survey Staff, 2014). The amount of available water to the expected maximum depth of root penetration (commonly either 1 or 1.5 m) or to a physical or chemical root limitation, whichever is shallower, has been formulated into a set of classes for root-zone available water storage. For the class sets, the depth of rooting that is assumed and the class limits that are stipulated differ among the taxonomic moisture regimes.

ii. **Hydrologic soil groups (HSG)**: Interpretive classes that have similar runoff potentials under conditions of maximum yearly wetness. It is assumed that the ground surface is bare and that ice does not impede infiltration and transmission of water downward. In some cases, HSG is used as a soil property.

iii. **Flooding**: Inundation by flowing water. The frequency and duration of flooding are placed in classes.

iv. **Ponding**: Inundation by stagnant water. The duration and month(s) of the year that ponding occurs are recorded.

v. **Moisture status**: The thickness of the zone with a particular water state, the kind of water state, and the months of year that the water state is present within the soil. Three general water state classes are used in the soil survey database—dry, moist, and wet.

3.2.3 Horizon Data

1. Particle Size and Fragments > 2 mm

i. **USDA texture classes and modifiers**: Texture is the relative proportion, by weight, of sand-, silt-, and clay-sized particles (texture classes). The texture classes are modified by adjectival classes based on proportion, size, and shape of rock fragments and by the proportion of organic matter, if the content is high.

ii. **Particle-size separates (based on < 2 mm fraction)**: The particle-size separates recorded in the soil survey database are percent total sand (2.0–0.05 mm), very coarse sand (2.0–1.0 mm), coarse sand (1.0–0.5 mm), medium sand (0.5–0.25 mm), fine sand (0.25–0.10 mm), very fine sand (0.10–0.05 mm), total silt (0.05–0.002 mm), coarse silt (0.05–0.02 mm), fine silt (0.02–0.002 mm), total clay (< 0.002 mm), and carbonate clay. Percentages are expressed as a weight percent and are based on the < 2 mm fraction. For soils that disperse with difficulty, the total clay percentage is commonly evaluated based on the ratio of 1500 kPa water retention to clay.

iii. **Soil fragments > 250 mm (based on whole soil)**: This quantity is expressed as a weight percent of the horizon occupied by fragments up to an unspecified upper limit (size of rock fragments does not exceed the size of the pedon). Fragments include pieces of bedrock, bedrock-like material, durinodes, concretions, nodules, and woody materials (organic soils). Fragments larger than 250 mm are not included in the determination of Unified or AASHTO class placements, but they may significantly influence suitability for certain soil uses.

iv. **Soil fragments 75–250 mm (based on whole soil)**: This quantity is expressed as a weight percent of the horizon occupied by fragments 75–250 mm in size. Fragments include pieces of bedrock, bedrock-like material, durinodes, concretions, nodules, and woody materials (organic soils). The upper fragment size limit cannot exceed the size of the pedon. Fragments greater than 75 mm do not affect the Unified and AASHTO class placements, but they may have a large influence on suitability for certain uses.

v. **Soil fragments > 2 mm (based on whole soil)**: This quantity is expressed as a volume percent (whole soil base) of the horizon occupied by the > 2 mm fragments. Associated data include the kind, size, shape, roundness, and hardness of the fragments. Fragments include pieces of bedrock, bedrock-like material, durinodes, concretions, nodules, and woody materials (organic soils).

vi. **Percent passing sieve numbers 4, 10, 40, and 200 (based on < 75 mm fraction)**: The weight percentage of material passing each sieve. Sieve openings are 4.8 mm (no. 4), 2.0 mm (no. 10), 0.43 mm (no. 40), and 0.075 mm (no. 200) in diameter. Quantities are expressed as a percentage of the < 75 mm material. Material passing the number 4 and 10 sieves may be estimated in the field (see chapter 3) or measured in the office or laboratory. Material passing the number 40 and 200 sieves may be measured directly in the laboratory. Percent passing sieves also may be estimated from USDA particle-size and rock fragment measurements made in the field or laboratory.

2. **Soil Fabric-Related Analyses**

i. **Moist bulk density**: The oven-dry weight in megagrams divided by the volume of soil in cubic meters at or near field capacity, exclusive of the weight and volume of fragments > 2 mm.

ii. **Linear extensibility percent (LEP)**: The linear reversible volume difference of a natural clod between field capacity and oven dryness, inclusive of rock fragments. The volume change is expressed as a percent change for the whole soil. Actual LEP (shrink-swell), in contrast, is dependent on the minimum water content that occurs under field conditions. Organic soils typically do not have reversible volume changes when oven dried. Shrink-swell classes are defined based on LEP.

iii. **Water retention (10, 33, and 1500 kPa)**: The water content that is retained at 10, 33, and 1500 kPa tension, expressed as a percentage of the oven-dry soil weight inclusive of rock fragments (whole soil). Measurements are conducted in the laboratory on clods (for 10 and 33 kPa tension) and sieved samples (for 1500 kPa tension). Pedotransfer functions are also used to estimate the water content at 10, 33, and 1500 kPa tensions.

iv. **Available water capacity**: This is defined in the section "Field Water Characterisation" above as the volume of water that should be available to plants if the soil, inclusive of rock fragments, were at field capacity. Field capacity is the volume of water that remains in the soil two or three days after being wetted and after free drainage becomes negligible. Contents of water are expressed both as a volume fraction and as a thickness of water. Available water is estimated as the amount of water held between 10 or 33 kPa and 1500 kPa tension. Reductions in water retention difference should be made for root-restricting layers that are associated with certain taxonomic horizons and features (such as fragipans) and for chemical properties that are indicative of root restriction (such as low levels of available calcium and high levels of extractable aluminum). Adjustments may also be made for the osmotic effect of high salt concentrations, if present.

v. **Saturated hydraulic conductivity (Ksat)**: The amount of water that would move downward through a unit area of saturated in-place soil in unit time under unit hydraulic gradient. It is used to convey the rate of water movement downward through the soil under saturated conditions (and unit hydraulic gradient).

3. **Engineering Classification**

i. **Liquid limit (LL):** The water content at the change between liquid and plastic states. It is measured on thoroughly puddled soil material that has passed a number 40 sieve (0.43 mm) and is expressed on a dry weight basis. Values are typically placed in interpretive classes.

ii. **Plasticity index (PI):** The range in water content over which soil material is plastic. The value is the difference between the liquid limit and plastic limit of thoroughly puddled soil material that has passed a number 40 sieve (0.43 mm). The plastic limit is the water content at the boundary between the plastic and semisolid states. Values are typically placed in interpretive classes.

iii. **Unified classification:** An interpretive classification system of soil material designed for general construction purposes. It is dependent on particle-size distribution of the < 75 mm, liquid limit, and plasticity index and on whether the soil material has a high content of organic matter. There are three major divisions: mineral soil material having less than 50 percent particle size < 0.074 mm (passing 200 mesh), mineral soil material having 50 percent or more particle size < 0.074 mm, and certain highly organic soil materials. The major divisions are subdivided into groups based on liquid limit, plasticity index, and coarseness of the material more than 0.074 mm in diameter (retained on 200 mesh).

iv. **AASHTO classification**: An interpretive classification system of soil material for highway and airfield construction (Procedure M 145- 91; AASHTO, 1997). It is based on particle-size distribution of the < 75 mm fraction and on the liquid limit and plasticity index. The system separates soil materials having 35 percent or less particles passing the no. 200 sieve (< 0.074 mm in diameter) from those soil materials having more than 35 percent. Each of these two divisions is subdivided into classification groups based on guidelines that employ particle size, liquid limit, and volume change. A group index may be computed based on the liquid limit and plasticity index in addition to percent of particles < 0.074 mm. The group index is a numerical quantity based on a set of formulas.

4. **Chemical Analysis**

i. **Calcium carbonate equivalent**: The quantity of carbonate in the soil expressed as $CaCO_3$ and as a weight percentage of the < 2 mm fraction. The available water capacity and availability of plant nutrients are influenced by the amount of carbonates, which affect soil pH.

ii. **Cation-exchange capacity (CEC):** The amount of exchangeable cations that a soil can adsorb at pH 7.0. Effective CEC (ECEC) is reported in soils where the pH in 1:1 water is 5.5 or less.

iii. **Gypsum:** The gypsum content pertains to amount in the < 20 mm fraction. The methods of reference are under 6F (Soil Survey Staff, 2014a).

iv. **Organic matter—**Measured organic carbon is multiplied by the Van Bemmelen factor of 1.72 to obtain organic matter content.

v. **Reaction (pH):** The standard method for pH is the 1:1 water extraction. For organic soil materials, the pH in 0.01M CaCl2 is used.

vi. **Salinity:** A set of classes is used to indicate the concentration of dissolved salts in a water extract. Classes are expressed as electrical conductivity (EC). The measurement of reference is made on water extracted from a saturated paste. Units are decisiemens per metere (dS/m).

vii. **Sodium adsorption ratio (SAR)**: SAR is evaluated for the water extracted from a saturated soil paste. The numerator is the concentration of water-soluble sodium, and the denominator is the square root of half of the sum of the concentrations of water-soluble calcium and magnesium.

viii. **Sulfidic materials:** Upon exposure to air, soil materials that contain significant amounts of reduced monosulfides develop very low pH. The requirements are defined in the latest edition of the Keys to Soil Taxonomy (Soil Survey Staff, 2014). Direct measurement of the pH after exposure to air is also used.

3.2.4 Physical Features or Processes

1. Depth to Restrictive Horizons or Layers

i. **Depth to bedrock**: The depth to unweathered, continuous bedrock. The bedrock is commonly indurated but may also be strongly cemented, and excavation difficulty is very high or higher.

ii. **Depth to cemented pan:** The depth to a pedogenic zone that is weakly cemented to indurated. Thin and thick classes are distinguished. The thin class indicates a pan that is less than 8 cm thick if continuous and less than 45 cm thick if discontinuous or fractured. Otherwise, the thick class applies.

iii. **Depth to permafrost**: The critical depth is determined by the active layer (the top layer that thaws in summer and freezes again in fall). Utilities, fencing, footings, etc. are placed below the active layer. The minimum depth is affected by depth of annual freezing. Permafrost depth may be strongly influenced by soil cover.

1. **Process Features**

i. **Total subsidence:** The potential decrease in surface elevation resulting from the drainage of wet soils having organic layers or semifluid mineral layers. Subsidence may result from loss of water and resultant consolidation, mechanical compaction, wind erosion, burning, or oxidation (of particular importance for organic soils).

ii. **Potential frost action:**The likelihood of upward or lateral movement of soil caused by the formation of ice lenses and the subsequent loss of soil strength upon thawing. Large-scale collapse that forms pits is excluded and considered mass movement. Predictions are based on soil temperature, particle size, and pattern of water states.

3.2.5 Erosion

Factors and Groupings Related to Water or Wind Erosion

i. **The K factor**: A relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall. This interpretive factor is used in the Revised Universal Soil Loss Equation (Renard et al., 1997). Measurements are made on plots of standard dimensions. Erosion is adjusted to a standard of 9 percent slope. K factors are currently measured by applying simulated rainfall on freshly tilled plots. Earlier measurements integrated the erosion for the year for cultivated plots under natural rainfall. The K factor may be computed from the composition of the soil, saturated hydraulic conductivity, and soil structure.

ii. **The T factor:** The maximum rate of annual soil erosion that will permit crop productivity to be sustained economically and indefinitely (the soil loss tolerance). It can be used in the Revised Universal Soil Loss Equation (Renard et al., 1997). T factors are integer values from 1 through 5 indicating tons per acre per year. The factor of 1 ton per acre per year is used for shallow or otherwise fragile soils, and that of 5 tons per acre per year is used for deep soils that are least subject to damage by erosion.

iii. **Wind erodibility groups**: A set of classes, using integer designations from 1 through 8, based on compositional properties of the surface horizon that affect susceptibility to wind erosion. Texture, presence of carbonates, content of iron oxides, materials with andic soil properties, and the degree of decomposition of organic soils are the major interpretive criteria. Each wind erodibility group is associated with a wind erodibility index, expressed in tons per acre per year. The wind erodibility index is the theoretical, long-term amount of soil lost per year through wind erosion. It assumes a soil that is bare, lacks a surface crust, occurs in an unsheltered position, and is subject to the weather at Garden City, Kansas (Soil Survey Staff 2017).

Some Key Facts About Soil Survey Interpretations (Soil Survey Staff 2017)

1. Inherent soil property spatial variability defines the resolution of soil interpretations and the precision of soil behavior predictions for specific areas. Soil survey interpretations are rarely suitable for such onsite evaluations as homesites without further evaluations at the specific site. Soil interpretations do provide information on the likelihood that an area is suitable for a particular land use and so are valuable for screening areas for a planned use. This likelihood may be expressed as a suitability or a limitation.
2. Other soil behaviour predictions are presented in terms of how suitable a soil is for a particular land use. Historically, soils have been rated for their suitability as a material, such as topsoil or a source of sand. Soil productivity indices for crops and plants are also typically reported in terms of suitability. The underlying principle is that the soil will be used as it exists with no measures to overcome whatever makes the soil less suitable for a function.
3. The major disadvantage of a suitability interpretation is that all of the soil and site properties that might impact the land use must be identified and evaluated. If a property that does not exist in the database is identified as being important, it must be derived or included in some manner in the rating process. Omission of a soil property that is not suitable will cause invalid positive ratings.
4. Certain considerations that determine economic value of land are not part of soil interpretations but are an integral part of determining soil potentials for a given land use. For example, local groups consider the location of a land area in relation to roads, markets, and other services when developing soil potential ratings based on costs to maintain the soil resource versus benefits derived.
5. Interpretations are sensitive to changes in technology and land uses. Crop yields generally have increased over time, and new practices may reduce limitations for nonagricultural uses. For example, the introduction of reinforced concrete slab-on-ground house construction has markedly reduced the limitation of shrink-swell for small building construction. Additionally, new uses of land or changes in technology will require new prediction models for soil interpretations.
6. Soil properties can also be interpreted in terms of the favorability of a soil for the growth of certain fungi, bacteria, and other organisms that are either unwanted (such as a disease-causing organism) or economically desirable. While the land is not necessarily managed for a particular organism, prediction of the presence or absence of the organism can be useful. Also, soil properties can be used to assess the

propensity of a soil to retain or transmit certain chemicals or energy (heat and cold). This propensity is not a limitation or a suitability, because it does not indicate a hazard or desirability, but rather a tendency.

7. Interpretations based on properties of the soil in place are only applicable if characteristics of the land area are similar to what they were when soil mapping was done. New interpretations may be required if the soil and site properties have been affected by physical movement, compaction, or bulking of soil material or changes in patterns of water states by irrigation, drainage, or alteration of runoff by construction.

4.0 CONCLUSION

Soil survey interpretations are provided for specific soil uses. Interpretations for each soil use are based on a set of interpretive soil properties. These properties include site generalities (e.g., slope gradient), measurements on individual horizons (e.g., particle-size distribution), and temporal repetitive characteristics that pertain to the soil as a whole (e.g., depth to free water).
Abbreviated descriptions for many commonly used interpretive soil properties used in the NCSS are explained below. For logical presentation, they are grouped into categories: site, component, and horizon data; physical features or processes; erosion; and corrosivity. Formal classes have been assigned to several interpretive soil properties.

5.0 SUMMARY

Specific soil behavior predictions are commonly presented as the degree of limitation imposed by one or more soil properties. Limitations posed by a particular soil property must be considered along with those of other soil properties to determine which property poses the most serious limitation. A high shrink-swell potential, for example, may be the only limiting soil property for building houses with basements for some soils. However, other soils that have a high shrink-swell potential may also have bedrock at shallow depths, and shallow depth to bedrock may represent a greater limitation than shrink-swell. Relatedly, some soils that have a low shrink-swell potential, which is favorable for homesites, may have limitations because of wetness, flooding, slope, etc. The degree of limitation imposed by a soil property on a land use may be thought of in terms of the added cost to perform the land use relative to a less limiting soil. If necessary, any limitation may be overcome, but the additional expense of installation, maintenance, and decreased performance may be prohibitive.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by soil interpretations and how are they developed?
2. Discuss five key facts about soil survey interpretations based on Soil Survey Report 2017.
3. Discuss in details the following as they relate to interpretation of soil properties:
   i. Site data
   ii. Component data
   iii. Horizon data
4. Explain four engineering classifications in soil interpretations.
5. Mention and briefly explain eight chemical analysis classifications in soil interpretations.

7.0 REFERENCES/FURTHER READING

Renard, K.G.; Foster, G.R.; Weesies, G.A. McCool, D.K. & Yoder, D.C. (1997). "Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)." USDA Agriculture Handbook No. 703.

Soil Survey Staff (2017). "Soil Survey Manual." United States Department of Agriculture Handbook No. 18

Soil Survey Staff (2014). *Keys to Soil Taxonomy*. (12th ed.). USDA Natural Resources Conservation Service.

MODULE 5 LAND EVALUATIONS

UNIT 1 THE NATURE AND PRINCIPLES OF LAND EVALUATION

CONTENTS

1.0 INTRODUCTION

Land evaluation is concerned with the assessment of land performance when used for specified purposes. It involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. To be of value in planning, the range of land uses considered has to be limited to those which are relevant within the physical, economic and social context of the area considered, and the comparisons must incorporate economic consideration.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss the meaning of land evaluation
- explain the purpose of land evaluation
- highlight the basic principles of land evaluation.

3.0 MAIN CONTENT

3.1 Meaning of Land Evaluation

Land evaluation may be concerned with present land performance. Frequently however, it involves change and its effects: with change in the use of land and in some cases change in the land itself. Evaluation takes into consideration the economics of the proposed enterprises, the social consequences for the people of the area and the country concerned, and the consequences, beneficial or adverse, for the environment. Thus land evaluation is all about the following:

3.1.1 The purpose of Land Evaluation

The purpose of land evaluation seeks to answer a number of questions that bother on how the land is presently managed, and possible improvement to enhance future productivity as well as economic viability of the land. The evaluation process does not in itself determine the land use changes that are to be carried out, but provides data on the basis of which such decisions can be taken. To be effective in this role, the output from an evaluation normally gives information on two or more potential forms of use for each area of land, including the consequences, beneficial and adverse, of each. It seeks answers to the following questions below:

i. How is the land currently managed, and what will happen if present practices remain unchanged?
ii. What improvements in management practices, within the present use, are possible?
iii. What other uses of land are physically possible and economically and socially relevant?
iv. Which of these uses offer possibilities of sustained production or other benefits?
v. What adverse effects, physical, economic or social, are associated with each use?
vi. What recurrent input e are necessary to bring about the desired production and minimise the adverse effects? What are the benefits of each form of use?

3.1.2 Land Evaluation and Land Use Planning

Land evaluation is only part of the process of land use planning. Its precise role varies in different circumstances. In the present context it is sufficient to represent the land use planning process by the following generalised sequence of activities and decisions:

i. Recognition of a need for change.

ii. Formulation of proposals, involving alternative forms of land use, and recognition of their main requirements.
iii. Recognition and delineation of the different types of land present in the area.
iv. Comparison and evaluation of each type of land for the different uses.
v. Selection of a preferred use for each type of land
vi. Project design, or other detailed analysis of a selected set of alternatives for distinct parts of the area; this, in certain cases, may take the form of a feasibility study.
vii. Decision to implement
viii. Implementation
ix. Monitoring of the operation.

3.2 Principles of Land Evaluation

Certain principles are fundamental to the approach and methods employed in land evaluation. These basic principles are as follows:

i. **Land suitability is assessed and classified with respect to specified kinds of use**
This principle embodies recognition of the fact that different kinds of land use have different requirements. As an example, an alluvial flood plain with impeded drainage might be highly suitable for rice cultivation but not suitable for many forms of agriculture or for forestry. The concept of land suitability is only meaningful in terms of specific kinds of land use, each with their own requirements, e.g. for soil moisture, rooting depth etc. The qualities of each type of land, such as moisture availability or liability to flooding, are compared with the requirements of each use. Thus the land itself and the land use are equally fundamental to land suitability evaluation.
ii. **Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land**
Land in itself, without input, rarely if ever possesses productive potential; even the collection of wild fruits requires labour, whilst the use of natural wilderness for nature conservation requires measures for its protection. Suitability for each use is assessed by comparing the required input, such as labour, fertilisers or road construction, with the goods produced or other benefits obtained.
iii. **A multidisciplinary approach is required**
The evaluation process requires contributions from the fields of natural science, the technology of land use, economics and sociology. In particular, suitability evaluation always incorporates economic considerations to a greater or lesser extort. In qualitative evaluation, economics may be employed in general terms only,

without calculation of costs and returns. In quantitative evaluation the comparison of benefits and inputs in economic terms plays a major part in the determination of suitability. It follows that a team carrying out an evaluation require a range of specialists. These will usually include natural scientists (e.g. geomorphologists, soil surveyors, ecologists), specialists in the technology of the forms of land use under consideration (e.g. agronomists foresters, irrigation engineers, experts in livestock management), economists and sociologists. There may need to be some combining of these functions for practical reasons, but the principle of multidisciplinary activity, encompassing studies of land, land use, social aspects and economics, remains.

iv. **Evaluation is made in terms relevant to the physical economic and social context of the area concerned**

Such factors as the regional climate, levels of living of the population, availability and cost of labour, need for employment, the local or export markets, systems of land tenure which are socially and politically acceptable, and availability of capital, form the context within which evaluation takes place. It would, for example be unrealistic to say that land was suitable for non-mechanized rice cultivation, requiring large amounts of low-cost labour, in a country with high labour costs. The assumptions underlying evaluation will differ from one country to another and, to some extent, between different areas of the same country. Many of these factors are often implicitly assumed; to avoid misunderstanding and to assist in comparisons between different areas, such assumptions should be explicitly stated.

v. **Suitability refers to use on a sustained basis**

The aspect of environmental degradation is taken into account when assessing suitability. There might, for example, be forms of land use which appeared to be highly profitable in the short run but were likely to lead to soil erosion, progressive pasture degradation, or adverse changes in river regimes downstream. Such consequences would outweigh the short-term profitability and cause the land to be classed as not suitable for such purposes.

vi. **Evaluation involves comparison of more than a single kind of use**

This comparison could be, for example, between agriculture and forestry, between two or more different farming systems, or between individual crops. Often it will include comparing the existing uses with possible changes, either to new kinds of use or modifications to the existing uses. Occasionally a proposed form of use will be compared with non-use, i.e. leaving the land in its unaltered state, but the principle of comparison remains. Evaluation is only reliable if benefits and inputs from any given kind of use can be compared with at least one, and usually several different, alternatives. If only one use is considered there is the danger that, whilst the land may indeed be suitable for that use, some other and more beneficial use may be ignored.

4.0 CONCLUSION

Land evaluation is preceded by the recognition of the need for some change in the use to which land is put; this may be the development of new productive uses, such as agricultural development schemes or forestry plantations, or the provision of services, such as the designation of a national park or recreational area. Recognition of this need is followed by identification of the aims of the proposed change and formulation of general and specific proposals. The evaluation process itself includes description of a range of promising kinds of use, and the assessment and comparison of these with respect to each type of land identified in the area. This leads to recommendations involving one or a small number of preferred kinds of use. These recommendations can then be used in making decisions on the preferred kinds of land use for each distinct part of the area. Later stages will usually involve further detailed analysis of the preferred uses, followed, if the decision to go ahead is made, by the implementation of the development project or other form of change, and monitoring of the resulting systems.

5.0 SUMMARY

The evaluation process requires contributions from the fields of natural science, the technology of land use, economics and sociology. In particular, suitability evaluation always incorporates economic considerations to a greater or lesser extort. In qualitative evaluation, economics may be employed in general terms only, without calculation of costs and returns. In quantitative evaluation the comparison of benefits and inputs in economic terms plays a major part in the determination of suitability. It follows that a team carrying out an evaluation require a range of specialists. These will usually include natural scientists (e.g. geomorphologists, soil surveyors, ecologists), specialists in the technology of the forms of land use under consideration (e.g. agronomists foresters, irrigation engineers, experts in livestock management), economists and sociologists. There may need to be some combining of these functions for practical reasons, but the principle of multidisciplinary activity, encompassing studies of land, land use, social aspects and economics, remains.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by the term "Land Evaluation"?
2. State five issues that the purpose of land evaluation are all about.
3. i). What is the relationship between land evaluation and land use planning?
   ii). State eight generalised sequence of activities and decisions in the relationship.
4. Discuss five principles of land evaluation.

7.0 REFERENCE/FURTHER READING

http://www.fao.org/docrep/x5310e/x5310e02.htm

UNIT 2 THE CONCEPT OF LAND EVALUATION

CONTENTS

1.0 INTRODUCTION

Land comprises the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use. Land is a wider concept than soil or terrain. Variation in soils, or soils and landforms, is often the main cause of differences between land mapping units within a local area: it is for this reason that soil surveys are sometimes the main basis for definition of land mapping units. However, the fitness of soils for land use cannot be assessed in isolation from other aspects of the environment, and hence it is land which is employed as the basis for suitability evaluation.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss key land evaluation concepts such as land and land mapping units
- explain different kinds of land use and land utilisation types
- highlight different land qualities that are available.

3.0 MAIN CONTENT

3.1 Concept of Land Evaluation

Land comprises the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use. It includes the results of past and present human activity, e.g. reclamation from the sea, vegetation clearance, and also adverse results, e.g. soil salinisation. A land mapping unit is a mapped area of land with specified characteristics. Land mapping units are defined and mapped by natural resource surveys, e.g. soil survey, forest inventory. Their degree of homogeneity or of internal variation varies with the scale and intensity of the study. In some cases, a single land mapping unit may include two or more distinct types of land, with different suitability, e.g. a river flood plain, mapped as a single unit but known to contain both well-drained alluvial areas and swampy depressions.

3.2 Land Use

Suitability evaluation involves relating land mapping units to specified types of land use. The types of use considered are limited to those which appear to be relevant under general physical, economic and social conditions prevailing in an area. These kinds of land use serve as the subject of land evaluation. They may consist of major kinds of land use or land utilisation types.

3.2.1 Major Kinds of Land Use and Land Utilisation Types

Major kind of land use is a major subdivision of rural land use, such as rain-fed agriculture, irrigated agriculture, grassland, forestry, or recreation. Major kinds of land use are usually considered in land evaluation studies of a qualitative or reconnaissance nature.

Land utilisation type is a kind of land use described or defined in a degree of detail greater than that of A major kind of land use. In detailed or quantitative land evaluation studies, the kinds of land use considered will usually consist of land utilisation types. They are described with as much detail and precision as the purpose requires. Thus land utilisation typos are not a categorical level in a classification of land use, but refer to any defined use below the level of the major kind of land use e.g. an irrigation and drainage scheme. Attributes of land utilisation types include data or assumptions on:

i. Produce, including goods (e.g. crops, livestock timber), cervices (e.g. recreational facilities) or other benefits (e.g. wildlife conservation).

ii. Market orientation, including whether towards subsistence or commercial production.
iii. Capital intensity.
iv. Labour intensity.
v. Power sources (e.g. man's labour, draught animals, machinery using fuels).
vi. Technical knowledge and attitudes of land users.
vii. Technology employed (e.g. implements and machinery, fertilisers, livestock breeds, farm transport, methods of timber felling).
viii. Infrastructure requirements (e.g. sawmills, tat factories, agricultural advisory services).
ix. Size and configuration of land holdings, including whether consolidated or fragmented.
x. Land tenure, the legal or customary manner in which rights to land are held, by individuals or groups.
xi. Income levels, expressed per capita, per unit of production (e.g. farm) or per unit area.

Management practices on different areas within one land utilisation type are not necessarily the same. For example, the land utilisation type may consist of mixed farming, with part of the land under arable use and part allocated to grazing. Such differences may arise from variation in the land, from the requirements of the management system, or both.

Some examples of land utilisation types are:

i. Rain-fed annual cropping based on groundnuts with subsistence maize, by smallholders with low capital resources, using cattle drawn farm implements, with high labour intensity, on freehold farms of 5-10 ha.
ii. Farming similar to (i) in respect of production, capital, labour, power and technology, but farms of 200-500 ha operated on a communal basis.
iii. Commercial wheat production on large freehold farms, with high capital and low labour intensity, and a high level of mechanization and inputs.
iv. Extensive cattle ranching, with medium levels of capital and labour intensity, with land held and central services operated by a governmental agency.
v. Softwood plantations operated by a government Department of Forestry, with high capital intensity, low labour intensity, and advanced technology.
vi. A national park for recreation and tourism.

3.2.2 Multiple and Compound Land Use

Two terms, multiple and compound land utilisation types, refer to situations in which more than one kind of land use is practiced within an area.

A multiple land utilisation type consists of more than one kind of use simultaneously undertaken on the same area of land, each use having its own inputs, requirements and produce. An example is a timber plantation used simultaneously as a recreational area.

A compound land utilisation type consists of more than one kind of use undertaken on areas of land which for purposes of evaluation are treated as a single unit. The different kinds of use may occur in time sequence (e.g. as in crop rotation) or simultaneously on different areas of land within the same organisational unit. Mixed farming involving both arable use and grazing is an example.

3.2.3 Land Characteristics, Land Qualities and Diagnostic Criteria

Land characteristic is an attribute of land that can be measured or estimated. Examples are slope angle, rainfall, soil texture, available water capacity, biomass of the vegetation, etc. Land mapping units, as determined by resource surveys, are normally described in terms of land characteristics. If land characteristics are employed directly in evaluation, problems arise from the interaction between characteristics. For example, the hazard of soil erosion is determined not by slope angle alone but by the interaction between elope angle, slope length, permeability, soil structure, rainfall intensity and other characteristics. Because of this problem of interaction, it is recommended that the comparison of land with land use should be carried out in terms of land qualities.

Land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Land qualities may be expressed in a positive or negative way. Examples are moisture availability, erosion resistance, flooding hazard, nutritive value of pastures, accessibility. Where data are available, aggregate land qualities may also be employed, e.g. crop yields, mean annual increments of timber species.

An illustrative list of land qualities related to productivity from three kinds of use and to management and inputs has been given below. It is not exhaustive, nor is each land quality necessarily relevant for a particular area and type of land use. The qualities listed in B and C are in addition to those of A, which may be relevant to all three kinds of use

(Beek and Bennema, 1972). There may also be land qualities related to major land improvements. These vary widely with the types of improvement under consideration. An example is land evaluation in relation to available supplies of water where irrigation is being considered.

A land quality is not necessarily restricted in its influence to one kind of use. The same quality may affect, for example, both arable use and animal product

There are a very large number of land qualities, but only those relevant to land use alternatives under consideration need be determined. A land quality is relevant to a given type of land use if it influences either the level of inputs required, or the magnitude of benefits obtained, or both. For example, capacity to retain fertilisers is a land quality relevant to most forms of agriculture, and one which influences both fertilizer inputs and crop yield. Erosion resistance affects the costs of soil conservation works required for arable use, whilst the nutritive value of pastures affects the productivity of land under ranching.

Land qualities can sometimes be estimated or measured directly, but are frequently described by means of land characteristics. Qualities or characteristics employed to determine limits of land suitability classes or subclasses are known as diagnostic criteria.

Diagnostic criterion is a variable which has an understood influence upon the output from, or the required inputs to, a specified use, and which serves as a basis for assessing the suitability of a given area of land for that use. This variable may be a land quality, a land characteristic, or a function of several land characteristics. For every diagnostic criterion there will be a critical value or set of critical values which are used to define suitability class limits.

Examples of Land Qualities

A. Land qualities related to productivity from crops or other plant growth:

- Crop yields (a resultant of many qualities listed below)
- Moisture availability
- Nutrient availability
- Oxygen availability in the root zone
- Adequacy of foothold for roots
- Conditions for germination
- Workability of the land (ease of cultivation)
- Salinity or alkalinity
- Soil toxicity
- Resistance to soil erosion

- Pests and diseases related to the land
- Flooding hazard (including frequency, periods of inundation)
- Temperature regime
- Radiation energy and photoperiod
- Climatic hazards affecting plant growth (including wind, hail, frost)
- Air humidity as affecting plant growth
- Drying periods for ripening of crops.

B. Land qualities related to domestic animal productivity:

- Productivity of grazing land (a resultant of many qualities listed under A.)
- Climatic hardships affecting animals
- Endemic pests and diseases
- Nutritive value of grazing land
- Toxicity of grazing land
- Resistance to degradation of vegetation
- Resistance to soil erosion under grazing conditions
- Availability of drinking water.

C. Land qualities related to forest productivity:
The qualities listed may refer to natural forests, forestry plantations, or both.

- Mean annual increments of timber species (a resultant of many qualities listed under A.)
- Types and quantities of indigenous timber species
- Site factors affecting establishment of young trees
- Pests and diseases
- Fire hazard.

D. Land qualities related to management and inputs:
The qualities listed may refer to arable use, animal production or forestry.

- Terrain factors affecting mechanisation (traffic ability)
- Terrain factors affecting construction and maintenance of access roads (accessibility)
- Size of potential management units (e.g. forest blocks, farms, fields)
- Location in relation to markets and to supplies of inputs.

3.3 Examples

Moisture availability to plants is a land quality that is relevant in a wide variety of circumstances. It can apply to arable cropping, animal productivity (via its influence on growth of pastures) and forest production. It can affect both productivity, e.g. crop yields, and inputs, e.g. mulching measures necessary, or amounts of irrigation water required. Among the land characteristics which affect the quality moisture availability are: amount of rainfall, its seasonal distribution and variability; potential evapotranspiration, and hence the characteristics which themselves affect it (temperature, humidity, wind speed, etc.); and available water capacity of the soil, and the characteristics which affect it - effective soil depth (depth to which roots penetrate) and the field capacity and wilting point of each soil horizon, the latter being in turn influenced by texture, organic matter content, etc. The probable recurrence interval at which the soil moisture level falls to wilting point within the entire rooting zone is a further land characteristic of importance (which can be estimated but not measured within a short period).

By no means all these land characteristics would be employed as diagnostic criteria. Supposing, for example, that differences in both rainfall and potential evapotranspiration within the surveyed area were so small as to be of little importance in differentiating types of land, then this characteristic would become part of the physical context of the evaluation and would not be used in defining class limits. The most appropriate diagnostic criterion used to define class limits might be available water capacity of the soil profile. However, where soil data were not available, then some function of effective depth and soil texture, believed to bear a linear relationship with available water capacity, could be used. In the former case, the set of critical values for available water capacity used to define class limits might be such as: over 40 cm, 30 40 cm, 24-30 cm.

3.4 Requirements and Limitations

Requirements of the land use refer to the set of land qualities that determine the production and management conditions of a kind of land use.

Limitations are land qualities, or their expression by means of diagnostic criteria, which adversely affect a kind of land use. For example, the requirements for mechanised cultivation of wheat include high availability of oxygen in the root zone and absence of obstructions (boulders or rock outcrops); waterlogging and the presence of boulders are limitations. Thus limitations may be regarded as land qualities expressed in such a way as to show the extent to which the conditions of the land fall short of the requirements for a given use.

3.5 Land Improvements

Land improvements are activities which cause beneficial changes in the qualities of the land itself. Land improvements should be distinguished from improvements in land use, i.e. changes in the use to which the land is put or modifications to management practices under a given use. Land improvements are classed as major or minor. A major land improvement is a substantial and reasonably permanent improvement in the qualities of the land affecting a given use. A large non-recurrent input is required, usually taking the form of capital expenditure on structure and equipment. Once accomplished, maintenance of the improvement remains as a continuing cost, but the land itself is more suitable for the use than formerly. Examples are large irrigation schemes drainage of swamps and reclamation of salinized land.

Minor land improvement is one which either has relatively small effects or is non-permanent or both, or which lies within the capacity of individual farmers or other land users. Stone clearance, eradication of persistent weeds and field drainage by ditches are examples. The separation of major from minor land improvements is intended only as an aid to making a suitability classification. The distinction is a relative one; it is not clear-cut and is only valid within a local context. In cases of doubt, the main criterion is whether the improvement is within the technical and financial capacity of individual farmers or other landowners (including small communal owners, e.g. village co-operatives). In many areas improvements such as subsoiling, dynamiting or terracing cannot be undertaken by individual farmers, and are therefore regarded as major land improvements; in countries with large farms and high capital resources coupled with good credit facilities, however, these changes may be within reach of individuals and are therefore considered as minor improvements. Field drainage is another improvement that may or may not be regarded as major, depending on farm size, permanency of tenure, capital availability and level of technology.

4.0 CONCLUSION

Sometimes an appropriate land utilisation type can be found by making several land mapping units part of the same management unit, e.g. livestock management which combines grazing on uplands in the rainy season and on seasonally flooded lowlands in the dry season. Land utilisation types are defined for the purpose of land evaluation. Their description need not comprise the full range of farm management practices, but only those related to land management and improvement. At detailed levels of evaluation, closely-defined land utilization types can be extended into farming systems by adding other aspects of farm management. Conversely, farming systems that have already been studied and described can be adopted as the basis for land utilisation types.

5.0 SUMMARY

There are a very large number of land qualities, but only those relevant to land use alternatives under consideration need be determined. A land quality is relevant to a given type of land use if it influences either the level of inputs required, or the magnitude of benefits obtained, or both. For example, capacity to retain fertilisers is a land quality relevant to most forms of agriculture, and one which influences both fertilizer inputs and crop yield. Erosion resistance affects the costs of soil conservation works required for arable use, whilst the nutritive value of pastures affects the productivity of land under ranching. Land qualities can sometimes be estimated or measured directly, but are frequently described by means of land characteristics. Qualities or characteristics employed to determine limits of land suitability classes or subclasses are known as diagnostic criteria.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define land and give examples of what constitute land.
2. Differentiate major kinds of land use from land utilisation types. Give at least five examples in each case.
3. Distinguish between multiple and compound land use.
4. Explain these two terms and state their differences:
    i. Land characteristics
    ii. Land qualities
5. Give at least five examples of land qualities as relates to the following:
    i. Crop or plant growth
    ii. Domestic animal productivity
    iii. Forest Productivity
    iv. Management and imputes
6. What is land improvement? Distinguish between major land improvement and minor land improvement.

7.0 REFERENCES/FURTHER READING

Beek, K.J. & Bennema, J. (1972). *Land Evaluation for Agricultural Land Use Planning. An Ecological Methodology*. Wageningen: Dept. Soil Sci. and Geol., Agric. University, 70 p.

Beek, K.J. (1975). “Land Utilisation Types in Land Evaluation. In: Land Evaluation in Europe.” Soils Bulletin 29, FAO, Rome. p. 87-106.

http://www.fao.org/docrep/x5310e/x5310e02.htm

UNIT 3 LAND SUITABILITY CLASSIFICATION

CONTENTS

1.0 INTRODUCTION

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. There may be certain parts of the area considered, for which particular kinds of use are not relevant, e.g. irrigated agriculture beyond a limit of water availability. In these circumstances, suitability need not be assessed. Such parts are shown on maps or tables by the symbol NR: Not Relevant.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- explain the meaning of Land suitability
- classify land suitability into orders, classes and subclasses.

3.0 MAIN CONTENT

3.1 Structure of the Suitability Classification

The framework has the same structure, i.e. recognises the same categories, in all of the kinds of interpretative classification. Each category retains its basic meaning within the context of the different classifications and as applied to different kinds of land use. Pour categories of decreasing generalisation are recognised:

Table 13: The Suitability Classification Structure

1	Land Suitability Orders:	reflecting kinds of suitability.
2	Land Suitability Classes:	reflecting degrees of suitability within Orders.
3	Land Suitability Subclasses:	reflecting kinds of limitation, or main kinds of improvement measures required, within Classes.
4	Land Suitability Units:	reflecting minor differences in required management within Subclasses.

3.1.1 Land Suitability Orders

Land suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders represented in maps, tables, etc. by the symbols S and N respectively. Land may be classed as not suitable for a given use for a number of reasons. It may be that the proposed use is technically impracticable, such as the irrigation of rocky steep land, or that it would cause severe environmental degradation, such as the cultivation of steep slopes. Frequently, however, the reason is economic: that the value of the expected benefits does not justify the expected costs of the inputs that would be required.

Table 14: Land Suitability Order

1	Order S Suitable:	Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.
2	Order N Not Suitable:	Land which has qualities that appear to preclude sustained use of the kind under consideration.

3.1.2 Land Suitability Classes

Land suitability Classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic numbers, in sequence of decreasing degrees of suitability within the order. Within the Order Suitable the number of classes is not specified. There might, for example, be only two, S1 and S2. The number of classes recognised should be kept to the minimum necessary to meet interpretative aims; five should probably be the most ever used. If three classes are recognised within the Order Suitable, as can often be recommended, the following names and definitions may be appropriate in a qualitative classification.

Table 15: Land Suitability Class

Class S1 Highly Suitable:	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
Class S2 Moderately Suitable:	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
Class S3 Marginally Suitable:	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

In a quantitative classification, both inputs and benefits must be expressed in common measurable terms, normally economic. In different circumstances different variables may express most clearly the degree of suitability, e.g. the range of expected net income per unit area or per standard management unit, or the net return per unit of irrigation water applied to different types of land for a given use.

Where additional refinement is necessary it is recommended that this should be achieved by adding classes, e.g. S4, and not by subdividing classes, since the latter procedure would contradict the principle that degrees of suitability are represented by only one level of the classification structure, that of the suitability class. This necessarily change e the meanings of class numbers, e.g. if four classes were employed for classifying land with respect to arable use and only three with respect to forestry, Marginally Suitable could refer to S4 in the former case but S3 in the latter.

An alternative practice has been adopted in some countries. In order to give a constant numbering to the lowest Suitable class, classes have been subdivided as, e.g. S2.1, S2.2. This practice is permitted within the Framework, although for the reason given in the preceding paragraph it is not recommended.

Suitability Class S1, Highly Suitable, may sometimes not appear on a map of a limited area, but could still be included in the classification if such land is known or believed to occur in other areas relevant to the study.

Differences in degrees of suitability are determined mainly by the relationship between benefits and inputs. The benefits may consist of goods, e.g. crops, livestock products or timber, or services, e.g. recreational facilities. The inputs needed to obtain such benefits comprise such things as capital investment, labour, fertilizers and power. Thus an area of land might be classed as Highly Suitable for rain-fed agriculture, because the value of crops produced substantially exceeds the costs of farming, but only marginally suitable for forestry, on grounds that the value of timber only slightly exceeds the costs of obtaining it.

It should be expected that boundaries between suitability classes will need review and revision with time in the light of technical developments and economic and social changes.

Table 16: Within the Order Not Suitable, there are normally two Classes

Class N1 Currently Not Suitable:	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Class N2 Permanently Not Suitable:	Land having limitations which appear so severe as to preclude any possibilities Of successful sustained use of the land in the given manner.

Quantitative definition of these classes is normally unnecessary, since by definition both are uneconomic for the given use. The upper limit of Class N1 is already defined by the lower limit of the roast suitable class in Order S.

The boundary of Class N2, Permanently Not Suitable, is normally physical and permanent. In contrast, the boundary between the two orders, Suitable and Not Suitable is likely to be variable over time through changes in the economic and social context.

3.1.3 Land Suitability Subclasses

Land suitability subclasses reflect kinds of limitations, e.g. moisture deficiency, erosion hazard. Subclasses are indicated by lower-case letters with mnemonic significance, e.g. S2m, S2e, S3me. There are no subclasses in Class S1.
The number of subclasses recognised and the limitations chosen to distinguish them will differ in classifications for different purposes. There are two guidelines:

- The number of subclasses should be kept to a minimum that will satisfactorily distinguish lands within a class likely to differ significantly in their management requirements or potential for improvement due to differing limitations.
- As few limitations as possible should be used in the symbol for any subclass. One, rarely two, letters should normally suffice. The dominant symbol (i.e. that which determines the class) should be used alone if possible. If two limitations are equally severe, both may be given.

Land within the Order Not Suitable may be divided into suitability subclasses according to kinds of limitation, e.g. N1m, N1me, N1m although this is not essential. As this land will not be placed under management for the use concerned it should not be subdivided into suitability units.

3.1.4 Land Suitability Units

Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. The units differ from each other in their production characteristics or in minor aspects of their management requirement e (often definable as differences in detail of their limitations). Their recognition permits detailed interpretation at the farm planning level. Suitability units are distinguished by Arabic numbers following a hyphen, e.g. S2e-1, S2e-2. There is no limit to the number of units recognised within a subclass.

3.1.5 Conditional Suitability

The designation Conditionally Suitable may be added in certain instances to condense and simplify presentation. This is necessary to cater for circumstances where small areas of land, within the survey area, may be unsuitable or poorly suitable for a particular use under the management specified for that use, but suitable given that certain conditions are fulfilled. The possible nature of the conditions is varied and might relate to modifications to the management practices or the input e of the defined land use (occasioned, for example, by localized phenomena of poor soil drainage, soil salinity); or to restrictions in the choice of crops (limited, for example, to crops with an especially high market value, or resistant to frost). In such instances, the indication "conditional" can avoid the need for additional classifications to account for local modifications of land use or local major improvements.

Conditionally Suitable is a phase of the Order Suitable. It is indicated by a lower case letter c between the order symbol and the class number, e.g. Sc2. The conditionally suitable phase, subdivided into classes if necessary, is always placed at the bottom of the listing of S classes. The phase indicates suitability after the condition(e) have been met.

Employment of the Conditionally Suitable phase should be avoided wherever possible. It may only be employed if all of the following stipulations are met:

i. Without the condition(s) satisfied, the land is either not suitable or belongs to the lowest suitable class.
ii. Suitability with the condition(s) satisfied is significantly higher (usually at least two classes).
iii. The extent of the conditionally suitable land is very small with respect to the total study area.

If the first or second stipulation is not met, it may still be useful to mention the possible improvement or modification in an appropriate section of the text. If the third stipulation is not met, then the area over which the condition is relevant is sufficiently extensive to warrant either a new land utilization type or a potential suitability classification, as appropriate.

As the area of land classed as Conditionally Suitable is necessarily small, it will not normally be necessary to subdivide it at the unit level.

It is important to note that the indication "conditional" is not intended to be applied to land for which the interpretation is uncertain, either in the sense that its suitability is marginal or because factors relevant to suitability are not understood. Use of "conditional" may seem convenient to the evaluator, but its excessive use would greatly complicate understanding by users and must be avoided.

3.1.6 Summary

The structure of the suitability classification, together with the symbols used, is summarised in Figure 10 below. Depending on the purpose, scale and intensity of the study, either the full range of suitability orders, classes, subclasses and units may be distinguished, or the classification may be restricted to the higher two or three categories.

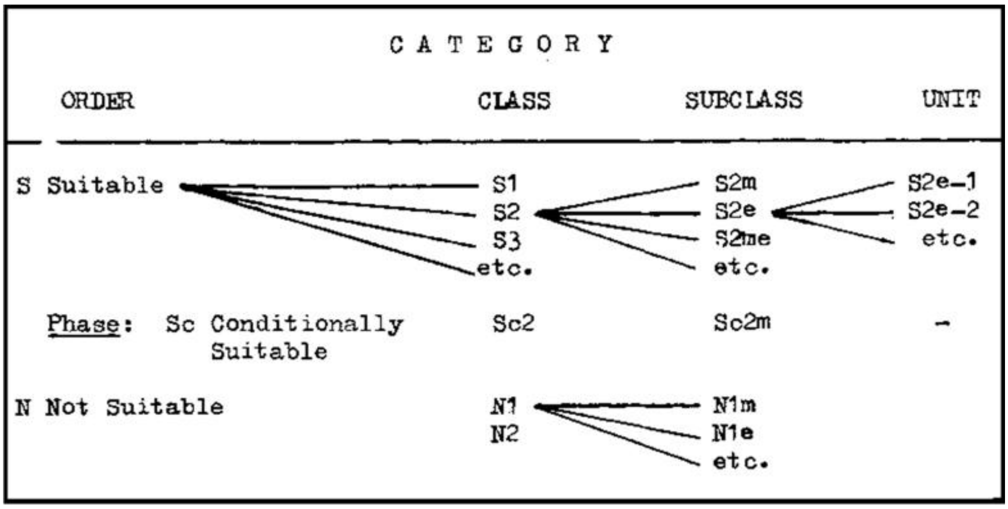

Fig. 10: Structure of the Suitability Classification

3.2 The Range of Classifications

The Framework recognises four main kinds of suitability classification, according to whether it is qualitative or quantitative, and refers to current or potential suitability. Each classification is an appraisal and grouping of land units in terms of their suitability for a defined use.

3.2.1 Qualitative and Quantitative Classifications

Qualitative classification is one in which relative suitability is expressed in qualitative terms only, without precise calculation of costs and returns. Qualitative classifications are based mainly on the physical productive potential of the land, with economics only present as a background. They are commonly employed in reconnaissance studies, aimed at a general appraisal of large areas.

Quantitative classification is one in which the distinctions between classes are defined in common numerical terms, which permits objective comparison between classes relating to different kinds of land use. Quantitative classifications normally involve considerable use of economic criteria, i.e. costs and prices, applied both to inputs and production. Specific development projects, including pre-investment studies for these, usually require quantitative evaluation. Qualitative evaluations allow the intuitive integration of many aspects of benefits, social and environmental as well as economic. This facility is to some extent lost in quantitative evaluations. The latter, however, provide the data on which to base calculations of net benefits, or other economic parameters, from different areas and different kinds of use. Quantitative classifications may become out of date more rapidly than qualitative ones as a result of changes in relative costs and prices.

3.2.2 Classifications of Current and Potential Suitability

Current suitability classification refers to the suitability for a defined use of land in its present condition, without major improvements. A current suitability classification may refer to the present use of the land, either with existing or improved management practices, or to a different use.

Potential suitability Classification refers to the suitability, for a defined use, of land units in their condition at some future date, after specified major improvements have been completed where necessary. Common examples of potential suitability classifications are found in studies for proposed irrigation schemes. For a classification to be one of potential suitability it is not necessary that improvements shall be made to all parts of the land; the need for major improvements may vary from one land unit to another and on some land units none may be necessary. In potential suitability classification, it is important for the user to know whether the costs of amortization of the capital costs of improvements have been included. Where these are included, the assumptions should state the extent to which input e have been costed and the rates of interest and period of repayment that have been assumed.

4.0 CONCLUSION

Land suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders represented in maps, tables, etc. by the symbols S and N respectively. Land may be classed as Not suitable for a given use for a number of reasons. It may be that the proposed use is technically impracticable, such as the irrigation of rocky steep land, or that it would cause severe environmental degradation, such as the cultivation of steep slopes. Frequently, however, the reason is economic: that the value of the expected benefits does not justify the expected costs of the inputs that would be required.

5.0 SUMMARY

Differences in degrees of suitability are determined mainly by the relationship between benefits and inputs. The benefits may consist of goods, e.g. crops, livestock products or timber, or services, e.g. recreational facilities. The inputs needed to obtain such benefits comprise such things as capital investment, labour, fertilisers and power. Thus an area of land might be classed as highly suitable for rain-fed agriculture, because the value of crops produced substantially exceeds the costs of farming, but only marginally suitable for forestry, on grounds that the value of timber only slightly exceeds the costs of obtaining it. It should be expected that boundaries between suitability classes will need review and revision with time in the light of technical developments and economic and social changes.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand be land suitability?
2. Classify land suitability into: Order, Class and Subclass.
3. Carefully explain the following terms:
   i. Highly Suitable
   ii. Moderately Suitable
   iii. Marginally Suitable
4. i. Distinguish between qualitative and quantitative classification.
   ii. Distinguish between current and potential suitability classification.

7.0 REFERENCE/FURTHER READING

http://www.fao.org/docrep/x5310e/x5310e02.htm

UNIT 4 LAND EVALUATION PROCEDURES

CONTENTS

1. 0 INTRODUCTION

The main activities in a land evaluation include the following; initial consultations, concerned with the objectives of the evaluation, and the data and assumptions on which it is to be based, Description of the kinds of land use to be considered, and establishment of their requirements, Description of land mapping units, and derivation of land qualities, Comparison of kinds of land use with the types of land present, Economic and social analysis, Land suitability classification (qualitative or quantitative), Presentation of the results of the evaluation.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- discuss the procedures involved in land evaluation
- explain why a soil surveyor must state his objectives clearly.

3.0 MAIN CONTENT

3.1 Land Evaluation Procedure

3.1.1 Initial Consultations

Within the Framework, considerable freedom exists in choice of the approach and procedures that are most appropriate in any set of circumstances. This choice is made on the basis of the objectives and assumptions of the study. Consultation between the planning authorities that have initiated the study and the organization which will carry it out is an essential first stage in all cases. Such meetings are not simply briefings, but a two-way interchange of ideas on the objectives of the survey and the kind of evaluation that will achieve these objectives. Terms of reference should be flexible, permitting iterative modification during the course of the survey in the light of its interim findings.

At the initial consultations, the following issues must be addressed:

i. The objectives of the evaluation
ii. The data and assumptions on which the evaluation is to be based
iii. The extent and boundaries of the area to be evaluated
iv. The kinds of land use which appear to be relevant for consideration
v. Whether a two-stage or parallel approach is to be followed
vi. The type of suitability classification to be employed
vii. The intensity and scale of the required surveys
viii. The phasing of activities in the evaluation.

The general assumptions can be divided into those referring to the physical, economic and social context of the area, and those underlying the evaluation process itself. In addition to these general assumptions, there may be assumptions specific to particular kinds of land use (e.g. size of landholdings, minor land improvements, techniques of farming); these latter assumptions are given in the descriptions of the respective uses.

1. Objectives

The first requirement is to establish the objectives of the proposed development or adjustment, constraints to change, other assumptions, and thus the forms of land use that must be considered. This requires discussions between resource surveyors, experts in land use technology (e.g. agriculturalists, foresters), engineers, economists, sociologists, planners, government officials and representatives of the local population likely to be affected.

It is necessary to identify the broad aims of the proposed changes and to formulate general and specific proposals designed to fulfil these aims. A broad aim might be, for example, self-sufficiency in food production; general proposals to achieve this might include increased wheat production, increased livestock production and expansion of irrigation. These in turn could be broken down into more specific proposals, such as the location of a mechanized food farm, or the irrigation of a particular valley. Other examples of broad aims might be providing land for settlement, evaluating land liable to be lost to rural uses through urban development or, the most general case, making a resource inventory of a country or region for overall planning and development purposes. At the opposite extreme there may be some specific objective, such as establishing a forestry plantation to supply firewood, or providing recreational land for an urban population.

Experience has shown that a suitability classification for only one use may be misleading. It is nearly always desirable to classify for at least one alternative form of use. This need not necessarily involve change but could be a continuation of the present use, with management practices either modified or unchanged. In the case of uninhabited land, it is possible, as a basis for comparison, to assess the benefits deriving from the present non-use.

2. The context of the study area

Some data and assumptions are so obvious under the physical, economic, social and political conditions of a country or region that they are not always specified. Examples are aridity in a desert region, and either a high or a low level of living. However, to assist in the transfer of information from one area to another, these assumptions should be recorded.

In order to avoid an excessive list, or pages of obvious statements, this requirement can be met by an initial description of the context of the study area. This will include the following:

- Location and accessibility
- Climatic zone
- Relief
- Present state of land improvements (e.g. reclamation, drainage)
- Population and its rate of change
- Level of living (e.g. gross domestic product per capita)
- Education
- Basis of the present economy
- Economic infrastructure (e.g. roads, urban services)
- Government subsidies
- Size of farms or other landholdings
- Land tenure system
- Political system.

Not only is it possible to infer some of the obvious assumptions from such a description, but also the significance of the suitability classification is dependent on the physical, economic and social context. Since economic and social conditions are continuously changing, the classification will eventually become obsolete and this background information will assist in judging the relevance of an evaluation sometime after it has been made.

3. Data and assumptions underlying the evaluation

Besides the general context, there are also assumptions used as a basis for evaluation, which affect the interpretation and the spatial and temporal applicability of the results. Such assumptions should be listed as such. Some examples, by no means covering the full range of possibilities, are as follows:

- Limits to information utilized (e.g. only the soil conditions shown on a given map have been used).
- The reliability and applicability of data available from within or outside the studied area (e.g. rainfall measured x km away is applicable).
- Location is, or is not, taken into account.
- Demography (e.g. present rates of population increase will continue, or will decrease).
- Infrastructure and services (e.g. repair services, credit facilities, agricultural extension services etc. will remain as at present, or will be improved).
- Level of inputs (e.g. recurrent inputs by users of land will remain at present levels, or will be increased).
- Land tenure and other institutional conditions (e.g. continuance of private freehold, or customary communal tenure is assumed, or farmers will co-operate within communal villages to be set up).
- Demand, markets and prices (e.g. existing prices in the region have been assumed, or, since no market for the projected crop exists in the region, world prices have been assumed; the effects of the expected large supply of produce from the project on the market price have, or have not, been taken into account).
- Land improvements; where a classification of potential suitability is to be made, the extent and nature of the land improvements are described.
- Basis for economic analysis (e.g. amortization costs of capital works have not, or have, been partly or wholly included; family labour by smallholders has, or has not, been included in costs; discount rates used in cost-benefit analysis).

Irrespective of whether land improvements are major or minor, their cost (or the magnitude of the effort required) should be considered in a land evaluation. This applies to the maintenance costs of the improvements as well as to the non-recurrent capital costs. If the costs cannot be assigned to specific areas of land (as is sometimes the case in multi-purpose improvements, e.g. irrigation and hydro-electric power projects), then the degree to which recurrent and capital costs have or have not been taken into account must be specified.

Location in relation to markets and supplies of inputs, may affect land suitability. Especially in less developed countries, there may be areas which in other respects would be suitable for some form of productive use, but which cannot presently be put to that use because of difficulties of access to markets and supplies of inputs (e.g. fertilizers). This may be caused by distance alone or because the areas lie amid difficult terrain or lack good roads.

4. Planning the Evaluation

Other matters discussed during the stage of initial consultations involve the nature and planning of subsequent activities in the evaluation.

i. **The extent and boundaries of land to be evaluated**
These may have been specified prior to the commissioning of the evaluation, as for example in preparing a development plan for a particular administrative unit. Alternatively, the area may be determined following selection of relevant kinds of land use, on the basis that certain areas only appear to have potential for that use. In particular, when surveys of a more intensive nature are being undertaken, maps from previous surveys at reconnaissance or other less intensive scales will be used to select promising areas for specified kinds of land use.

ii. **The kinds of land use which appear to be relevant for consideration**
These are selected on the basis of the objectives of the evaluation and the physical, economic and social background of the area. The objectives indicate whether a wide range of kinds of land use are to be included, or whether the study is directed towards one specific use. In most cases the physical background, e.g. features of climate found over the whole area under consideration, will substantially reduce the range of uses of land which are relevant. There will also be constraints set by economic and social factors, e.g. levels of living or a requirement that a

particular type of land tenure, individual or communal, be employed.

iii. **Whether a two-stage or parallel approach is to be followed**
This depends on the purposes, scale and intensity of the study and also on the times when the specialists are available.

iv. **The type of suitability classification to be employed**
Selection of a qualitative or quantitative classification, and one of either current or potential suitability, is made on the basis of the objectives, scale and intensity of the evaluation. Qualitative classifications are normally employed on reconnaissance surveys for general planning purposes, quantitative for more specific proposals. Where major land improvements, such as drainage, reclamation or irrigation schemes, are contemplated, classifications of potential suitability are necessary; in such cases it may be desirable additionally to classify the land on the basis of its current suitability, or order that benefits with and without the proposed development can be compared.

v. **The scope, intensity and scale of the required surveys**
This is decided by means of comparison between the data required, as determined by the purposes of the evaluation, and that which is already available. The nature of the data required is greatly influenced by the kinds of land use being considered (e.g. soil survey for agricultural use, ecological survey for grazing of natural pastures). It is first necessary to review the existing information e.g. topographic maps, air photograph cover, soil maps, river discharge data, population, production and other statistical data, projections of demand. This is compared with the requirements for an evaluation of the given type and intensity. Decisions made will include, for example, whether new air photograph coverage is required, whether a soil survey is necessary and if so at what scale and density of observation, and what economic data must be collected.

vi. **Phasing of the activities**
Having made initial decisions on the aspects detailed above, it is then necessary to estimate the time to be allotted to each of the subsequent activities and their relative phasing.

The initial consultations are an essential part of any land evaluation study. Through a clear understanding of the objectives and assumptions it is possible to plan the subsequent activities so that they are directed towards producing information relevant to the purposes of the evaluation and, conversely, to avoid activities, particularly time-consuming and costly field surveys, which will yield information of an inappropriate type or level of intensity. Some of the decisions made during the initial consultations may later be modified, by iteration, during the evaluation. Such decisions should therefore be left flexible. Where a written agreement is involved e.g. between clients and consultants, provision should be made for its subsequent modification, by further discussion and agreement.

The following sections outline subsequent activities in an evaluation, including surveys, analysis, classification and presentation of results.

3.1.2 Kinds of Land Use and Their Requirements and Limitations

1. **Description of kinds of land use**

   The identification and description of the type of land use which are to be considered is an essential part of the evaluation procedure. Some restrictions to the range of uses relevant for consideration will have been set by the objectives and assumptions. Two situations may be distinguished:

   - The kinds of land use are specified at the beginning of the evaluation procedure.
   - The kinds of land use are broadly described at the beginning and subject to modification and adjustment in accordance with the findings of the evaluation procedure.

   The first situation can arise in qualitative surveys aimed at evaluation in terms of major kinds of land use. It can also occur in studies aimed at locating land for only one or for a limited number of land utilization types, e.g. sites for irrigated fruit growing or for a forest reserve; in such circumstances the kinds of land use to be considered are largely defined by the objectives.

   The second situation occurs, for example, in land development projects which are likely to include arable farming of several kinds, livestock production and forestry. Initially the land utilization types are described in general terms, e.g. arable farming by smallholders. As the evaluation proceeds, such details as crop selection, recommended rotations, required soil conservation measures and optimum farm size are progressively determined, so that at the end of the study the land utilization types are described in detail.

In the first situation, the kinds of land use are described prior to the land suitability classification. In the second, they are modified during the classification. In practice the distinction is not sharp as some adjustment or reconsideration of uses may take place in the first situation.

2. **Identification of requirements of the use and limitations**
After, or concurrently with the description of kinds of land use, their requirements are determined. Each kind of land use needs different environmental conditions if it is to be practiced on a sustained and economically viable basis. For example, most perennial crops require available moisture within root range throughout the year, irrigated rice culture requires land which is level or can be made level at acceptable cost, and forestry requires a certain foothold for roots although it is usually tolerant of steep slopes.

The limitations for each type of land use are determined at the same time as the requirements. These requirements and limitations indicate the types of data which are required for evaluation, and thus condition the nature of the surveys needed.

It should be noted that the description of kinds of land use and the identification of their requirements and limitations are operations requiring studies in the field. These are likely to include visits to sites where production data (e.g. crop yields, cattle carrying capacity, rates of tree growth) are available, and comparison of these data with environmental conditions and methods of management. These sites need not be confined to the area being evaluated. Fieldwork of this nature may constitute a major activity in the evaluation in terms of time and manpower, perhaps equaling or exceeding that spent on the survey of basic resources.

3.1.3 Description of Land Mapping Units and Land Qualities

Most land evaluation studies require physical resource surveys, although occasionally there may be sufficient information already available. The surveys will frequently include a soil or soil-landform survey, and sometimes such work as pasture resource or other ecological surveys, forest inventory, surveys of surface-water or groundwater resources, or road engineering studies. The objects of such surveys are to define and determine boundaries of the land mapping units and to determine their land qualities.

The delineation of land mapping units will be based in part on land characteristics most readily mapped, frequently landforms, soils and vegetation. However, at the stage of resource survey, the land qualities believed to have significant effects on the types of land use under consideration have already been provisionally identified; consequently, special attention should be given to those qualities during field survey. For example, in surveys for irrigation projects, particular attention is given to the physical properties of the soil, to the quality and amount of available water and to the terrain conditions in relation to methods of irrigation considered.

3.1.4 Comparison of Land Use with Land

The focal point in the evaluation procedure is that at which the various data are brought together and compared, the comparison leading to the suitability classification. These data are:

i. The relevant kinds of land use and their requirements and limitations
ii. The land mapping units and their land qualities
iii. The economic and social conditions.

The comparison of land use with land is here described separately from economic and social analysis, although in practice there may be considerable overlap between them.

1. Matching of land use with land

Matching represents the essence of the interpretative step following the resources surveys in the land evaluation procedure, and is based on the functional relationships that exist between the land qualities, the possibilities for land improvement and the requirements of the land use. In its simplest form matching is the confrontation of physical requirements of specific crops (or grasses, trees, etc.) with the land conditions to give a prediction of crop performance. Matching becomes more complex when the production factor is complemented by other performance conditioning characteristics of the land utilization type, including non-physical aspects like labour intensity and capital intensity.

Suppose, for example, that one of the land utilization types is growth of a perennial tree crop such as oil palm. It is essential that soil moisture should remain above wilting point within some part of the rooting zone throughout the year and, in addition, yields are depressed or made irregular by moisture stress. Thus moisture availability is identified as a relevant land quality for this land utilization type. The moisture availability of each land unit on which oil palm cultivation is being considered is determined from their land characteristics, such as rainfall regime, rooting depth and available water capacity. The crop yield under optimum moisture conditions, for specified standards of management, is estimated. The probable depression in yields caused by specified deficiencies in moisture is then assessed. In a qualitative study some rather arbitrary depression in yield, 50 percent for example, may be taken as the criterion separating land Suitable and Not Suitable for this kind of use. In a quantitative study the economic consequences of yield reductions are calculated.

Among the purposes served by matching are:

i. To check the relevance and refine the descriptions of land utilisation types.
ii. To permit systematic determination of the management and improvement specifications of each land utilisation type on each land mapping unit to which it is suited, and thus of the required inputs (in terms of capital, labour, etc.).
iii. To estimate the magnitude of the benefits from each land utilisation type on each suitable land mapping unit.

2. Estimation of benefits and inputs

One of the main means to assess the desirability of proposed changes in land use is a comparison between the benefits obtained and the inputs or costs required to obtain them.

The benefits may consist of produce, services and other intangible benefits. Produce includes crops, harvested pasture, livestock products, timber and forest extraction products. Intangible benefits include the creation of employment, provision of recreational or tourist facilities, nature conservation (flora and fauna), and aesthetic considerations. The benefit of water conservation, whether by vegetation conservation in catchments or through flooding of land by reservoir construction, might be regarded as either produce or intangible benefits.

Benefits are first assessed in physical terms, e.g. volume of production, estimated numbers of tourists. These are then, so far as practicable, translated into economic terms, on the basis of stated assumptions about prices, etc.

The evaluation of intangible benefits presents special problems. Land used for recreation or protected as a nature reserve does not necessarily produce directly measurable benefits, and in particular it is difficult to translate such benefits into economic terms. In place of a purely commercial approach, a political decision may be needed to set aside areas of land for aesthetic, health, educational and conservational needs.

This calls for methods of rating land in terms of land qualities which have a positive or negative effect on its use for recreation or conservation. For example, sustained carrying capacity expressed as man-days per year per unit area could be one measure of land suitability for recreation. It is as necessary to assess inputs, or costs, as it is to estimate production. These consist of recurrent and non-recurrent (capital) inputs.
As with benefits, inputs are first described in physical terms, which are subsequently translated into costs. In the case of recurrent inputs, it is first necessary to specify the management techniques, possibly amplifying the details of these already given in descriptions of land utilization types. The goods and services required are then listed. These will frequently include:

i. Recurrent material inputs, e.g. seed, fertiliser.
ii. Irrigation water.
iii. Labour requirements, skilled and unskilled.
iv. Machinery (operation, maintenance, and depreciation).
v. Transport requirements.

A similar estimate is made of inputs needed for capital works, including those needed for major land improvements where intended. Both the recurrent and non-recurrent inputs are then converted into costs.

4.0 CONCLUSION

At an early stage in the evaluation a provisional selection has been made of those kinds of land use which appear to be relevant in the light of the objectives and the overall physical and socio-economic conditions. Once systematic surveys and studies have accumulated further data the broad indications of the kinds of land use and their requirements will need to be reconciled with more precise information on the land qualities.

5.0 SUMMARY

Either the broad aims or the general or specific proposals can form the objectives for land evaluation: broad aims in the case of reconnaissance surveys for resource inventory and identification of development possibilities, more specific proposals in semi-detailed and detailed surveys. The objectives serve to define, at least as a first approximation, the relevant kinds of land use. This in turn limits the range of information needed and hence the types of surveys necessary. Where the objectives are very specific, e.g. land for smallholder tea production, survey activity is concentrated on the type of information relevant to this use and the land surveyed and personnel engaged are correspondingly limited.

6.0 TUTOR-MARKED ASSIGNMENT

1. What are the land evaluation procedures you studied in this unit?
2. Mention and briefly explain at least five key issues that must be sorted out at the initial consultation level in the evaluation procedures.
3. Explain what you understand by matching land use with land. Mention three major purposes of marching.
4. Mention and briefly explain five components of planning in land evaluation procedures.

7.0 REFERENCES/FURTHER READING

FAO (2007). "Land Evaluation: Towards a Revised Framework." FAO Discussion Papers.

FAO/UNEP (1993). "Agro-Ecological Assessments for National Planning: The Example of Kenya." FAO Soils Bulletin, 67, p 154.

http://www.fao.org/ag/agl/agll/aez.htm

http://www.fao.org/ag/agl/agll/gaez/index.htm

http://www.fao.org/catalog/book_review/giii/w9692-e.htm

http://www.fao.org/ag/agl/agll/soter.stm

http://www.css.cornell.edu/landeval/ales/ales.htm