SSIGL 5

NATIONAL GUIDELINES

For Small Scale Irrigation Development in Ethiopia

Soil Survey and Land Suitability Evaluation



November 2018

Addis Ababa

MINISTRY OF AGRICULTURE

National Guidelines for Small Scale Irrigation Development in Ethioipa

SSIGL 5: Soil Survey and Land Suitability Evaluation

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First Edition 2018

Ministry of Agriculture
Small-Scale Irrigation Development Directorate
P. O. Box 62347
Tel: +251-1-6462355
Fax: +251-1-6462355
Email: SSIDdirectorate@moa.gov.et
SSIDdirectorate@gmail.com
eDMS (intranet): MoA SSID DMS (http://172.28.1.188:8080/DMS/login.jsp)
Website: www.moa.gov.et

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FORWARD

Ministry of Agriculture, based on the national strategic directions is striving to meet its commitments in which modernizing agriculture is on top of its highest priorities to sustain the rapid, broad-based and fair economic growth and development of the country. To date, major efforts have been made to remodel several important strategies and national guidelines by its major programs and projects.

While efforts have been made to create access to irrigation water and promoting sustainable irrigation development, several barriers are still hindering the implementation process and the performance of the schemes. The major technical constrains starts from poor planning and identification, study, design, construction, operation, and maintenance. One of the main reasons behind this outstanding challenge, in addition to the capacity limitations, is that SSIPs have been studied and designed using many ad-hoc procedures and technical guidelines developed by various local and international institutions.

Despite having several guidelines and manuals developed by different entities such as MoA (IDD)-1986, ESRDF-1997, MoWIE-2002 and JICA/OIDA-2014, still the irrigation professionals follow their own public sources and expertise to fill some important gaps. A number of disparities, constraints and outstanding issues in the study and design procedures, criteria and assumptions have been causing huge variations in all vital aspects of SSI study, design and implementation from region to region and among professionals within the same region and institutions due mainly to the lack of agreed standard technical guidelines. Hence, the SSI Directorate with AGP financial support, led by Generation consultant (GIRDC) and with active involvement of national and regional stakeholders and international development partners, these new and comprehensive national guidelines have been developed

The SSID guidelines have been developed by addressing all key features in a comprehensive and participatory manner at all levels. The guidelines are believed to be responsive to the prevalent study and design contentious issues; and efforts have been made to make the guidelines simple, flexible and adaptable to almost all regional contexts including concerned partner institution interests. The outlines of the guidelines cover all aspects of irrigation development including project initiation, planning, organizations, site identification and prioritization, feasibility studies and detail designs, contract administration and management, scheme operation, maintenance and management.

Enforceability, standardization, social and environmental safeguard mechanisms are well mainstreamed in the guidelines, hence they shall be used as a guiding framework for engineers and other experts engaged in all SSI development phases. The views and actual procedures of all relevant diverse government bodies, research and higher learning institutions, private companies and development partners has been immensely and thoroughly considered to ensure that all stakeholders are aligned and can work together towards a common goal. Appropriately, the guidelines will be familiarized to the entire stakeholders working in the irrigation development. Besides, significant number of experts in the corresponding subject matter will be effectively trained nationwide; and the guidelines will be tested practically on actual new and developing projects for due consideration of possible improvement. Hence, hereinafter, all involved stakeholders including government & non-governmental organizations, development partners, enterprises, institutions, consultants and individuals in Ethiopia have to adhere to these comprehensive national guidelines in all cases and at all level whilst if any overlooked components are found, it should be documented and communicated to MOA to bring them up-to-date.

Therefore, I congratulate all parties involved in the success of this effort, and urge partners and stakeholders to show a similar level of engagement in the implementation and stick to the guidelines over the coming years.

H.E. Dr. Kaba Urgessa
State Minister, Ministry of Agriculture

SMALL SCALE IRRIGATION DEVELOPMENT VISION

Transforming agricultural production from its dependence on rain-fed practices by creating reliable irrigation system in which smallholder farmers have access to at least one option of water source to increase production and productivity as well as enhance resilience to climate change and thereby ensure food security, maintain increasing income and sustain economic growth.

ACKNOWLEDGEMENTS

The preparation of SSIGLs required extensive inputs from all stakeholders and development partners. Accordingly many professionals from government and development partners have contributed to the realization of the guidelines. To this end MOA would like to extend sincere acknowledgement to all institutions and individuals who have been involved in the review of these SSIGLs for their comprehensive participation, invaluable inputs and encouragement to the completion of the guidelines. There are just too many collaborators involved to name exhaustively and congratulate individually, as many experts from Federal, regional states and development partners have been involved in one way or another in the preparation of the guidelines. The contribution of all of them who actively involved in the development of these SSIGLs is gratefully acknowledged. The Ministry believes that their contributions will be truly appreciated by the users for many years to come.

The Ministry would like to extend its appreciation and gratitude to the following contributors:

- Agriculture Growth Program (AGP) of the MoA for financing the development and publication of the guidelines.
- The National Agriculture Water Management Platform (NAWMP) for overseeing, guidance and playing key supervisory and quality control roles in the overall preparation process and for the devotion of its members in reviewing and providing invaluable technical inputs to enrich the guidelines.
- Federal Government and Regional States organizations and their staff for their untiring effort in reviewing the guidelines and providing constructive suggestions, recommendations and comments.
- National and international development partners for their unreserved efforts in reviewing the guidelines and providing constructive comments which invaluably improved the quality of the guidelines.
- Small-scale and Micro Irrigation Support Project (SMIS) and its team for making all efforts to have quality GLs developed as envisioned by the Ministry.

The MOA would also like to extend its high gratitude and sincere thanks to AGP's multi development partners including the International Development Association (IDA)/World Bank, the Canada Department of Foreign Affairs, Trade and Development (DFATD), the United States Agency for International Development (USAID), the Netherlands, the European Commission (EC), the Spanish Agency for International Development (AECID), the Global Agriculture and Food Security Program (GAFSP), the Italy International Development Cooperation, the Food and Agriculture Organization (FAO) and the United Nations Development Program (UNDP).

Moreover, the Ministry would like to express its gratitude to Generation Integrated Rural Development Consultant (GIRDC) and its staff whose determined efforts to the development of these SSIGLs have been invaluable. GIRDC and its team drafted and finalized all the contents of the SSIGLs as per stakeholder suggestions, recommendations and concerns. The MoA recognizes the patience, diligence, tireless, extensive and selfless dedication of the GIRDC and its staff who made this assignment possible.

Finally, we owe courtesy to all national and International source materials cited and referred but unintentionally not cited.

Ministry of Agriculture

DEDICATIONS

The National Guidelines for Small Scale Irrigation Development are dedicated to Ethiopian smallholder farmers, agro-pastoralists, pastoralists, to equip them with appropriate irrigation technology as we envision them empowered and transformed.

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ACRONYMS

AGP	Agricultural Growth Program
ATA	Agricultural Transformation Agency
AWC	Available Water Holding Capacity
C/N	Carbon Nitrogen Ratio
DAP	Diammonium phosphate
DEM	Digital Elevation Model
ESP	Exchangeable Sodium Percentage
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
GIRDC	Generation Integrated Rural Development Consultant
GIS	Geographic Information System
GPS	Global Positioning System
IR	Infiltration Rate
K	Hydraulic Conductivity
LUR	Land Use Requirement
LUT	Land Utilization Types
MOANR	Ministry of Agriculture and Natural Resource
MOWIE	Ministry of Water, Irrigation and Electricity
MS	Microsoft
OC	Organic Carbon
PBS	Percent Base Saturation
PWP	Permanent Wilting Point
RSG	Reference Soil Group
SAR	Sodium Absorption Ratio
SMU	Soil Mapping Unit
SOM	Soil Organic Matter
SSID	Small Scale Irrigation Development
SSIGL	Small Scale Irrigation Guideline
SSIP	Small Scale Irrigation Project
SSIS	Small Scale Irrigation Scheme
SWC	Soil and Water Conservation
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
WRB	World Reference Base

PREFACE

While irrigation development is at the top of the government's priority agendas as it is key to boost production and improve food security as well as to provide inputs for industrial development. Accordingly, irrigated land in different scales has been aggressively expanding from time to time. To this end, to enhance quality delivery of small-scale irrigation development planning, implementation and management, it has been decided to develop standard SSI guidelines that must be nationally applied. In September 2017 the Ministry of Agriculture (MoA) had entrusted Generation Integrated Rural Development Consultant (GIRDC) to prepare the National Small-scale Irrigation Development Guidelines (SSIGLs).

Preparation of the SSIGLs for enhancing development of irrigated agriculture is recognized as one of the many core initiatives of the MoA to improve its delivery system and achieve the targets in irrigated agriculture and fulfill its mission for improving agricultural productivity and production. The core objective of developing SSIGLs is to summarize present thinking, knowledge and practices to enable irrigation practitioners to properly plan, implement and manage community managed SSI schemes to develop the full irrigation potential in a sustainable manner.

As the SSIGLs are prepared based on national and international knowledge, experiences and practices, and describe current and recommended practice and set out the national standard guides and procedures for SSI development, they serve as a source of information and provide guidance. Hence, it is believed that the SSIGLs will contribute to ensuring the quality and timely delivery, operation and maintenance of SSI schemes in the country. The SSIGLs attempt to explain and illustrate the important concepts, considerations and procedures in SSI planning, implementation and management; and shall be used as a guiding framework for professionals engaged in SSI development. Illustrative examples from within the country have been added to enable the users understand the contents, methodologies presented in the SSIGLs.

The intended audiences of the SSIGLs are government organizations, NGOs, CSOs and the private sector involved in SSI development. Professionally, the SSIGLs will be beneficial for experienced and junior planners, experts, contractors, consultants, suppliers, investors, operators and managers of SSI schemes. The SSIGLs will also serve as a useful reference for academia and researchers involved and interested in SSI development. The SSIGLs will guide to ensure that; planning, implementation and management of SSI projects is formalized and set procedures and processes to be followed. As the SSIGLs provide information and guides they must be always fully considered and applied by adapting them to the local specific requirements.

In cognizance with the need for quality SSIGLs, the MoA has duly considered quality assurance and control during preparation of the guidelines. Accordingly, the outlines, contents and scope of the SSIGLs were thoroughly discussed, reviewed and modified by NAWMP members (senior professionals from public, national and international stakeholder) with key stakeholders in many consultative meetings and workshops. Moreover, at each milestone of SSIGL preparation, resource persons from all stakeholders reviewed and confirmed that SSIGLs have met the demands and expectations of users.

Moreover, the Ministry has mobilized resource persons from key Federal, National Regional States level stakeholders and international development partners for review, validation and endorsement of the SSIGLs.

Several hundreds of experienced professionals (who are very qualified experts in their respective fields) from government institutions, relevant private sector and international development partners have significantly contributed to the preparation of the SSIGLs. They have been involved in all aspects of the development of SSIGLs throughout the preparation process. The preparation process included a number of consultation meetings and workshops: (i) workshop to review inception report, (ii) workshop on findings of review of existing guidelines/manuals and proposed contents of the SSIGLs, (iii) meetings to review zero draft SSI GLs, (iv) review workshop on draft SSI GLs, (v) small group review meetings on thematic areas, (vi) small group consultation meetings on its final presentation of contents and layout, (vii) consultation mini-workshops in the National States on semi-final versions of the SSIGLs, and (viii) final write-shop for the appraisal and approval of the final versions of SSIGLs.

The deliberations, concerns, suggestions and comments received from professionals have been duly considered and incorporated by the GIRD Consultant in the final SSIGLs.

There are 34 separate guidelines which are categorized into the following five parts concurrent to SSI development phases:

Part-I. Project Initiation, Planning and Organization Guideline which deals with key considerations and procedures on planning and organization of SSI development projects.

Part-II. Site Identification and Prioritization Guideline which treats physical potential identification and prioritization of investment projects. It presents SSI site selection process and prioritization criteria.

Part-III. Feasibility Study and Detail Design Guidelines for SSID dealing with feasibility study and design concepts, approaches, considerations, requirements and procedures in the study and design of SSI systems.

Part-IV. Contract Administration and Construction Management Guidelines for SSI development presents the considerations, requirements, and procedures involved in construction of works, construction supervision and contract administration.

Part-V. SSI Scheme Management, Operation and Maintenance Guidelines which covers SSI Scheme management and operation.

Moreover, Tools for Small Scale Irrigation development are also prepared as part of SSIGLs.

It is strongly believed and expected that; the SSIGLs will be quickly applied by all stakeholders involved in SSI development and others as appropriate following the dissemination and familiarization process of the guidelines in order to ensure efficient, productive and sustainable irrigation development.

The SSIGLs are envisioned to be updated by incorporating new technologies and experiences including research findings. Therefore, any suggestions, concerns, recommendations and comments on the SSIGLs are highly appreciated and welcome for future updates as per the attached format below. Furthermore, despite efforts in making all types of editorial works, there may still errors, which similarly shall be handled in future undated versions.

UPDATING AND REVISIONS OF GUIDELINES

The GLs are intended as an up-to-date or a live document enabling revisions, to be updated periodically to incorporate improvements, when and where necessary; may be due to evolving demands, technological changes and changing policies, and regulatory frameworks. Planning, study and design of SSI development interventions is a dynamic process. Advancements in these aspects are necessary to cope up with the changing environment and advancing techniques. Also, based on observation feedbacks and experiences gained during application and implementation of the guidelines, there might be a need to update the requirements, provisions and procedures, as appropriate. Besides, day-by-day, water is becoming more and more valuable. Hence, for efficient water development, utilization and management will have to be designed, planned and constructed with a new set up of mind to keep pace with the changing needs of the time. It may, therefore, be necessary to take up the work of further revision of these GLs.

This current version of the GLs has particular reference to the prevailing conditions in Ethiopia and reflects the experience gained through activities within the sub-sector during subsequent years. This is the first version of the SSI development GLs. This version shall be used as a starting point for future update, revision and improvement. Future updating and revisions to the GLs are anticipated as part of the process of strengthening the standards for planning, study, design, construction, operation and management SSI development in the country.

Completion of the review and updating of the GLs shall be undertaken in close consultation with the federal and regional irrigation institutions and other stakeholders in the irrigation sub-sector including the contracting and consulting industry.

In summary, significant changes to criteria, procedures or any other relevant issues related to technological changes, new policies or revised laws should be incorporated into the GLs from their date of effectiveness. Other minor changes that will not significantly affect the whole nature of the GLs may be accumulated and made periodically. When changes are made and approved, new page(s) incorporating the revision, together with the revision date, will be issued and inserted into the relevant GL section.

All suggestions to improve the GLs should be made in accordance with the following procedures:

I. Users of the GLs must register on the MOA website: Website: www.moa.gov.et
II. Proposed changes should be outlined on the GLs Change Form and forwarded with a covering letter or email of its need and purpose to the Ministry.
III. Agreed changes will be approved by the Ministry on recommendation from the Small-scale Irrigation Directorate and/or other responsible government body.
IV. The release date of the new version will be notified to all registered users and authorities.

Users are kindly requested to present their concerns, suggestions, recommendations and comments for future updates including any omissions and/or obvious errors by completing the following revisions form and submitting it to the Ministry. The Ministry shall appraise such requests for revision and will determine if an update to the guide is justified and necessary; and when such updates will be published. Revisions may take the form of replacement or additional pages. Upon receipt, revision pages are to be incorporated in the GLs and all superseded pages removed.

Suggested Revisions Request Form (Official Letter or Email)

To: --
From: ---
Date: ---
Description of suggested updates/changes: Include GL code and title, section title and # (heading/subheading #), and page #.

GL Code and Title	Date	Sections/ Heading/Subheading/ Pages/Table/Figure	Explanation	Comments (proposed change)

Note that be specific and include suggested language if possible and include additional sheets for comments, reference materials, charts or graphics.

GLs Change Action

Suggested Change	Recommended Action	Authorized by	Date

Director for SSI Directorate**: _________________________Date: _________________**

The following table helps to track initial issuance of the guidelines and subsequent Updates/Versions and Revisions (Registration of Amendments/Updates).

Revision Register

Version/Issue/Revision No	Reference/Revised Sections/Pages/topics	Description of revision (Comments)	Authorized by	Date

1 INTRODUCTION

Any development activities including development of irrigated and rained agriculture, should be based on physical resources assessment, soil among others, are important land resource that influences suitability of land for different purposes.

The information from soil survey and land evaluation is important in planning specific land use and the practices needed to obtain desired results. The design of the irrigation scheme itself is dependent on detailed knowledge of soils, lying within the irrigable land. Land evaluation is a step for future land use planning

The use of soil surveys and land evaluation data avoids the waste caused by ignorance of soil limitations when major changes of land use are contemplated or when new lands are to be brought into use.

Soil surveys provide a basis for decisions about the kind and intensity of land management needed, including those operations that must be combined for satisfactory soil performance. For instance, soil survey information is useful in planning, designing, and implementing an irrigation system.

The soil and its associated characteristics obtained from soil survey help agronomist and engineers in selecting suitable crop, estimating crop water requirement; scheduling, frequency of irrigation. the amount and rate to be applied, & design of irrigation lay out (furrow length, width and shape; drainage spacing and leaching requirement), operation and management of irrigation schemes for maintaining optimum soil conditions for plant growth and sustained irrigated agriculture. However, soil survey and land evaluation studies were not carried out for most of small scale irrigation projects in Ethiopia and the system layout and design of irrigation scheme that require soil data were prepared based on literature data and assuming that all the command area is equally suitable and which is unlikely in most of the cases.

In order ensure that soil survey and land evaluation studies are undertaken as part of the study and design of small scale irrigation projects, the presence of standards soil survey and land evaluation guideline in one hand and creating enforcing mechanism to use this standard guideline for the study, design, operation and management of smalls scale irrigation on the other hand are crucial issues that needs to be addressed. Application of soil survey and land evaluation is in small scale irrigation development and management is shown in figure 1-1

The primary intent of this guideline is therefore, to promote accuracy and consistency in methodology and approaches of planning, soil survey and mapping, land suitability evaluation and laboratory analysis and presentation of standard soil survey and land evaluation study reports.

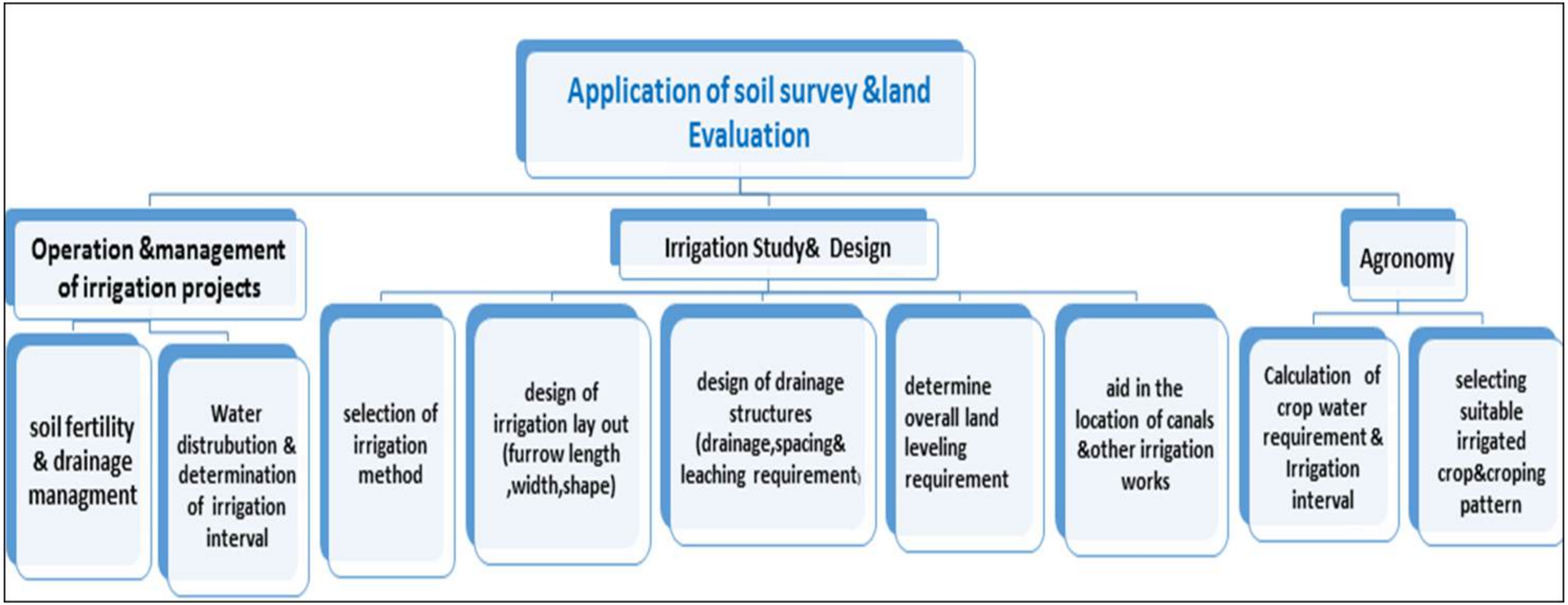


Figure 1-1: Application of soil survey and land evaluation data

2 OBJECTIVES AND SCOPE OF THE GUIDELINE

2.1 OBJECTIVES

The objective of the guideline is to provide basis and establish consistent methodology, approach and procedures in planning, and organizing soil survey, soil description & classification, interpretation and land suitability evaluation in the study of small scale irrigation projects.

2.2 THE ROLE OF SOIL SURVEY IN IRRIGATION DEVELOPMENT

The role of survey in irrigation development will be but not limited to;

- Support the engineer to delineate command area and lay out of the specific ISSIP
- determine extent of potential irrigation suitability for irrigation and quantify the net irrigable land from suitability point of view
- Determine type of irrigation system.
- Support the engineers in planning irrigation infrastructures;
- determine irrigation water needs and Scheduling of Irrigation of specific soil types;
- determine drainage needs of specific soil types;
- determine soil and land management needs including use of fertilizers, use of soil amendments, sub-soiling, safe land levelling, etc
- determine SWC and specifically erosion control needs;
- determining land suitability for specific irrigation type and proposed crops;
- determine toxicity such as salinity and alkalinity, status, reclamation needs;
- Support in delineating water logging of the command area.

2.3 SCOPE

- Prepare soil survey planning and methodology for study of small scale irrigation projects
- Prepare land suitability evaluation methodology and approaches for study of small scale irrigation projects
- prepare soil mapping techniques and description of soil physical and chemical analyses
- Prepare soil laboratory analysis methods and guide for interpretation of laboratory analysis results
- Prepare methodologies and procedures for in situ physical tests
- Prepare soil and land management requirements
- Prepare guide for irrigation water quality evaluation and interpretation

3 SOIL SURVEY PLANNING

3.1 GENERAL

Soil survey planning is important in order to obtain the optimum balance between various activities and to ensure that the work is completed within the time and economic budget allowed. This is best achieved by preparing reasonable work plan before starting field wok.

To deliver timely soil survey data to agronomists and irrigation engineers, soil survey and land evaluation studies should be undertaken as early as possible before other sectoral studies.

The basic procedure of a soil survey includes the following steps:

- Base map preparation
- Preparation of field data format, equipment's
- Auger Survey and Between site observation
- Profile pit description
- In-situ site test
- Sample collection (Both disturbed and undisturbed)
- Updating base map with field survey results
- Laboratory analysis
- Data compilation, analysis and mapping
- Soil characterization and classification
- Soil mapping and Land Evaluation
- Preparing soil, water, crop and land management
- Presenting the results (Report and maps)

3.2 PRE-FIELD WORK

At this planning stage collect, review and compile all relevant background study data on the targeted area including previous soil study reports, topographic maps, Aerial photographs satellite imagery, geologic maps, existing and planned land use and land cover maps and reports. Based on the planning stage, identify the data gaps to be filled. Moreover, preparation of field soil survey guidelines, data collection format for auger and profile description and in situ physical test are part of this planning stage.

All necessary field equipment, material and other logistics will be arranged and fulfilled before departure (Table 3-1).

Table 3-1: List of important Soil Survey Equipment

Nr	Description	Remark
1	Dutch Auger	Required number depend on number of survey crew to be deployed
2	Munsell color chart	,,
3	GPS	,,
4	Alkaline Battery for GPS	
5	Clinometers	,,
6	Double ring infltrometer	,,
7	Core ring &Core sampler	,,
8	Field bags	,,
9	Clip board	,,
10	Plastic bags for soil sample (size 5kg)	,,
11	strings for to tie soil sample bags	,,
12	Markers	,,
13	Measuring Tape(meter)	,,
14	10% HCl and acid dropper	
15	Spades, Shovel, Pickaxes, mattock or crowbar for digging pits	,,
16	sacks for sample packing	
17	Digital Camera	
18	scotch tape/plaster	
19	Stereoscope &AP	

Preparation of Base Map: base maps are prepared by overlay of landform, slope and land use/cover maps from imageries to be later confirmed through ground truthing as shown in Figure 3.3

Creating a slope map from the Digital Elevation Model (DEM) layer
Slope information can be easily computed from grid, raster or digital elevation models (DEMs) using GIS applications. The slope values can be expressed either in degrees or as a decimal (rise/run) which can then be computed as a percentage.

Steps for Generating Slope Map using ArcGIS
The Slope tool can be used to create a slope map by identifying the slope from each cell of a raster surface.

- Add DEM layer of the project area
- Navigate to System Toolboxes > Spatial Analyst Tools > Surface > Slope.
- Select the output of the Topo to Raster tool as the input raster.
- Specify the location of the output raster.
- Select the output measurement.
- Click OK. The slope map is created from the DEM layer.

A typical slope map generated using the above step is shown in Figure 3.1 below.

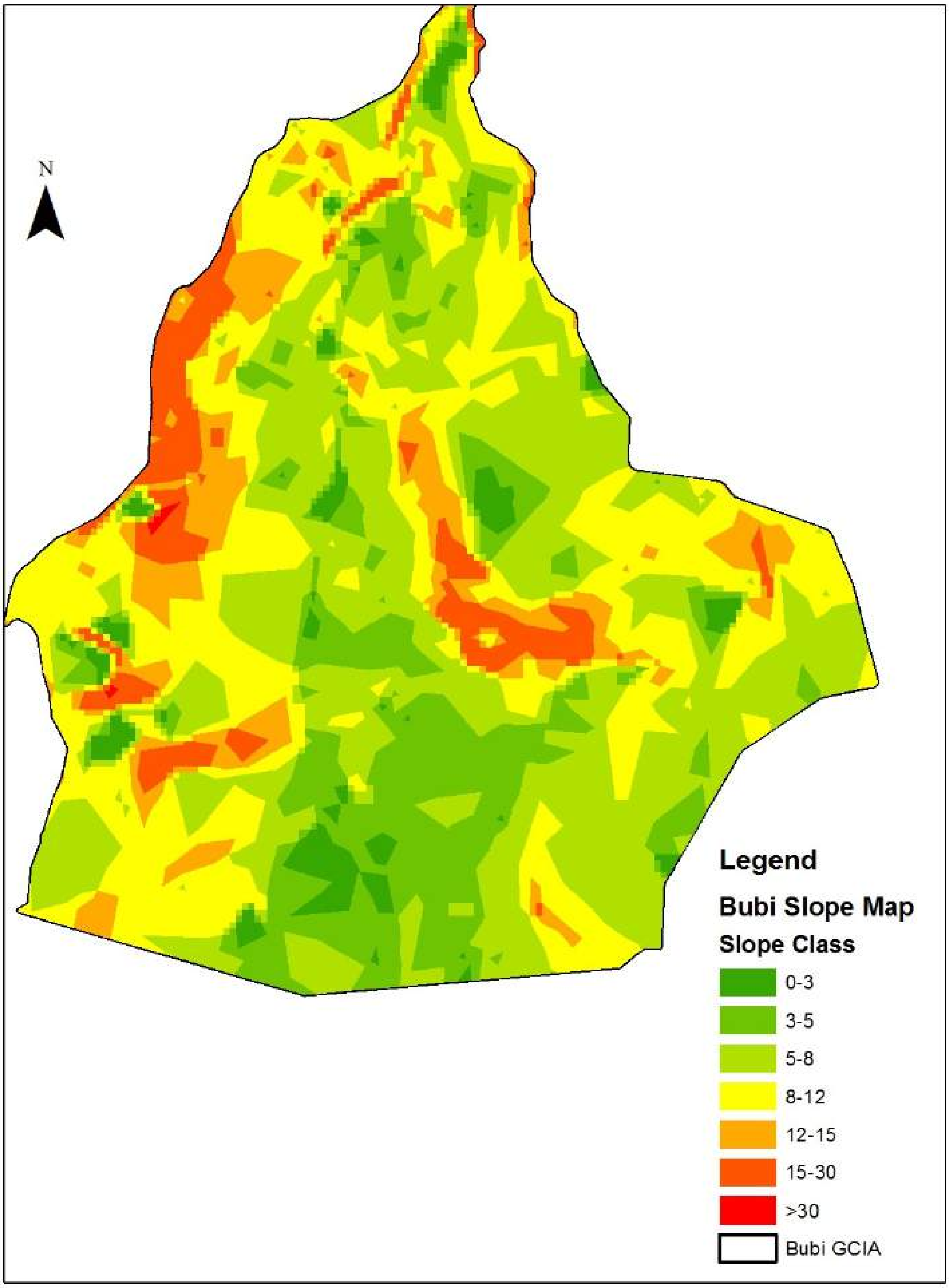


Figure 3-1: Typical Example of SSIP Soil Survey Slope Map

Land Use and Land Cover Map

The distribution of land use/cover can be prepared by using different techniques. For SSIP a land use/cover map can easily be prepared by digitizing the units based on changes in color tone using high resolution satellite imageries.

A typical example of delineated land use/cover from satellite imagery has been given in Figure 3.2 below.

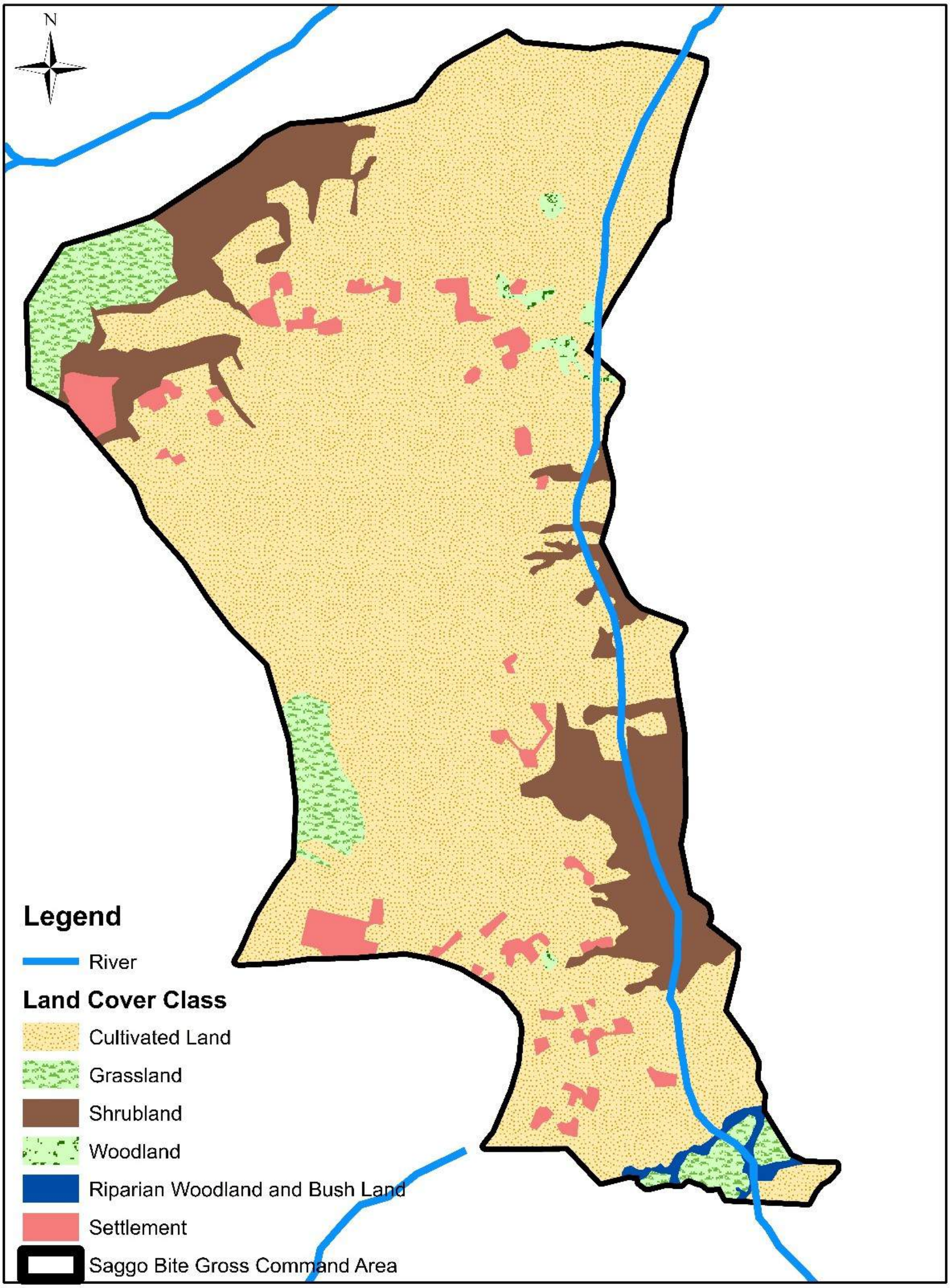


Figure 3-2; Typical Example of SSIP Land Use / Land cover Map

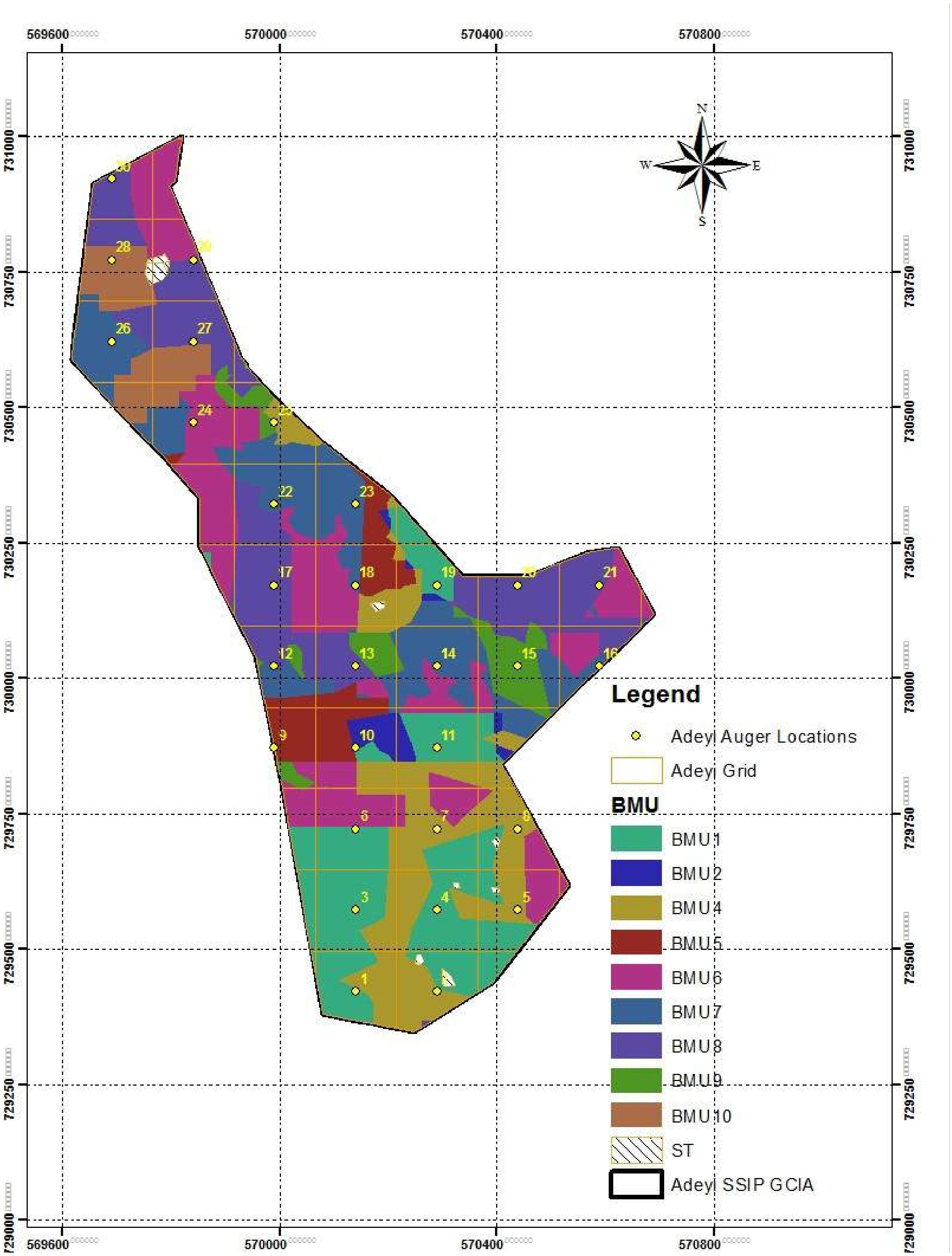


Figure 3-3: Typical Example of SSIP Soil Survey Base Map

3.3 FIELD WORK

The fieldwork should start with community consultation, preliminary field visit, familiarization of the survey crew with the project area and followed by design of the main fieldwork activities including auger-hole and profile description.
Conduct routine auger survey based on the location points from base map and add additional points if necessary.

The soil auger survey has to be described based on the class limits presented in the next sections. Apart from the routine soil augering the survey should note and geo-referenced relevant features along the soil survey traverses. These features include: slope and land form changes; gullies and streams; soil boundaries; rock outcrops; shallow, stony or eroded areas; wet depressions; wells and settlements. Between-sites observations are intended to enhance the accuracy of soil and land use/land cover mapping.

After conducting the routine auger soil survey, the surveyor should characterize and classify the soils in to specific soil types and update the preliminary land unit map.

Based on the extent and the spatial distributions of the land unit, locate and describe profile pit then collect standard representative soil samples for laboratory analysis.

Select representative profiles based on properties which influence the soil water characteristics for in-situ infiltration and hydraulic conductivity tests. From these sites collected undisturbed core samples for Bulk density and AWC analysis to the depth of irrigation.

All survey observation has to be geo-referenced to utilize in GIS environment.

Detail fieldwork activities to be undertaken at feasibility level are presented below under the methodology section.

3.4 DATA INTERPRETATION AND MAPPING

After finalizing field work, submit, the soil samples to accredited laboratories for analysis of important soil physiochemical parameters such as texture, bulk density, soil moisture content at filed capacity and permanent welting point, soil pH, electrical conductivity, available phosphorous organic carbon (OC), total nitrogen, cation exchange capacity, exchangeable cation and exchangeable acidity (pH<5..5)

Calculate soil organic matter (SOM) by multiplying organic carbon by 1.72, percentage base saturation (PBS), Cation-ratio, exchangeable sodium percentage, available water holding capacity (AWC):,Carbon/Nitrogen ratio (C/N): based on laboratory analysis result

Compile and enter all data collected from the fieldwork and laboratory to computer database (Microsoft Access and MS Excel) including database for auger, profile, field test and soil moisture content and physiochemical analysis results for storage and utilization and link to Arc GIS.

Based on the field and laboratory data analysis and interpretation, prepare maps of auger-hole and profile location, major soils, land suitability evaluation and mapping unit at scale of 1:20,000.

4 SOIL SURVEY METHODOLOGY

4.1 SOIL SURVEY METHOD

Major Soil survey methods are divided into Physiography survey, Systematic survey, Grid Survey, Free survey. For small scale irrigation projects, combination of Grid and Free survey is recommended.

4.2 OBSERVATION TYPES, INTENSITY, SAMPLING AND TESTING

Observation intensity should follow standard based on the command area (minimum of a 10: 10:10 rule) i.e 10% of the command area for auger observation, and 10 % of auger-hole observation for profile description and 10 % of profiles for infiltration and hydraulic conductivity test.

4.2.1 Routing auger survey

Auger-hole observations are made to check homogeneity of soil (routine soil observation) and to establish their boundaries. At this level of study adopt free - grid transect to conduct the survey with soil auger observations.
General Procedures:

- Dived the proposed command area into fixed grid transects spaced by 250mx400 m which give auger-hole observation density of 1 per 10 ha
- Align transects lines perpendicular to the general direction of the river and make the observation points closer along the transect
- Use Geographic positioning system (GPS) determine direction (waypoint) and distance between sampling locations.
- Undertake auger-hole observation to 1.2m depth unless hindered by rock
- Register the location of auger-hole observation using the hand-held GPS

Auger observations are then made at free –grid intervals irrespective of the soil or landform boundaries, which may occur in between any two observation points.

The maps are then prepared at a scale of 1: 20,000 scale by delineating the similar observation points together (Figure 4-1). Such surveys are conducted to provide the detailed information required for a proper assessment of the soil properties, terrain features, erosion aspects and related factors which can help working out the details about land evaluation and the management practices that would be needed for ensuring sustained irrigated agriculture and better crop production.

Figure 4-1: Auger-hole samples with arranged based on soil depth &other observed characters

During auger-hole observation record site and soil characteristics such as color, texture, depth of soil, drainage, stoniness, rockiness, evidence of salinity, cracking, land form slope, erosion status, land use and land cover and record on standard auger data collection description sheet. Figure 4-2 and 4-3 below shows sample layout of grid transects that cross different soil, landform, land use and topography.

Figure 4-2: Alignment of auger transects

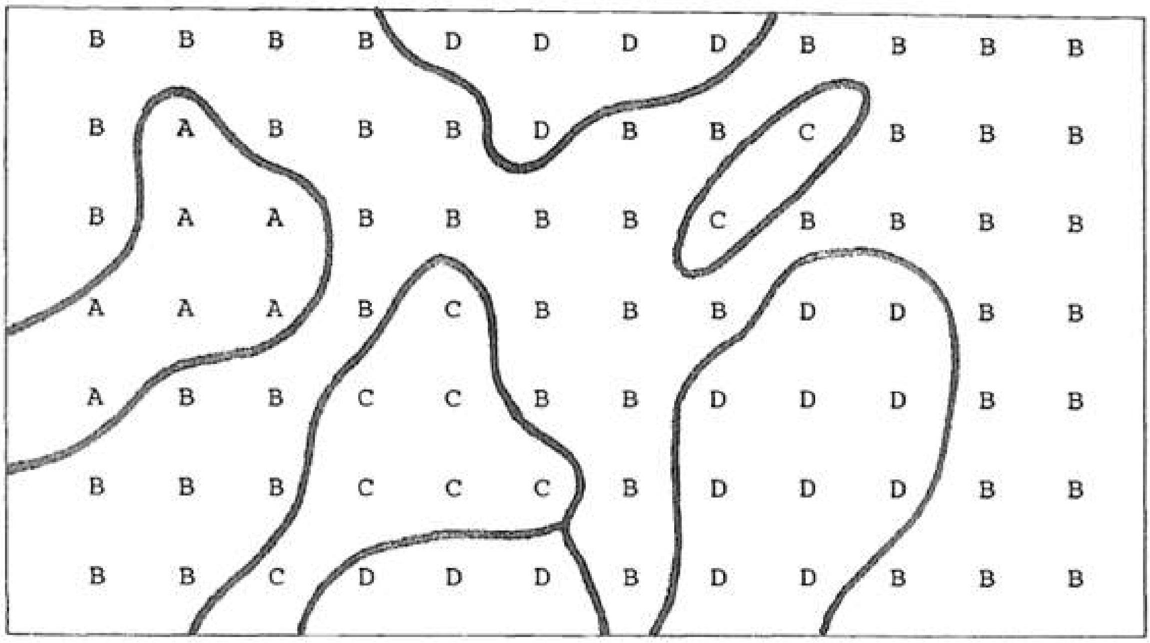


Figure 4-3: An example of layout of auger observation and soil boundary demarcation

4.2.2 Profile description and sampling

By the time that auger-hole observations in the project area approach near completion, select representative sites for all important soils to excavate profiles. The purpose of soil profile description is to obtain detailed information on the morphology, physical &chemical characteristics of each soil unit occupying a significant area of the project.

Number of profiles to be described: Depending upon the soil heterogeneity and variations in the terrain the profile sites for characterization of the soils would be located; at least two profiles shall be described per soil type and/or mapping unit depending on variability of the soils in the area..

The basic steps and considerations to follow when locating and digging an open profile are:

- Locate the profile away from trees, roads, field bunds or wells or soil mapping unit boundaries.
- Align profiles east west
- Dig a profile with very straight sides 2-meter-long, 1meter wide and 2-meter deep soil profile if less, until you reach the parent rock, leaving steps opposite to the description side for easy access. Description side should be selected so that during the time, planned for profile description, sun can be on that soil face
- Throw spoil the top soil in one side and the sub soil in the other side of the pit. Cut a couple of steps into the pit for easy access, digging and sampling.
- Assess the deeper layers by soil auger with particular attention to check depth of parent rock, hard pans, ground water and presence of salinity or alkalinity.
- Take photographs of the surrounding landform and the soil profile. Make sure that the tape appears vertical scale taken after the layers have been identified
- Assess site characteristics around the profile and the vertical variability of the soil horizons in the profile pit and carefully investigating the differencing in color pattern, texture variation, resistance to penetration by knife, consistency, structure, biological activities, humus accumulation, presence of clay coating, inclusions, mottles, slickenside, manganese, cementation, rooting pattern and so on and record on standard profile format (Appendix I).

Sampling soil profile: In terms of obtaining representative soil physical and chemical characteristics the possibility of error due to sampling is far greater than that due to laboratory procedure. Special attention must be given, therefore, to the careful selection of sites for soil sampling soil for laboratory analysis and the collection of the samples themselves to ensure that they are both representative and uncontaminated.

Sampling precautions depend on the nature of the analyses contemplated but the following general precautions should be observed: -

- Carefully clean the whole vertical profile;
- Remove stones and large pieces of organic material such as leaves and roots in surface samples and clean up any spade marks on the sampling face
- Once the whole vertical profile has been carefully cleaned, sample each horizon from bottom to top, starting with the lowest horizon and proceeding upward. This minimizes contamination by falling debris
- Don't touch the sample by hand while sampling to avoid contamination
- Avoid mixing samples from different horizons and make sure soil sample is taken from the middle of soil horizon;
- Hang a tape marked at 10 cm intervals on the left-hand side of the sampling face
- Mark boundary between horizon
- Take at least 1kg of disturbed soil samples using shovel from each horizon for physiochemical analysis. Sample should not be touched by hand during soil sampling to avoid soil contamination and potentially erroneous soil salinity reading sat the laboratories (sweat contamination
- samples should be placed directly in to plastic bags and securely tied
- Securely label all sample bags to correctly indicate the pit identification number of the sampling location, the depths of the horizon sampled and the date. Use more than one label to minimize chance of losing the label. In wet soils, put the label in a second plastic bag.

Describe and classify the soil profiles in accordance with the FAO guideline for profile description (FAO, 2006) and World reference base for soil resource (WRB, 2015).

Then describe and record the following soil physical and morphological properties on the soil profile description sheet (Appendix II). Detail description of soil physical and morphological properties presented in section 6.

- Horizon depth & Horizon thickness
- Horizon nomenclature
- Matrix color (moist) and dry, if the soil sample is originally dry.
- Field soil texture
- Soil structure type, grade, and size
- Dry, moist and wet consistence
- Boundary topography and distinctness
- Depth to, abundance, and contrast of redoximorphic features
- Soil pH (field determination at select locations)
- Hard pan or water-restrictive subsoil features
- Soil stickiness and plasticity estimates
- Depth to bedrock
- Determination of drainage class
- anthropogenic disturbance such as road building, logging, mining and other activities
- Presence of apparent subsurface water tables.
- Land use and land cover etc.

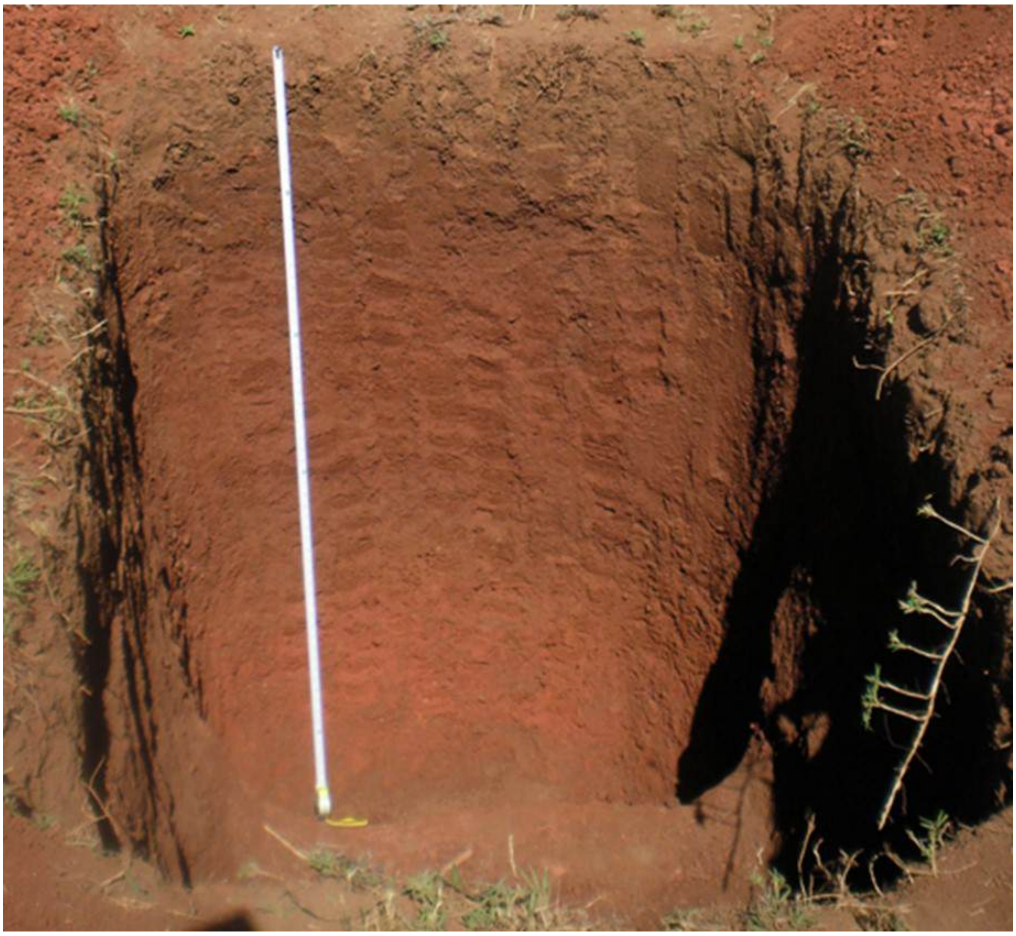


Figure 4-4: soil profile with different horizons

Deep auger boring: Deep boring is made in areas where salinity problem related to ground water rise and permeability problems are suspected. The Purpose is to check characteristics of subsoil and substrata layers with particular reference to permeability and salinity and to locate any impermeable layers and the depth and quality of groundwater. Observation (and laboratory analysis if required) of samples obtained by auger with extension rode on the bottom of profile to a depth of 5m.

Density of deep boring: Undertake at least one deep boring per 50 ha to a depth of 3 to 5 meter. Record all soil horizons in deep borings and should be completely described and retained as permanent records. Sampling at appropriate depths for salinity analysis is usually desirable. Groundwater should be sampled or its electrical conductivity should be determined on the spot. Deep boring is conducted in areas where susceptible ground water, salinity and impermeable layer

Figure 4-5: Deep boring at the base of profile below 200cm

4.2.3 Undisturbed core sampling

Undisturbed core ring soil samples: Undisturbed samples maintaining their natural aggregation in the form of structural peds, voids and the related physical soil characteristics are taken in standard cylindrical containers (core rings) for determination of field capacity, permanent welting point &finally available water holding capacity.

Core ring sampling field technique involves collecting core sample from each major horizon starting from the topsoil to a depth of about 100 cm.

The core samples should be labeled with indelible ink on its outside, as well as on the upper lid, for site number and sampling depth and cover with scotch tape to prevent water loss by evaporation. Take bulk density samples with an extra core sample for determination of bulk density.

Before leaving the site, check that all the required samples are taken and the profile description sheet has been completed.

4.2.4 Laboratory analysis

Selecting a laboratory that can supply fast and accurate results is important since laboratories may vary in providing correct results. Studies have shown that when the same soils were sent to different laboratories requesting, significantly different recommendations have been provided.

For instance, some laboratories in Ethiopia report overestimated values of soil moisture test result (field capacity& permanent welting point), soil organic carbon and available phosphorus values. Therefore, it is important to find and select accredited laboratories before submitting soil sample for laboratory analysis. Soil sample analysis will take about 20 days on average. Table4-1below presents standard laboratory method for soil sample analysis.

Table 4-1: Summary of standard laboratory method

Soil Properties	Method	Remark
ECe	saturated paste, conductivity meter	
pH (1:2.5 soil suspension, water and KCl)	pH electrode	
Texture	Hydrometer method	
Organic Carbon	Walkley and Black	
Free calcium carbonate, CaCO3	Acid Neutralization Method	filtration and titration with NaOH
CEC	ammonium acetate method at pH 7	
Exchangeable cations(Ca, Mg)	atomic absorption spectrophotometer	pH 7.0 ammonium acetate extraction, EDTA titration
Exchangeable cations Na, K	Flame photometer.	pH 7.0 ammonium acetate extraction, flame photometer
Total N	Kjeldahl method	
P (available)	Olsen method	Applicable for pH>7.0
	Bray or Morgan method	Applicable for acid soil
Available potash, K	Morgan‟s solution and flame photometer)	
Exchange acidity (H + Al)	samples with pH <4.5 (1N KCl leachate; NaOH titration)	
Micronutriment analyses (Fe, Cu, Mn, Zn	Atomic absorption spectrophotometer	DTPA extraction

4.2.5 In situ tests

Infiltration Rate: infiltration or water intake rate is important for selection of suitable methods and designs for irrigation systems and management techniques. For example soils with high basic infiltration rates are unsuitable for furrow irrigation instead drip or sprinkler irrigation is preferable.

Appropriate method of IR testing is Double Ring Infiltrometer. The specifications for the set of instrument is as follow

- Three steel cylinder sets, 40cm high (for ease of transport replicate cylinders should be slightly different diameters to allow concentric stacking when not in use: the inner ones should be about 30 cm and the outer ones about 60 cm in diameter; these dimensions allow an old inner tube to be floated in the outer ring to dissipate the force of water during refills.
- One hardwood 15x15 cm timber (optionally having 0.6 cm steel plate bolted to one side)
- Means of storing and transporting water (Drums or Gerry-can plus six buckets)
- 7 kg sledged-hammer, or heavy weight with handle
- Three still wells (20 to 25 cm lengths of 10 cm ID perforated plastic drainpipe) used to reduce movement of water surface caused by refills.
- Three floats and scales; three float guides
- Three old inner tubes
- Piece of sacking and plastic sheet
- Auger and shovel
- Knife or shears for cutting vegetation
- Three stop-watches
- Standard observation form
- See figure 4.6 below

Figure 4-6: Double Ring Infiltrometer with Accessories

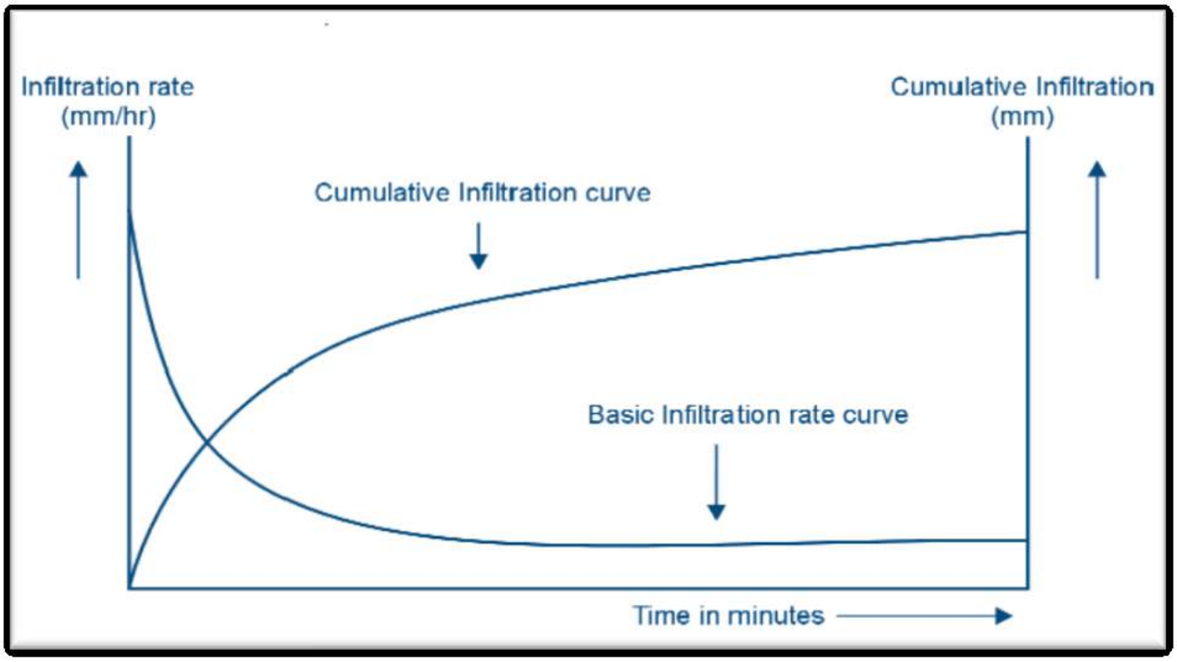
The procedure for installing the infiltrometer & taking measurements is as follows:

- Select possible locations for three to four infiltrometers spread over the irrigation scheme and examine the sites carefully for signs of unusual surface disturbance, animal burrows, stones and so on, as they may affect the test results
- Drive the cylinder into the soil to a depth of approximately 15 cm by placing a driving plate over the cylinder, or placing heavy timber on top, and using a driving hammer. Rotate the timber every few pushes or move the hammer equally over the surface in order to obtain a uniform and vertical penetration.
- Fix a gauge (almost any type) to the inner wall of the inner cylinder so that the changes in water level can be measured
- Fill the outer ring with water to a depth approximately the same as will be used in the inner ring and also quickly add water to the inner cylinder till it reaches 10 cm or 100 mm on the gauge
- Record the clock time immediately when the test begins and note the water level on the measuring rod and properly fill the infiltration test sheets (Appendix V).
- The initial infiltration will be high and therefore regular readings at short intervals should be made in the beginning, for example every minute, after which they can increase to 1,

2, 5, 10, 20, 30 and 45 minutes, for example. The observation frequencies should be adjusted to infiltration rates

- After a certain period infiltration becomes more or less constant (Figure4-7). Then the basic infiltration rate is reached. After reading equal water lowering at equal intervals for about 3 or 5 hours, the test can stop.
- After the tests the cylinders should be washed before they become encrusted. This makes them easy to drive into the soil, with minimal soil disturbance, next time they are to be used.

Figure 4-7: Double ring infiltrometer



Source: FAO 2002

Figure 4-8Basic infiltration rate and cumulative infiltration curves

Hydraulic Conductivity

The average hydraulic conductivity of a soil profile is used to determine subsurface drainage and to evaluate the possibility of perched, water table conditions developing: which may injure crop roots. The inversed auger-hole method should be used for measurement hydraulic Conductivity above water table and auger-hole method when water table is present.

A hole is augured to a certain depth well above the groundwater table. Water is flowed into the dry hole, and then the rate of lowering of the water level is measured. From this rate of decreasing and from the geometry of the borehole, the value of hydraulic conductivity is calculated.

In general, the auger-hole should be filled with water 1 to 3 times on loam and clay soils, depending upon the moisture content of the soil, in order to obtain a difference of less than 10 to 15 percent between the successive measurements. On sandy soils it may be necessary to repeat the measurements 3 to 6 times.

5 DESCRIPTION OF THE LAND CHARACTERISTICS

Land characteristics influence on the planning and design of irrigation schemes. Therefore, understanding and recognizing land and their connections with one another is important for making sound decisions regarding soil use and management.

The following section briefly describes the importance of each land characteristics. The description of land characteristics in the following section should be read with Appendix I: field guide for auger-hole and profile description which presents list of differ land characteristics, their description and class limits.

5.1 TOPOGRAPHY

Topography refers to the configuration of the land surface described in four categories including the major landform, which refers to the morphology of the whole landscape; the position of the site within the landscape, slope form and slope angle.

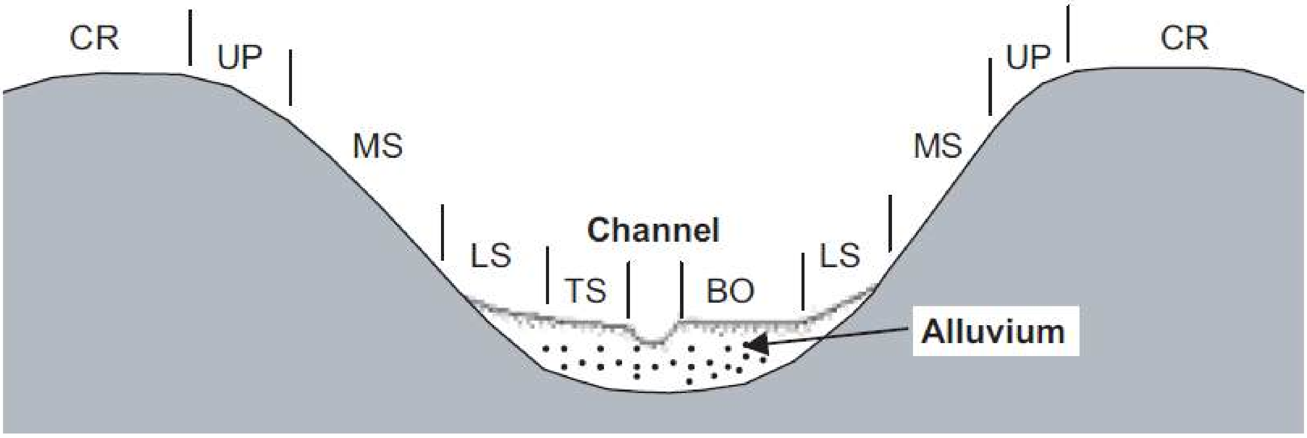
Land topography is often a major factor in irrigation evaluation and selection of the most suitable areas for irrigation as it may influence the choice of irrigation method, drainage, the type of erosion, irrigation efficiency, costs of land development, size and shape of fields, labour requirements, range of possible crops, etc. It is therefore important to record following typographic features at each auger-hole and profile description sites.

Major land form: The land form is the shape of the land surface and should be classified as Level lands **(**Plain, plateau, depression, and valley) and sloping and steep lands (hills, mountains).

Slope gradient (%): The slope gradient refers to the slope of the land immediately surrounding the auger profile site.

Slope may affect intended methods of irrigation, erodibility and erosivity and cropping pattern .It is measured using a clinometers or can be generated from digital elevation model (DEM) of high resolution. Slope description should include actual slope in percent, length and shape.

Physiographic position: position in the landscape is important as it affects the hydrological conditions of the site (external and internal drainage, surface runoff), which may be interpreted as being predominantly water receiving, water shedding or neither of these. It is particularly essential in the case of low lying areas (alluvial flood plain, swamp, lake shores and riparianareas) possible need for flood protection or drainage. Therefore, the relative position of the site within the land should be indicated during field soil survey. Figure 6-1 below indicates the relative position of slope in a land escape.



Position in undulating to mountainous terrain
CR = Crest (summit), UP = Upper slope (shoulder) ,MS = Middle slope (back slope)
LS = Lower slope (foot slope), TS = Toe slope, BO = Bottom (flat)
Source: FAO,2006

Figure 5-1: Slope positions in undulating and mountainous terrain

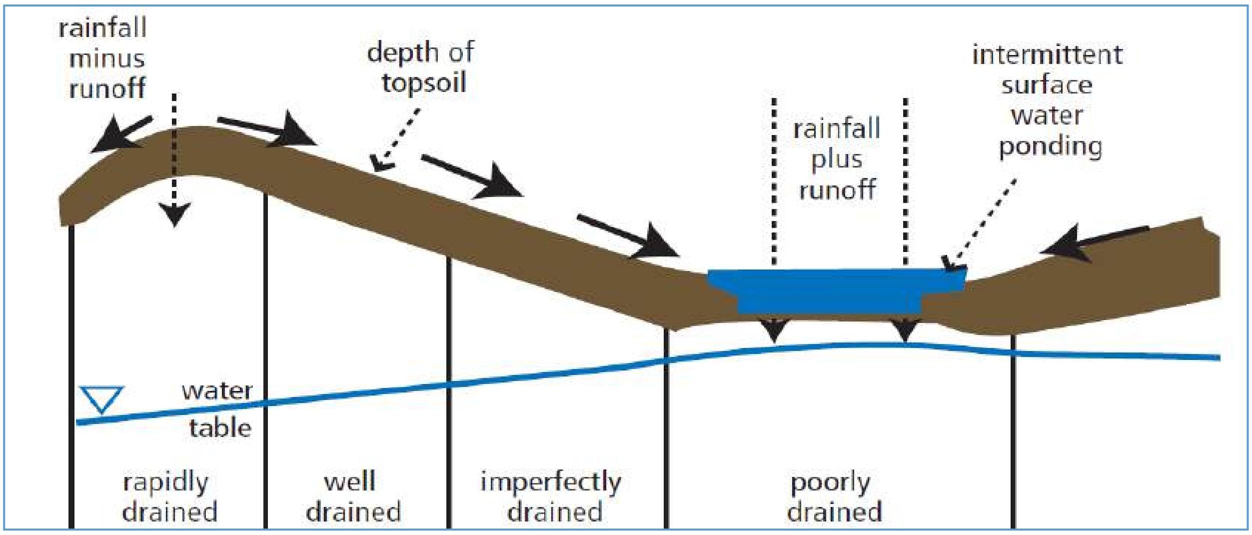
5.2 DRAINAGE

5.2.1 Internal drainage

Internal drainage is the downward flow of excess water. The internal drainage is recognized and recorded in to six classes including very poorly drained, poorly drained, imperfectly drained, moderately well drained, well drained, somewhat excessively drained and excessively drained

5.2.2 External drainage

The external drainage refers to the rate of at which water is removed by over land flow. Ponded, very slow, slow, medium, rapid and very rapid are the six external drainage class to be recorded at each site. Figure 5-2presents effect of topographic position on soil drainage.



Source: Manitoba Agriculture, Food And Rural Initiatives, 2008

Figure 5-2: Effect of topographic position on soil drainage &ground water level

5.3 FLOOD HAZARD

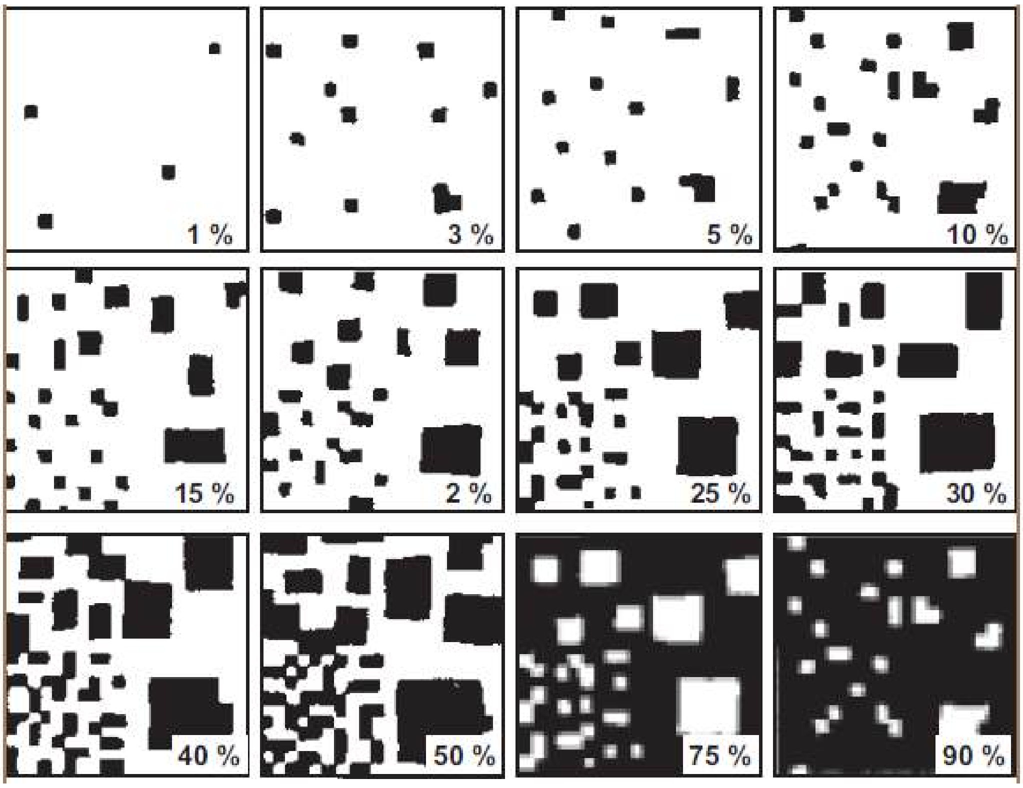
Floods are important events when describing a site. Visual analysis and local knowledge should be used for describing the frequency of floods. Flooding, depth of water and period of inundation (how many days the water stays on the soil surface),

Flooding can be measured by frequency of occurrence: daily, weekly, monthly, quarterly, annually, biannually, every 3,4,5,10, 20, ...etc. years. Duration implies the time elapsed for an hour, 2,3,4, 5 ...etc. hours, for < one day, 1- 15 days, 15- 30 days, 30 - 90 days, 90 - 180 days, 90 - 180 days, 180 - 360 days and continuously flooded.

5.4 STONINESS AND ROCK OUT CROPS

Stoniness refers the relative proportion of stones over 2mm in diameter in or on the soil surface. The presence of stones can limit types of land use. Therefore, stoniness should be visually estimated by the coverage and size of stones

Rock out crops limit the use of agricultural equipment. Rocky outcrops should be described in terms of percentage surface cover, together with size, spacing and hardness of the individual outcrops. Chart for estimating percent of stoniness, rock outcrop nodules, mottles coverage is shown on figure 5-3.



Source: FAO ,2006

Figure 5-3: Chart for visual estimating proportions stoniness, rock fragments, nodules, &mottles

5.5 STATUS OF SOIL EROSION

In describing soil erosion, emphasis should be given to accelerated or human induced soil erosion. Soil erosion should be recorded at each observation site by category (sheet, rill, and gully) & by degree of erosion (slight, moderates, severeextreme).

5.6 SURFACE CRACK

Information on surface crack is important for soil classification and management. Surface cracks develop in shrink–swell clay-rich soils after they dry out. The width of the cracks at the surface and the average distance between cracks should be recorded

5.7 SURFACE SEALING

Surface sealing is used to describe crusts that develop at the soil surface after the topsoil dries out. These crusts may inhibit seed germination, reduce water infiltration and increase runoff. Therefore, the thickness (none, thin, medium, thick & very thick) and consistency (slightly hard, hard, very hard &extremely hard) of surface sealing should be recorded.

5.8 LOCAL GEOLOGY AND PARENT MATERIAL

The parent material is the material from which the soil has presumably been derived. Parent material and geology influence the soil formation, type of soil physical and chemical characteristics. Therefore, it should be described as accurately as possible, indicating its origin and nature.

There are basically two groups of parent material on which the soil has formed: unconsolidated materials including transport material & insitu; and weathering materials overlying the hard rock from which they originate.

5.9 LAND USE AND LAND COVER

Land cover is observed (bio) physical cover on the earth surface. When considering land cover in a strict sense it should be confined to describe the vegetation and the human-made features. However, absence of cover, as where the surface consists of bare rock or bare soil, or a shallow water surface, in practice is described under land cover as well. Land cover should not be confused with land use. For example, woodland or forest is a land cover, but the land use may be hunting. Land Use is the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it. Land use defined in this way establishes a direct link between land cover and the actions of people in their environment (FAO, 2006, FAO, 2007).

Land use applies to the current use of the land, whether agricultural or non-agricultural in which the site/soil is located. Land Cover of the site should be described as it is a dominant factor in soil formation and the primary source of organic matter and because of its major role in the nutrient cycling and hydrology of a site.

Recording and description of land use and land cover enhances the interpretative value of the soil data considerably. For arable land use, the dominant crops grown should be mentioned, and as much information as possible given on soil management and use of fertilizers.

Information on crops is important because it gives an idea of the nature of soil disturbance as a result of crop management practices as well as the nutrient and soil management requirements of the crops.

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6 SOIL PHYSICAL AND MORPHOLOGICAL CHARACTERISTICS

6.1 GENERAL

Soil physical characteristics have great influence on the design, operation and management of irrigation schemes. Therefore, understanding and description of their property is important for making sound decisions regarding the suitability of soil and its management.

The following section briefly describes the importance of each soil physical property which should be measured in the field and some of the property in laboratory.

The description of soil physical and morphological characteristics in the following section should be read with Appendix I: field guide for auger-hole and profile description &Appendix II recommended criteria for interpretation of soil physical& chemical analysis results

6.2 DESCRIPTION OF SOIL PROFILE CHARACTERISTICS

The description of soil profile consists of essentially the description of its several horizons. The soil profile description provides an understanding of the properties and, soil forming processes Soil description is carried out in a soil profile dug at a location specified in the sampling scheme. Table 6-1: below shows important profile characteristics to be described and their application

Table 6-1: Summary important soil profile characteristics and their application

profile characteristics	Application
Horizon boundaries described in terms of depth, distinctness, topography &shape	provide information on the dominant soil-forming processes, soil development, past anthropogenic impacts, Erosional / dispositional status, textural grade
Coatings described in terms of abundance, contrast, nature &location (illuviated clay, coatings of calcium carbonate, manganese, organic or silt), slickenside and pressure faces	Soil classification
Rocks and mineral fragments- Amount and Size	Water holding capacity, weathering status, erosion / depositional character
Mottles described in terms of color, abundance, size & contrast	Drainage condition, oxidation and reduction
Cementation and compaction	physically root restriction
Boundary Distinctness and Shape	Erosional / dispositional status, textural grade
Colour	Drainage, oxidation, fertility, correlation with other physical, chemical and biological properties
Field Texture	Erodibility, hydraulic conductivity, moisture retention, root penetration, CEC
Roots – Amount and Size	Effective rooting depth, vegetative sustainability
Animal burrow Ants, Termites, Worms	Biological mixing depth

6.3 EFFECTIVE SOIL DEPTH

Effective soil depth is the depth of soil at which root growth of grasses or crops is strongly inhibited, rooting depth being plant specific. The effective depth of soil is governed by such factors as the presence of cemented, toxic or compacted layers; hard rock; or indurate gravel layers. A high permanent water table may also control the effective soil depth, but may change after drainage.

Effective soil depth is important criterion for soil and land classification. Depending on the site, soil depth should be recorded and described as very shallow, shallow, moderately deep, deep and very deep.

6.4 COLOUR

Soil color indicates many important soil properties as it provides information about the soil's source materials and the climatic current soil condition, serves as an indicator of current soil: water (or aeration status) and reflects the organic matter status of the soil and is particularly useful when comparing surface materials of long-term cropping. General interpretation of soil colors is given in Figure 6-1**.**

To determine soil color using soil color chart, take a ped of soil from each horizon and note on the data sheet whether it is moist, dry or wet. If it is dry, moisten it slightly with water from your water bottle. Break the ped and stand with the sun over your shoulder so that sunlight shineson the color chart and the soil sample you are examining.

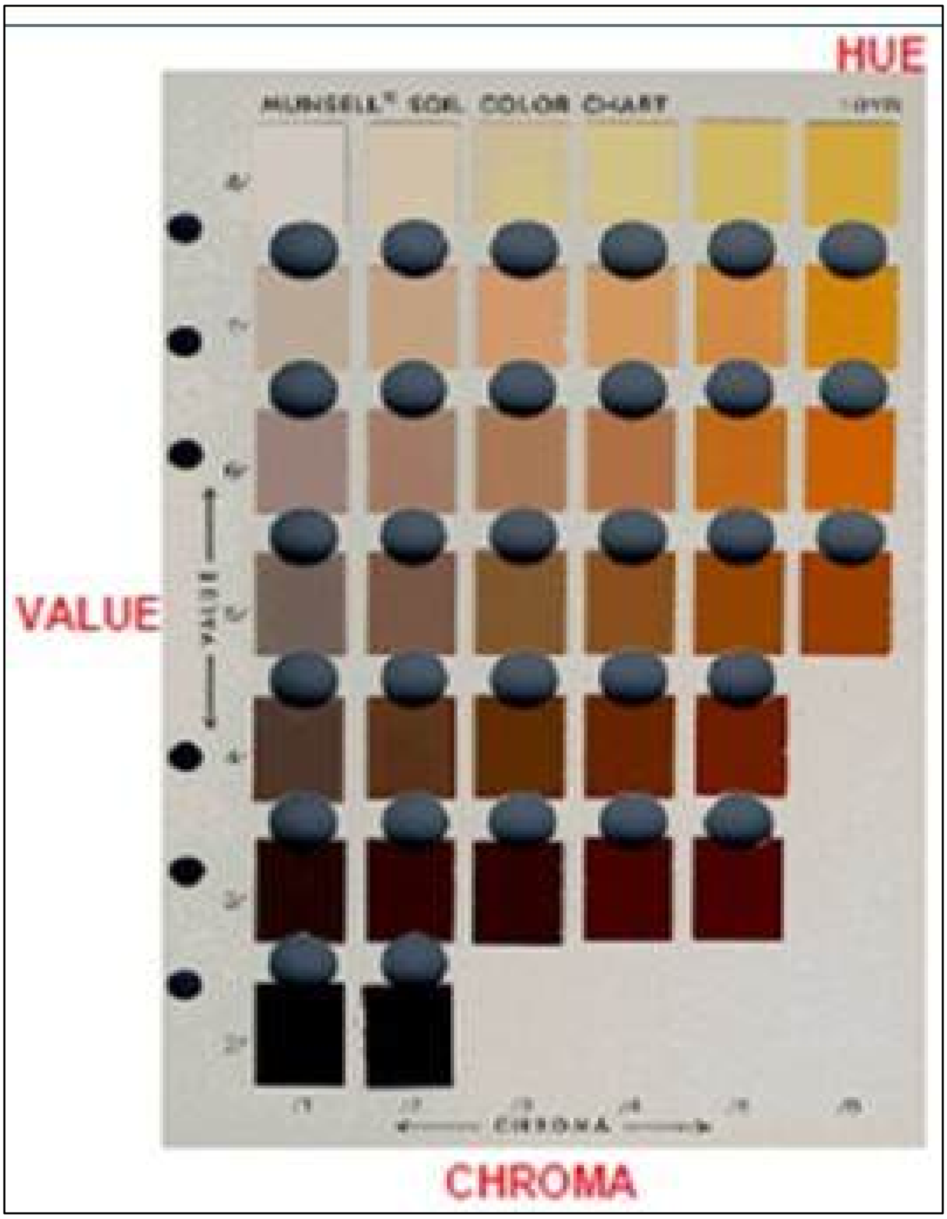


Figure 6-1: Munsell soil colour chart

Table 6-2:General interpretation of soil colors

Soil Color	Due To The Presence Of:	Comments
Dark or black	Organic matter	Mostly found at soil surfaces. Associated with well-aggregated soils with above-average nutrient levels, Manganese
Clear or white	Calcium and magnesium, gypsum, carbonates, soluble salts or high proportion of sand (quartz crystals	May indicate considerable leaching and low organic matter.
Red and bright yellowish	Iron is oxidized and not hydrated with water	Under dry conditions or well-drained soils. The iron oxides have strong surface charge properties that promote good aggregation of soil particles with sufficient porous that allow air and water for root development
Yellowish brown/orange	Less oxidation of iron and hydration	Average air and moisture conditions
Mucky soil mass or clay with spots of red, yellow, and gray colors	Ferrous and ferric compounds	In soils that are waterlogged for at least one part of the year, or due to the activity of plant roots living in ponding
Grey/green/bluish-grey	Iron and manganese in reduced state	In waterlogged soils with lack of oxygen with colorless forms due to the loss of pigments.

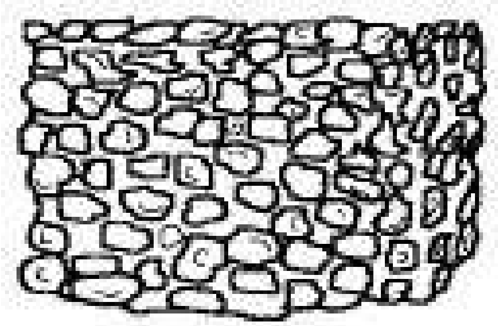
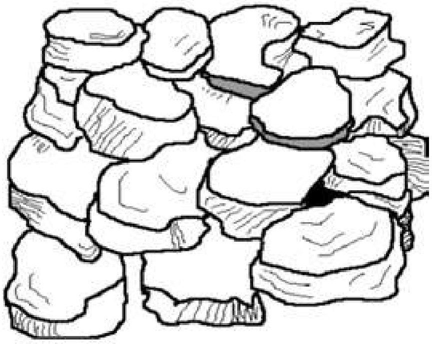
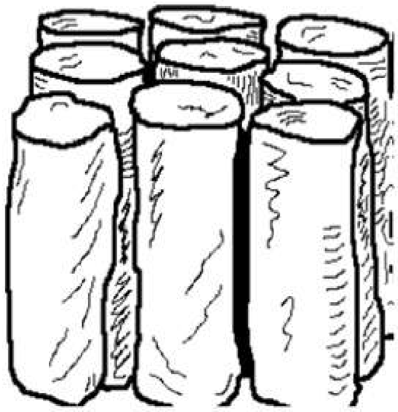
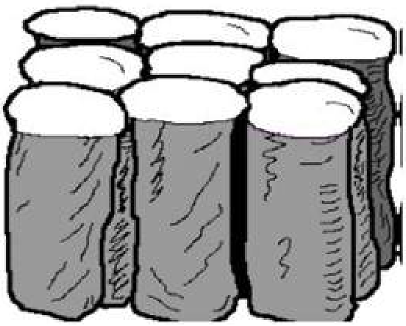
Source: Sigma –Aldrich Corporation., 2015.

6.5 SOIL STRUCTURE

Soil structure is the shape that the soil takes based on its physical and chemical properties. Each individual unit of soil structure is called a ped.

Single grained and massive soils are structure less. In single-grained soils, such as loose sand, water percolates rapidly. Water moves very slowly through most clay soils.

A more favorable water relationship occurs in the soils that have blocky, granular and prismatic structures. Plate-like structure in fine and medium soils impedes the downward movement of water. Structure can be improved with cultural practices, such as conservation tillage, improving internal drainage, liming or adding sulphur to soil, using grasses in crop rotation, incorporating crop residue and adding organic material or soil amendments. Structure can be destroyed by heavy tillage equipment. Figure 6-2 shows the possible choices of soil structure

Granular: Resembles cookie crumbs and is usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.	 
Blocky: Irregular blocks that are usually 1. 5–5.0 cm in diameter.	 
Prismatic: Vertical columns of soil that might be a number of cm long. Usually found in lower horizons.	 
Columnar: Vertical columns of soil that have a white, rounded salt "cap" at the top. Found in soils of arid climates.	 

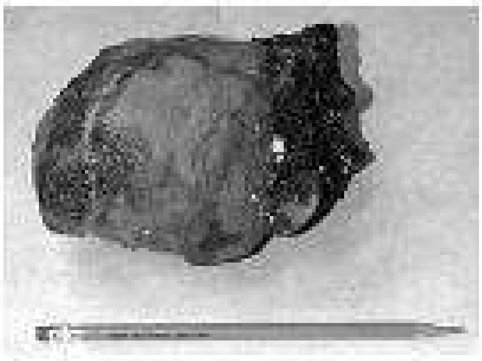
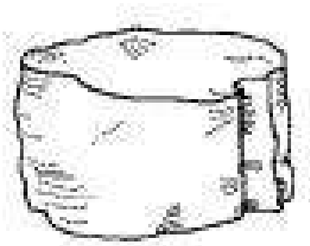
Platy: Thin, flat plates of soil that lie horizontally. Usually found in compacted soil.	
Single-Grained: Soil is broken into individual particles that do not stick together. Always accompanies a loose consistence. Commonly found in sandy soils.	
Massive: Soil has no visible structure, is hard to break apart and appears in very large clods.	 

Figure 6-2: Types of soil Structure

6.6 SOIL TEXTURE

Soil texture is the most stable characteristic of soils and exerts a considerable influence on moisture retention, surface infiltration rate, permeability and capillary flux.

Soil texture the relative proportion of various soil separates in a soil material. On the basis of the relative proportion of these separates, various textural grouping are made. Soil texture is estimated in the Laboratory by actual fractionation into the soil separates.

Texture class is determined in the field by feeling the sand particles and estimating silt and clay content by flexibility and stickiness.

Sand: Is loose and single grained. The individual grains can be readily seen and felt. Squeezed in the hand when dry, sand falls apart when pressure is released Squeezed when moist, it forms a cast, but crumbles when touched. The soil remains loose and can only be heaped into a pyramid.

Loamy sand: Contains a high percentage of sand, but has enough silt and clay to make it somewhat coherent. The individual sand grains can be readily seen and felt. It can be shaped into a ball that easily falls apart.

Silt loam: As for loamy sand, but the soil can be shaped by rolling into a short, thick cylinder.
Loam: Has a relatively even mix of different grades of sand, silt and clay. It is friable with a somewhat gritty feel, but is fairly smooth and slightly plastic. It can be rolled into a cylinder of about 15 cm long that breaks when bent.

Clay loam: As for loam, although the soil can be bent into a U, but no further, without being broken.

Heavy clay: The soil can be bent into a circle without showing cracks.

Appendix VII Presents the procedure and flow chart for determining textural class by feel method in the field

6.7 CONSISTENCY

Consistency refers to the strength and nature of the cohesive and adhesive forces within a soil and the resistance of the soil to mechanical disintegration and deformation. Consistency depends largely on the soil texture, especially the clay content. It also depends on the moisture content of the soil.

Consistence of the soil material is observed for dry and moist soil in the field separately. Stickiness and plasticity are estimated at the appropriate moisture content in the soil.

Plasticity: Plasticity is the degree to which puddled soil material is permanently deformed without rupturing by force applied continuously in any direction. The determination is made on thoroughly puddled soil material at water content where maximum plasticity is expressed

Stickiness: refers to the capacity of a soil to adhere to other objects. The determination is made on puddled < 2 mm soil material at the water content at which the material is most sticky. The sample is crushed in the hand, water is applied while manipulation is continued between thumb and forefinger until maximum stickiness is reached.

To determine Soil Consistence:

- Take a ped from the top soil horizon. If the soil is very dry, moisten the face of the profile using a water bottle with a squirt top and then remove a ped to determine consistence. (Repeat this procedure for each horizon in your profile.)
- Holding it between your thumb and forefinger, gently squeeze the ped until it pops or falls apart.
- Record one of the following categories of moist soil consistence on the data sheet.

Figure 6-3 below presents description of moist soil consistency

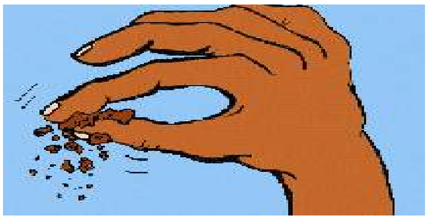
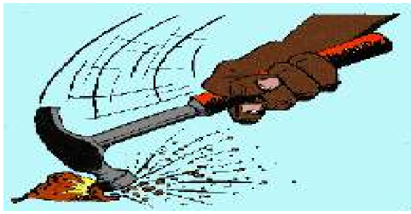
Loose: You have trouble picking out a single ped and the structure falls apart before you handle it. Note: Soils with Single-Grained structure *always* have Loose consistence.	
Friable: The ped breaks with a small amount of pressure.	
Firm: The ped breaks when you apply a larger amount of pressure and the ped dents your fingers before it breaks.	
Extremely Firm: The ped can't be crushed with your fingers (you need a hammer!)	

Figure 6-3: Moist soil consistency

6.8 BULK DENSITY

The bulk density varies indirectly with total pore space present in the soil and gives a good estimate of porosity of soil. Bulk density is great in understanding the physical condition of soil. Soil bulk density is defined as the ratio of the mass of the oven dry soil to its bulk volume.

Measurements of bulk density are commonly made by carefully collecting a soil sample of known volume and then drying the sample in an oven to determine the dry weight fraction.

Bulk densities of highly productive soils usually range from 1.0-1.5 (medium to fine texture) and 1.1-1.65 (coarse texture). Excessive bulk densities inhibit root penetration and proliferation and may impede drainage, infiltration and permeability rates are usually low in medium or fine textured soils with bulk densities exceeding 1.65.

Then the dry weight of the soil is divided by the known sample volume to determine bulk density.

$$D_s = \frac{\text{Mass (weight) of dry soil}}{\text{Bulk volume of soil}}$$

Where:

Ds = Soil bulk density

Most methods developed for determining bulk density use a metal cylinder sampler that is driven into the soil at a desired depth in the profile. Bulk density varies considerably with depth and over a site. Thus, it is generally necessary to repeat the measurements in different places to develop reliable estimates.

Worked example:
A cylindrical core soil sample 10 cm in diameter and 10 cm long has been carefully taken so that negligible compaction has occurred. It was weighed before oven drying (1284 g) and after (1151 g). Calculate the bulk density of the soil.

Mass of dry soil=1151 gm

$$V = Ah = \pi r^2 h$$

∏=3.14, r=5, h=5

V=3.14 * (5 cm)^2 * 10 cm =785 cm^3

Bulk density = 1151 g / 785 cm^3= 1.466 g/cm^3

6.9 INFILTRATION

Infiltration refers to the process of downward entry of water in to the soil. This is an important process because its rate often determines the amount of accumulation or runoff over the soil surface during irrigation or precipitation. Hence, infiltration measurement enables the soil surveyor to provide the agronomist and irrigation engineer with basic intake curves on which field design and irrigation practices can, in part, be based

Table 6-3: Infiltration Rates in Relation to Soil Texture

Texture	Representative infiltration rate (cm/hr)	Normal infiltration rate 9cm/hr)
Sand	5	2-5
Sandy loam	2	1-8
Loam	1	1-2
Clay Loam	0.8	0.2-1.5
Silty clay	0.2	0.03-0.5
Clay	0.05	<0.1-0.8

Source: Landon, 1991

6.10 HYDRAULIC CONDUCTIVITY

The saturated hydraulic conductivity is a measure of readiness with which a saturated soil transmits water through its body and is expressed as length per unit time. Hydraulic conductivity is of a considerable importance for irrigation, drainage and evaporation studies.

Saturated hydraulic conductivity of the surface soil is important for agronomic and water management purposes including design of irrigation systems. Hydraulic conductivity is very variable, depending on the actual soil conditions. In clear sands it can range from 1-1 000 m/day, while in clays it can range from 0.001-1 m/day.

Several methods for field measurement of hydraulic conductivity have been established. The most commonly used methods auger-hole and inverse auger-hole methods.

Auger-hole method

The auger-hole method is based on a hole bored in to the soil to a certain depth below the water table. When equilibrium is reached with the surrounding ground water, a volume of water is removed from the hole and the surrounding ground water allowed to seep in to replace it.

The rate at which the water rises in the hole is measured and then converted by a suitable formula to the hydraulic conductivity (K) for the soil. The use of this method is limited to areas where a high GWT occurs.

Inverse Auger-hole

The inverse auger method is an auger-hole test above the water table. In general, the auger-hole should be filled with water 1 to 3 times on loam and clay soils, depending upon the moisture content of the soil, in order to obtain a difference of less than 10 to 15 percent between the successive measurements. On sandy soils it may be necessary to repeat the measurements 3 to 6 times.

The Hydraulic Conductivity data above the ground water can be calculated using the formula:

$$K = \frac{1.15r[\log(h(t_1) + r/2) - \log(h(t_n) + r/2]}{t_n - t_1}$$

Where,

K= Hydraulic Conductivity

h(ti) =depth of water above base of hole at start of test, cm

h(tn) =depth of water above base of hole at finish of test, cm

tn-ti = total (cumulative) time, seconds

r =radius of auger-hole

Worked Example:

A hole with a diameter of 8 cm was augured to a depth of 40 cm above the groundwater table (on replicate) on a Cambisol with a sandy topsoil and gravelly sub soil. Water is flowed into the dry hole, and then the rate of lowering of the water level was measured. The depths of water above base of hole at start and finish of test for the 3 replicate are given in table 7-4 below. Calculate the hydraulic conductivity of the soil in m/day?

Table 6-4: scummy of Hydraulic conductivity measurement data &its calculation

Profile code	Rep. No	Soil type	Depth cm	r	1.15r	h(ti)	r/2	h(ti)+r/2	A			B	C	E	F	G	K, m/day
									log (h(ti)+r/2)	h(tn)	h(tn)+r/2	log (h(tn)+r/2	A-B	tn-ti	C/E	1.15r*F	F*864
	1		40	4	4.6	24	2	26	1.41	20	22	1.34	0.07	616	0.000118	0.000542	**0.47**
	2		40	4	4.6	24	2	26	1.41	18	20	1.30	0.11	484	0.000235	0.001083	**0.94**
P01	3	**Cambisol**	40	4	4.6	24	2	26	1.41	18	20	1.30	0.11	60	0.001899	0.008736	**7.55**
Average																	2.98

Table 6-5: Approximate relationship between soil texture, soil structure and hydraulic conductivity

Texture	Structure	Hydraulic Conductivity (cm/hr)	m/day
Coarse sand , gravel	Single grain	> 50	>12
Medium sand	Single grain	25 - 50	6 - 12
Loamy sand, find sand	Medium crubm, Single grain	12 - 25	3 - 6
Fine sandy loam, sandy loam	Fine crumb, coarse granular & sub angular blocky	6 - 12	1.5 - 3
Light clay loam, silt, silt loam, v.fine sandy loam, loam	Medium prismatic, sub-angular & angular blocky	2 - 6	0.5 - 1.5
Clay, slity clay, sandy clay, clay loam, silty clay loam silt loam, silt, sandy clay loam	Fine & medium prismatic, platy, angular blocky	0.5 - 2	0.1 - 0.5
Clay loam, silty clay, clay, sandy clay loam	Very fine & prismatic, angular. Blocky, platy	0.25 - 0.5	0.1- 0.05
clay, heavy clay	Massive, very .fine / fine columnar	<0.25	<0.05

Source: Landon, 1991

6.11 SOIL WATER RETENTION CAPACITY

Knowledge of the amount of water retained at various soil water suctions such as saturation (S), field capacity (FC), refill point (RP), and permanent wilting point (PWP) is required for many purposes and is frequently used in irrigation.

6.11.1 Field capacity (FC)

Field capacity is defined as the condition in a soil where free drainage of fully saturated soil took place for about 1 to 2 days and the maximum amount of water that a particular soil can temporarily hold. Depending on soil type the soil moisture at FC is held with a tension of 0.1- 0.3 atmosphere (bars). The lighter the soil the lower the soil tension.

6.11.2 Permanent welting point

The permanent wilting point of a soil is the condition where the suction force of plant roots cannot overcome the tension of 15 atmospheres (bars) and the remaining water is held around the soil particles. Sand can store less water than clay or loam but, put under a slight pressure, sand releases the water more easily than clay or loam. It should be mentioned that the structure also plays a role: well aggregated soil can store water in between the macro-pores of the aggregates.

6.11.3 Available water holding capacity (AWC)

The values of AWC are most commonly used for determination of the depth and frequency of irrigation required and they are frequently quoted as millimeter per meter.
The water-holding capacity of a soil or the available moisture is defined as the difference between field capacity (FC) and permanent wilting point (PWP).

Having determined the moisture content at FC and PWP, the water-holding capacity of the soil or the total available soil moisture on a volumetric basis in millimeter per meter can be calculated by the following equation:

AWC = <u>Field capacity (% by wt) - Water content at wilting point * B.D * horizon depth</u>
100

Where:
AWC: Available water holding capacity
B.D: bulk Density

Worked Example:
A reddish brown soil with top soil horizon depth of 0-10 cm has a bulk density of 1.4 g/cc and soil moisture content at field capacity (FC) and permanent welting (WP) 23.3% &14.53 % respectively. The sub soil with a depth of 10-100 cm has a bulk density 1.58, moisture content at FC of value of 11.49 % and PWP of 4.42% Calculate the corresponding available water holding capacity per top 1meter.

AWC of soil horizon 1 = (FC - PWP) * BD*soil depth= (23.3-14.53) *1.4*10/100=12.28 mm (per 10 cm of soil)

AWC of soil horizon 2 = (FC - PWP) * BD*soil depth= (11.49-4.4) *1.4*90/100=100.5 (per 90 cm of soil)

AWC per top 1.0 m=12.28+100.5=**112.8 mm/m**

Table 6-6: Range of average moisture contents for different soil textures

Textural Class	Field Capacity (Vol. %)	Permanent Welting Point (Vol. %)	Water-Holding Capacity (WHC) or Available Moisture(Mm/M)
Sandy	10-20 (15)	4-10 (7)	60-100 (80)
Sandy loam	15-27 (21)	6-12 (9)	90-150 (120)
Loam	25-36 (31)	11-17 (14)	140-190 (70)
Clay loam	31-41 (36)	15-20 (17)	160-210 (190)
Silty clay	35-46 (40)	17-23 (19)	180-230 (210)
Clay	39-49 (44)	19-24 (21)	200-250 (230)

Source: FAO,2002

7 SOIL CHEMICAL CHARACTERISTICS

Soil chemical properties have great influence on planning soil and agronomic programs best suited to the proposed irrigation projects and preparation of land evaluation reports.

This chapter describes the importance of each soil chemical properties should be measured in the laboratory.

The description of soil chemical characteristics in the following section should be read with Appendix II: recommended criteria for interpretation of soil physical and chemical analysis result.

7.1 SOIL REACTION

Soil reaction is an important characteristic in soil studies because of its intrinsic importance in various phases of soil development. The determination of pH in soil survey is important as it plays a great role in availability of nutrients to plants. Soil pH is a useful indicator of soil health and other soil properties.

It has a large influence on microbiologic activities, availability and uptake of various plant nutrients, and the reaction of applied fertilizer to the soil. The intensity ‘of soil acidity or alkalinity is expressed as pH value.

The pH value is determined by in soil-water suspensions (pH H_2O) and pH in potassium chloride (pH (KCl). When ΔpH, (pH $_{KCl}$ – pH $_{H2O}$) is negative, it indicate that the soils have colloidal complexes of net negative charges.

pH values of water saturated soil paste above 7.6 usually indicate the presence of alkaline earth carbonates, but a non-calcareous and non-sodic soil may have a pH as higher as 7.4. soils with pH value less than 7.5 almost always contain no alkaline earth carbonate and those less than 5.5 contains significant amount of exchangeable hydrogen or aluminum. pH (paste) values 8.5 commonly suspect /indicate an exchangeable sodium percentage above 15 with values below 8.5 the exchangeable sodium percent may or may not exceed 15.

Table 7-1: Soil pH rating

PH	Rating
< 4.5	Extremely acid
4.5 - 5.0	Very strongly acid
5.1 - 5.5	Strongly acid
5.6 - 6.0	Moderately acid
6.1 - 6.5	Slightly acid
6.6 - 7.3	Neutral
7.4 - 8.0	Slightly alkaline
8.1 - 9.0	Strongly alkaline
>9.0	Very strongly alkaline

Source: Landon, 1991

7.2 ELECTRICAL CONDUCTIVITY

The determination of electrical conductivity in soil studies and land evaluation serves to give an idea of the total quantity of soluble salts and the degree of salinity. Salinity is the prominent features of arid and semiarid areas where there is insufficient rainfall to leach soluble salts of mostly chlorides and sulfates of sodium, calcium and magnesium. These salts will remain on the surface after evaporation of the limited available moisture due to high temperature. The critical level of electrical conductivity of saturated soil paste extracts (ECe) for most crops is 4 dS/m. Soils with ECe greater than 4 dS/m are saline soils. These are considered restrictive for most crops and values as low as 2 dS/m may affect the more sensitive crops (Table 7-2).

Table 7-2: Classification of salt-affected soils

Salt-affected soil classification	Electrical conductivity (EC)	Sodium adsorption Ratio(SAR)	Exchangeable sodium Percentage(ESP)
None	Below 4	Below 13	Below 15
Saline	Above 4	Below 13	Below 15
sodic	Below 4	Above 13	Above 15
Saline-sodic	Above 4	Above 13	Above 15

Source: Oregon State University, 2007

7.3 ORGANIC CARBON &ORGANIC MATTER

Organic carbon (OC) is often used as a measure of the quantity of organic matter in the soil, which in turn is taken as a crude measure of fertility status.

Determination of organic matter in soil and land evaluation studies helps to distinguish soils that may behave differently, but is rarely useful in predicting yields of irrigated crops. It is very seldom a proper criterion for grouping soils in categories of varying suitability for irrigation.

Besides its value as a source of plant nutrients, organic matter has a favorable effect upon soil physical properties especially soil structure.

The organic matter content of a typically well drained mineral soil is low varying from 1 to 6% by weight in the top soil and even less in the subsoil. Measured organic carbon is multiplied by a factor of 1.72 to obtain percent of organic matter.

A high organic matter content may be indirect importance in evaluating the nature and influence of other soil characteristics, e.g. texture, water holding capacity, cation exchange capacity and clay mineralogy.

Soil with very high organic matter content (peat soils, Histosols) present pronounced problems for irrigation because of their instability, and require special management techniques, such as sub-irrigation.

The C: N ratio is generally used as indicator of the level of humification, the type of organic matter present and the resultant availability of soil nitrogen to plants.

Soils with narrow range (<10:1) have good quality of organic matter and humification and relatively rich in nitrogen. Soils with higher ranges of ratio (>14:1) have poor humification and relatively low nitrogen which implies that the breakdown and humification of humus materials are low.

7.4 TOTAL NITROGEN

The total nitrogen is an indicator of the total amount of the different form of nitrogen such as organic nitrogen, NO3, NO2-, and NH4 ions. Nitrogen is one of the essential nutrient elements that are taken up by plants in greatest quantity after carbon, oxygen and hydrogen.

7.5 AVAILABLE PHOSPHOROUS

Next to nitrogen, phosphorous is most critical essential element in influencing plant growth & production. Available Phosphorus, is the amount of P readily available for nutrient absorption by the plant roots. Table 7-3 presents range of available phosphorus rages determined by different laboratory methods.

Table 7-3: Range of available phosphorus

Available(ppm)	Interpretation	Methods
<10	Low and crop respond to application of phosphate fertilizer is expected.	Mehlich
11-31	Moderate and response to phosphorus fertilizer is probable	
>31	High and phosphate response unlikely	
<15	Low& fertilizer response most likely	Bray
15-50	Medium& fertilizer response probable	
>50	High &fertilizer response unlikely	
<5	Low & fertilizer response most likely	Olsen
5-15	Medium & fertilizer response likely	
>15	High &fertilizer response unlikely	

7.6 AVAILABLE POTASSIUM

Next to nitrogen and phosphorous, potassium is the most critical essential element in influencing plant growth and production.

Potassium is essential for photosynthesis, for protein synthesis, for starch formation and for translocation of sugars. Also, it exerts a balancing effect on the effects of both nitrogen and phosphorous. Thus, it is essential to determine the available potassium present in soil.

7.7 EXCHANGEABLE CATIONS

The levels of exchangeable cations in a soil are more immediate value than CEC, because they do not only indicate existing nutrient status, but can also be used to asses balance among different cations. This is of great importance because many effects, for example on soil structure and on nutrient uptake by crops, are influenced by the relative concentration of exchangeable cation.

Exchangeable calcium values greater than 6 me/100 g of soil are considered to be adequate for the nutrition of most crops. Normally ca deficiency as a plant nutrient occurs only in soils of low CEC at pH of 5.5 or less.

The presence of Mg deficiency in a crop may not only be associated with low Mg content in a soil but also with the presence of other cations particularly Ca and K. Exchangeable magnesium greater than 3 me/100 g soil is considered adequate for plant nutrition.

Exchangeable potassium less than 0.1 me/100 g soil are considered deficient, from 0.1 to 0.2 me/100 g intermediate and greater than 0.2 me/100 g adequate. In general terms K fertilizer is likely when a soil has an exchangeable value of below 0.2 meq/100g of soil.

7.8 CATION EXCHANGE CAPACITY

The CEC is the capacity of soil to hold and exchangeable cations. The higher the CEC of soil, the more cations it can retain.

The cations exchange capacity depends on amount and kind of clay and organic matter present. High clay soil can hold more exchangeable cations than a low clay soils. CEC also increases as organic matter increases. So, the kind and amount of clay and organic matter content greatly influence the CEC of soil.

7.9 EXCHANGEABLE SODIUM PERCENTAGE

The exchangeable sodium percentage (ESP), which equals exchangeable sodium (meq/100 g soil) divided by the cation exchange capacity (meq/100 g soil) times 100, is the primary measure of sodicity. It is widely used to measure the effect of high sodium level. An ESP value of 15% is often regarded as the boundary between sodic and none sodic soils.

High levels of exchangeable sodium cause increased dispersion and swelling, reducing water movement and affecting aeration and increase the pH thereby adversely affecting both the physical and nutritional properties of the soil with consequent reduction in crop growth. Therefore, both exchangeable sodium percentage and Sodium Adsorption Ratio should be determined in soil and land evaluation studies.

7.10 CALCIUM CARBONATES

The amounts of carbonates present, the form of its distribution in soil are all important in the suitability evaluation of soils for agriculture. High levels of carbonate (>15%) affect physical as well as chemical characteristics of a soil. Continuous horizon of carbonate accumulation may not restrict water movement severely, but may prevent root penetration.

The presence of calcium carbonate ($CaCO_3$) insoil could be determined in the field by adding some drops of 10-percent HCl to the soil. In calcareous soils if CaCO3 is present in problematic amount, improvement may be done by drainage of subsoil for breaking the hard pan formed due to CaCO3 accumulation at lower depth and leaching. If there is a caco3 indication, samples should be analyzed for $caco_3$ in the laboratory

7.11 EXCHANGEABLE ACIDITY (AL AND H)

Exchangeable hydrogen together with exchangeable aluminum is known as soil exchangeable acidity.

Soil acidity occurs when acidic H+ ions occur to a great extent and when the Al^{3+} ions in the soil solution reacts in water (hydrolysis) and the reaction results in the release of H+ and hydroxyl Al3+ ions into the soil solution. The H+ ions thus released lower the pH of the soil solution and are the major sources of hydrogen in highly acidic soils.

In soils, the concentration of the H+ to cause acidity is pronounced at pH values below 4 while excessive concentration of Al3+ is observed at pH below 5.5. Presence of more than 1 mg/kg of Al3+ in the soil solution can significantly bring toxicity to plants. If the p^H of soil is <5.5, the sample should be analyzed for exchangeable acidity.

7.12 MICRO NUTRIENTS

Micro nutrients play a vital role in the growth and development of plant. Micro nutrients like B, Cu, Fe, Mn, and Zn though required in lesser amounts for plant growth but are as essential as N, P and K. Micro nutrients also play an important role in the absorption and translocation of major plant nutrients like N, P and K.

In recent years, attention is given to the use of micro nutrients in Ethiopia. Fertilizer blending plants have been established for blending DAP&UREA with important micro nutrients. The micro nutrient level of soils over all the country is studied & determined by ATA. So, these secondary micro nutrient data should be used. But if micro nutrient deficiency symptom is observed, then soil samples should be analyzed for micro nutrient level.

Boron: Boron is unique in soils by its narrow range between deficiency (for plant growth) and toxicity.

Boron deficiency occurs at lower level less than 0.2ppm in fairly fertile sandy soil (coarse textured soil) than in fine textured soils. A common result of boron deficiency in all crops is an interruption in flowering and fruiting.

Copper (Cu): The soils in which copper (Cu) deficiency occurs are usually organic soils, calcareous soils or sandy soils.

Copper deficiency starts from values as low as 0.2ppm and toxicity occurs from values as high as 200ppm. Copper availability is influenced by soil PH and it's availably decrease slowly with increasing PH.

Iron (Fe): Iron (Fe) deficiency is common in leached tropical soils, particularly in calcareous soils derived from limestone and in poorly drained soils.

Crop response to Fe is likely if iron concentration in soil is less than 5 ppm, probable between 5-10 ppm and unlikely greater than 10ppm of iron concentration in soil.

Manganese (Mn): Manganese acts as catalyst in oxidation and reduction reactions within the plant tissues. It helps in chlorophyll formation, supports movement of iron in the plant, counteracting the bad effect of poor aeration.

Toxic levels of Mn are most common in acid soils with pH values <5.5 or less but plant response to high value varies.

Crop responses to Mn fertilizer on soils with low extractable Mn are more likely in high pH .Soil manganese deficiency occurs at high pH and in naturally poorly drained soils. Manganese concentration values less than 15 ppm are considered deficient, 15-100 normal and greater than 100ppm toxic to plants.

Zinc (Z): Sometimes zinc (Zn) may be present in the soil, but not available to plants. A high soil pH or a calcareous soil means that zinc is less soluble. Crops under these soil conditions may suffer from zinc deficiency. This tends to result in stunted growth, while young leaves are smaller than normal.

Both the solubility of zinc in soils, and the uptake of zinc by plants, fall rapidly as the soil pH increases. High levels of phosphorus in soils have been known to make zinc deficiency worse in a number of crops.

Zinc Values less than 0.3ppm are considered deficient, from 0.3 to 0.8 ppm intermediate and greater than 0.8 ppm adequate. Table 7-4 presents summary of nutrient deficiencies toxicities related to soil property.

Table 7-4: summary of nutrient deficiencies, toxicities related to soil property

Essential Nutrient	Deficiency/Toxicity Symptoms	Typical soil Conditions
Nitrogen (N)	Leaves (first older ones) turn yellow/ brown, plants are spindly, lack vigour and may be dwarfed	Sandy soils under high rainfall conditions and soils low in organic matter, where leaching occurs
Phosphorus (P)	Where. Deficiency is severe, plant will be stunted, the leaves will take on a purplish tint and the stem will be reddish in colour	Acid soils rich in iron and aluminum oxides (i. red tropical soils)
Potassium (K)	Yellow/brown spots appear on older leaves and/or necrosis of edges	More frequent on light soils (as K is concentrated in the clay fraction of soils)
Calcium (Ca)	Roots are usually affected first – growth is impaired &rotting often occurs. In vegetative proportions of sodium growth, deficiency may show in distorted leaves, brown scorching or spotting on foliage or bitter fruit (e.g. apple) or blossom-end rot (e.g. tomato)	Acid soils, or alkali or saline soils containing high proportion of sodium
Magnesium (Mg)	Interveinal chlorosis, first on older leaves	Acid, sandy soils in areas with moderate to high rainfall. Often occurs in conjunction with Ca deficiency
Iron (Fe)	Chlorosis of younger leaves	Calcareous soils, poorly drained and with high pH.(In neutral and alkaline soils P may prevent the absorption of Fe)
Manganese (Mn)	Chlorosis of younger leaves	Badly drained soils, over-liming or deep ploughing of calcareous soils can lead to Mn deficiency, as can the presence of high levels of Mg. The combination of high pH values (> 6.5) and high levels of organic matter can immobilize soil Mn
Zinc (Zn)	Symptoms vary with plant type – in cereals young plants display purpling, whereas in broad-leaved plants symptoms include interveinal chlorosis, reduced leaf size and sparse foliage	Soils with high pH. Available Zn is reduced by the application of lime or phosphates
Copper (Cu)	Chlorosis of the tips of the youngest leaves and die-back of growing points	Peat soils, or leached sandy or acid soils
Boron (B)	Crops other than cereals, the apical	Sandy soils, dry conditions and liming can

Essential Nutrient	Deficiency/Toxicity Symptoms	Typical soil Conditions
	growing point on the main stem dies and lateral buds fail in B deficiency to develop shoots. Legumes (beans, peas) are very sensitive to Boron deficiency	result in B deficiency
Manganese toxicity	Brown spots and uneven chlorophyll in older leaves	Soils with pH of < 5.0 (for susceptible species)
Boron toxicity	Progressive necrosis of the leaves, starting from the tips and/or margins the tips and/or margins	Soils with low pH
Aluminum toxicity	Plants die after early growth	Acid mineral soils, aggravated by low P status

Source: FAO, 2002

8 WATER QUALITY FOR IRRIGATION

8.1 BACKGROUND

An assessment of the quality of available water is important in irrigation development studies. The quality of available water may be more significant, in some cases, than soil characteristics in determining the suitability of some lands for irrigation.

Excellent soils may be unsuitable for irrigation, for example, if the available water would quickly render them saline or sodic. As a result, determination of irrigation suitability is made by jointly viewing the land and soil characteristics on one hand and the quality of available irrigation water on the other hand.

Irrigation water quality parameters are commonly selected considering their impact on crop production, livestock health and human health. The effect on crop production is evaluated by considering salinity (electrical conductivity) and Sodicity (sodium adsorption ratio) of irrigation water

8.2 SODIUM ABSORPTION RATIO AND ELECTRICAL CONDUCTIVITY OF WATER

Sodicity affects soil structure and hence the rate of infiltration, water availability thus affecting crop growth. An important criterion used in estimating water quality is sodium absorption ratio (SAR) which is defined as given below:

$$SAR = \frac{Na+}{\sqrt{\frac{Ca^{2=} Mg^{2+}}{2}}}$$

Where Ca 2+ and Mg 2+ are ionic concentrations in meq/l of solution

The following ratings of irrigation water sodicity are used to classify water for irrigation: -

1. SAR< 10: Suitable for most crops
2. SAR 10-18: Suitable coarse textured soil
3. SAR 18-26: may be used with special amendments like gypsum
4. SAR >26: generally unfit for irrigation

Electrical conductivity is also commonly used as a means of indicating the salt content or salinity of a water the following rating of irrigation water salinity are used to classify water for irrigation (table 8-1).

Table 8-1: Rating of water salinity

EC_w(mmhos/cm)	Water quality guideline (Interpretation)
<0.7	No problem
0.7-3.0	Increasing problem
>3.0	Severe problem

The ECw expressed in mnhos/cm multiplied by 10 is approximately equal to the total soluble cation concentration in meq/1 when the ECw is in the range of 0.1 to 5.0 mmhos/cm.

Other water parameter evaluating irrigation water qualities for surface irrigation are presented in table 8-2.

Table 8-2: Other water quality parameters for evaluating irrigation water quality

Parameter	Water quality guideline (Interpretation)		
	No problem	**Increasing problem**	**Severe problem**
Chloride (meq/1)	<4	4-10	>10
Boron (meq/1)	< 0.7	0.7-2.0	>2.0
pH*	Normal pH range is 6.5-8.4	<6.5 & > 8.4	

Source: FAO, 1979

9 SOIL CLASSIFICATIONS

9.1 INTERNATIONAL SOIL CLASSIFICATION SYSTEM

Soil classification systems have been developed in many countries, but the majority have restricted international appeal because they are applicable to only a small range of soil types, or are based on theoretical concepts (e.g. of soil genesis) which are difficult to apply explicitly.
Soil Taxonomy (USDA, 2014 1993) and FAO, World Reference Base (2015) (WRB) are two systems of soil classification widely used worldwide.

At the international level, Food and Agriculture Organization of the United Nations (FAO -world reference base for soil resource (WRB) have been extensively used to soil classification serve as a common denominator for communication at the international level. In Ethiopia, it is the mostly widely used soil classification system used in most of soil survey studies. Hence, in this guideline, world reference base for soil resources (FAO, 2015) which is International soil classification system for naming soils and creating legends for soil maps shall be used for soil classification.

The reader of this guideline should refer FAO-Word Reference Base for Soil Resource, 2015 for complete definition.

9.2 PRINCIPLES OF CLASSIFICATION

The Word Reference Base for Soil Resource classification system is based on soil properties defined in terms of diagnostic horizons, diagnostic properties and diagnostic materials, which to the greatest extent possible should be measurable and observable in the field soil.

The soil surveyor should attempt to classify the soil in the field as precisely as possible on the basis of the soil morphological features that have been observed and described.

The final classification is made after the analytical data have become available. It is recommended that the occurrence and depth of diagnostic horizons, properties and materials identified be listed (below).

The general principles on which the classification according to the WRB is based (IUSS working Group WR) can be summarized as follows:

- The classification of soils is based on soil properties defined in terms of diagnostic horizons, properties and materials, which should be measurable and observable in the field.
- The selection of diagnostic characteristics takes into account their relationship with soil forming processes.
- High levels of generalization, diagnostic features are selected that are of significance for soil management.

General soil description and classification steps

1. Check the profile description to find references to soil-forming processes (qualitatively) and express them in the horizon designation. Examples may be:

- Darkening of topsoil is comparison to subsoil → enrichment with organic material → Ah-horizon.

- Browning and finer texture in the middle part of a soil profile in comparison to the parent material → enrichment of Fe-oxides and clay → weathering → Bw-horizon.

2. Check profile description and the horizon designation whether the expression, thickness and depth of certain soil characteristics correspond with the requirements of WRB diagnostic horizons, properties and materials.

3. Compared diagnostic horizons, properties and materials with the world reference base soil resource base Key (WRB, 2015) in order to find reference soil group (SRG) which is the first level of WRB classification.

5. For the second level of WRB classification, qualifiers are used. The qualifiers are listed in the Key with each RSG as prefix and suffix qualifiers. Prefix qualifiers comprise those that are typically associated to the RSG and the intergrades to other RSGs.

A quick guide to identify the major soils frequently occurring in Ethiopia has been given in Appendix IX.

Example of a World Reference Base for soil source (WRB, 2015) soil classification:

A. Field description: A soil developed from loess with high-activity clays has a marked clay increase at 60 cm depth, clay coatings in the clay-rich horizon and a field pH value around 6 in the depth from 50 to 100 cm. The clay-poor upper soil is subdivided into a darker upper and a light-colored lower horizon. The clay-rich horizon has a limited amount of mottling with intensive colors inside the soil aggregates and reducing conditions in some parts during spring time.

The following conclusions can be drawn from information about the soil profile

- clay increase and/or clay coatings →argichorizon
- argic horizon with high CEC and high base saturation (inferred by pH 6) →Luvisol
- light colour →Albic qualifier
- some mottles→stagnicproperties
- stagnic properties and reducing conditions starting at 60 cm→ Endostagnic qualifier
- clay coatings → Cutanic qualifier
- clay increase→ Differentic qualifier

Therefore, the field classification based on the above information is Albic Endostagnic Luvisol (Cutanic, Differentic)

B. Laboratory analyses: The laboratory analyses confirm a high CEC kg-1 clay in the argic horizon and a high base saturation in the depth from 50–100 cm. It is further detected that the texture class of silty clay loam with 30% clay (Siltic qualifier) in the topsoil and of silty clay with 45% clay (Clayic Qualifier) in the subsoil. The final classification is: *Albic Endostagnic Luvisol (Endoclayic, Cutanic, Differentic, Episiltic)*

10 DESCRIPTION OF SOIL MAPPING UNITS

The areas having similar land suitability class and similar soil and land characteristics are shown on the soil classification map by mapping units.

A mapping unit shown on a soil classification map will represent the area that will behave similarly under altered water regime due to irrigation and will require similar management practices. Hence, soil mapping unit (SMU) represent the dominant soil type with similar properties and with uniform topographic positions which are supposed to behave in similar way in view of their production potential

The following are the type of mapping units:

Simple mapping unit: is a soil map unit in which a boundary delineation's consist dominantly of a single soil type or very similar to it. In soil nature it is very difficult to get a uniform mapping unit.

Soil complexes mapping units: unit are compound map units consisting of two or more dissimilar (contrasting) components and other components similar to them that occur in a regularly repeating pattern and are too small to set apart at that particular mapping scale. Its application in irrigation development planning is limited as the mixed complex soil may create devastating impact

Soil associations mapping units: are different soil types that occur together on the same parent material and differ in characteristics related to local variations. The dominant soil is extensively described and mapped. In irrigation most of the time the mapping unit types are soil associations. An associated mapping unit can be a soil series, phases, polypedon, group of soil properties, land form (slope), drainage pattern and others as preferred by the soil surveyor. The mapping units are important as it serves as a basis for describing and predicting soil behavior. One has to bear in mind that, a typical soil mapping unit includes an unknown amount of variation usually said to be insignificant in respect to management of the soil. Hence in delineating the boundary of the mapping unit in irrigation, a surveyor has to concentrate on important boundary lines such as permeability, salinity/sodicity, slope, stoniness etc. instead of looking for the uniformity of the soil.

Soil consociation mapping unit: are soil map units in which all boundary delineations consist dominantly of a single component or components very similar to it.

Other Soil Mapping units: For practical soil and land management purposes any mappable land soil characteristics can be used as a mapping unit. The most common ones are, soil type/ units, sub units, series, phases, variants. Major individual or group of soil properties and limitations such as stoniness, permeability, salinity- sodicty, acidity, fertility etc. can be mapped as a soil mapping unit within the intended objective.

Moreover, significant land characteristics such as slope, land form, drainage pattern, catena, microclimate, vegetation is commonly used as a soil and/or land mapping unit.

Soil mapping units should be as pure as possible and should contain all or most similar soil types and are expected to contain about 85% of the soil unit after which the mapping unit is labeled (Landon, 1991).

In feasibility level studies the mapping unit may be composed of different soil classes; they include then dominant soils comprising more than 85% of the soil cover with in the unit. Delineating soil mapping unit may cross cut soil classes.

Some of the commonly used distinguishing criteria that should be considered in delineating a soil mapping unit include slope, effective soil depth, soil texture, Surface coarse fragments, salinity and sodicitiy.

The procedures for delineating major soils and soil mapping unit include:

- classifying each soil auger site and each soil profile pit according to its soil unit
- plotting these data and then grouping them into polygons of similar content such as by using by linking in to Arc GIS and delineate boundaries of soil mapping unit using Arc GIS Thiessen polygon analysis tool or kriging method

Complex soil mapping units are scarcely used by agronomists, planners and other professionals who seek a quick insight into the soil pattern and a short description of features that can be recognized in the field. Therefore, the soil mapping unit should be as simple as possible and should include some less technical descriptions as well as the technical classifications to be easily understood by all users.

An example of simple soil mapping unit prepared for Rassa Small Scale irrigation project in Around Wondo Genet Area is shown in table 10-1.

Table 10-1: Simple soil mapping unit prepared for Rassa Irrigation Project

Soil Mapping unit	Soil Units	Description
SMU1	Eutric Fluvisol	Very deep, loam textured, well drained, dark brown soils developed on 0-5 % slope
SMU2	Andic Cambisol	Very deep, loam over clay loam textured, moderately well drained soils with andic properties developed on 0-5 % slope
SMU3	Chromic Cambisol	Deep, well drained, sandy clay loam over overlying clay loam textured reddish soils developed on slope ranging from 8 to 12 % .
SMU4	Chromic Cambisol	Deep, well drained, sandy clay loam over overlying clay loam textured reddish soils developed on slope ranging from 12 to 15 % .

11 LAND EVALUATION FOR IRRIGATION

11.1 GENERAL

Land evaluation is the process whereby the suitability of land for specific purposes, such as irrigated agriculture, is assessed (FAO, 1985). The primary objective of the land suitability classification is to show the distribution of land suitable for a range of potential uses the so-called land utilization types (LUTs). Land evaluation for irrigation is pre-request for preparation of land use planning that should be considered by the respective institution in the future.

The main product of land evaluation is a land classification that indicates the suitability of various kinds of land for specific land uses, usually depicted on maps with accompanying reports.

Three approaches have been widely adopted for land evaluation USBR Irrigation suitability system (USBR, 1953), USDA land capability classification (Klingebiel& Montgomery, 1961) & land suitability classification (FAO 1976, &1985, 2007).

These methods differ from each other in the original purpose for which they were proposed, in terms of terminology, in the number and kind of soil properties taken into account, and in the logic of the procedures followed to arrive at a suitability rating which are described in the following section.

11.2 LAND CAPABILITY CLASSIFICATION

The USDA land capability classification is based on the potential of the land with assumed high management practices and permanent limitations such as slope, drainage, climate, erosion and soil root zone. A land capability classification evaluates the potential of land for general agricultural use.

The major disadvantage of the land capability approach is that objective comparison between alternative land uses for the same land is often not possible. This occurs because land uses are defined in general terms only and there is an implicit priority of uses: cultivation is the most important, followed by grazing, with recreation and wildlife conservation at the lowest level. Therefore, no proper judgment for detailed land use planning or management can be made using a land capability system although it remains useful for regional land planning.

The arable bias of land capability classification and the very generalized nature of the information does not help choice between alternative uses, except to eliminate the grossly unsuitable land.

11.3 THE USBR SYSTEM

The Land Classification System of the Bureau of Reclamation of the US Department of the Interior (USBR 1953) was developed for planning irrigation projects. It classifies land in terms of its payment capacity - the money remaining for the farmer after all costs except water charges are met and after making an allowance for family living costs.

This system does not use a rigid or fixed methodology. Instead general principles are applied to fit land classification to the economic, social, physical and legal conditions existing in a project area.

The classification is quantitative, with an emphasis on economic appraisal. The system uses six classes. Four classes are suitable for surface irrigation, one is potentially suitable and one class is unsuitable. The USBR system is not widely used for irrigation studies in Ethiopia

11.4 FAO LAND EVALUATION SYSTEM

FAO land evaluation system assesses the potential for a specific kind of land and address limitation of land capability classification approaches in USBR system.

The land evaluation proposed by FAO defines the basic concepts and principles followed universally. The basic concepts include the land and its major utilization type, characteristics, qualities and diagnostic criteria.

The first principle of the framework is that evaluation is for a specified land use type, relevant to local conditions in terms of the physical environment and social acceptability. The first step is, thus, to identify and define promising land use types and establish their land requirements.

These principles draw on FAO framework for land evaluation which has been the primary approach used worldwide and is discussed in various references.

FAO land evaluation system is widely used in evaluation of land suitability for irrigated agriculture in Ethiopia. Therefore, FAO land Evaluation approached should used in assessing the land suitability of proposed small-scale irrigation schemes. Table11-1 provides FAO recommended land class definitions.

11.4.1 Methodology

The methodology of the classification is to compare the requirements of irrigated agriculture against the soil and land characteristics described by the soil survey. Follow the procedures and terminology of the framework &guideline for Land Evaluation (FAO Soils Bulletins 1985,).

11.4.2 Land evaluation procedures

According to FAO (1985), the main procedures for evaluating and classifying land should comprise:

I. The study of relevant existing information and field appraisals of land conditions
II. The selection of cropping, irrigation and management alternatives and the description of prospective land utilization types (LUTs) for evaluation
III. The selection of types of data required for the evaluation and the preparation of a land resource inventory
IV. The selection of class-determining factors
V. The classification and mapping of 'provisionally-irrigable' land
VI. Modification of the 'provisionally-irrigable' classification as additional pertinent physical, engineering, hydrologic and economic information is obtained assisted where necessary by updated class-determining factors and critical limits.
VII. The classification and mapping of the 'irrigable' land delineating the location of the specific lands found to be suitable for irrigation development under a project plan

The other procedures to be followed in land evaluation activities are:

I. Initial consultation with stakeholder: The active participation of all stakeholders and their representatives in the formulation of land-use objectives and in a dialogue on the procedures of land resource evaluation should ensure that the proposed land uses are socially acceptable.

In some of the irrigated schemes in Ethiopia, proposed crops for irrigation during project feasibility study are not used by farmers. This is attributed from limited community participation during planning and land evaluation stages.

At this stage, the following items need to be dealt with:

- Definition of the objectives in consultation with all the stakeholders;
- Identification of the constraints of the existing situation;
- The kinds of land use which appear to be relevant for consideration;
- Planning of the evaluation in consultation with the stakeholders

II. Diagnosis of land use problems

Diagnosis of land use problems' should be taken where it is known that existing land use systems in an area are facing problems, which is likely in many land evaluation exercises, and where one of the objectives of the evaluation is to assist in solving these. Examples are declining soil fertility, overgrazing, fuel wood shortage.

III. The identification of kinds of land use (land utilization types)

Identification and description of the kinds of land use 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.

IV. Land use requirements, functions and limitations

Land use requirements play a major role in land evaluation procedures, at an early stage guiding what properties of the land should be ascertained, and at a later, key, stage, determining suitability when they are compared with these properties

V. Description of land mapping units and land qualities

These stages correspond to the soil survey. These data could be obtained from soil survey.

VI. Comparison of land use with land-Matching of requirements

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

- the relevant kinds of land use and their requirements
- the land mapping units and their land qualities, limitations and functions

11.4.3 Land Suitability Orders and classes

The basis of the FAO land evaluation system is land orders and land classes defined by calculated or inferred potential productivity levels (Table11-1). There are two orders of land: Suitable land has favorable soil and site characteristics such that for the proposed land utilization type (LUT) at least the recurrent investments will eventually be recouped through productivity. Not Suitable land has characteristics that preclude sustained use because of an unacceptable level of recurrent or development inputs. The Not Suitable order of land is divided into two classes to differentiate land that is potentially suitable pending some major improvement (class N1) from land that is permanently unsuitable (class N2).

Table 11-1: FAO recommended land class definitions.

Class	Definition
Highly suitable(S1)	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.
Moderately suitable (S2)	Land having limitations that, 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.
Marginally suitable (S3)	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.
Currently not suitable (N1)	Land otherwise suitable (S1 to S3) for sustained application of a given use but having a limitation(s) which, although possibly surmountable in time, cannot be corrected at currently acceptable cost. The limitation(s) is so severe as to preclude successful sustained use of the land in the given manner at present.
Permanently not suitable (N2)	Land having limitations that are so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

11.4.4 Land suitability subclasses: the major limitations for irrigated agriculture

For each suitability class, there are a number of subclasses which reflect the kind of limitations that restrict the suitability of the land for the proposed LUT. With the exception of S1 which has no significant limitations-deficiencies each suitability class is subdivided in to sub classes according to their dominant limitations. Each subclass is designed by a suffix (table11-2).

Table 11-2: Summary of land suitability subclasses: major limitations that could be commonly identified on proposed irrigation sites

Sub Class Suffix	description of Suffix designation
c	Climate (Temperature): Land units having either very low or very high temperatures below or above the critical temperatures, which may cease the plant growth and may have adverse effect on rate of plant growth, depending on the type of plants and varieties to be grown.
m	Moisture availability: Land with soil moisture deficiencies; there is a need for an increased amount & frequency of irrigation and/or drought-resistant varieties should be selected. Sprinkler irrigation may be more (cost-) efficient
e	Currently eroded / eroding land and land having an increased risk of water erosion under irrigation. Run-off Control and conservation practices must be employed.
f	Floodplain land regularly flooded. Irrigated farming is only feasible if flood protection bunds are constructed
d	Oxygen availability: land having soil drainage deficiencies, poorly drained soils due to ground water table fluctuation, flooding, water logging, slow permeability and surface

Sub Class Suffix	description of Suffix designation
	drainage. Land development like special drainage system required
t	Land having topographic limitations ascribed to unfavorable slope angel, which needs a higher initial land development cost, requiring land leveling (or short channel lengths and drop structures), grading, terracing. Care required to minimize run off and erosion.
r	Rooting condition: Land having soil depth limited by bed rock or extremely gravels
z	Toxicity: Land having a significant proportion of strongly acidic soils (pH < 5.5) and a risk of aluminum and /or manganese or other micro nutrient toxicity; liming may be required
n	**Nutrient retention and availability**: Land with soils of low CEC to supply or retain nutrient or low nutrient reserve (low soil fertility). Thus, additional inputs may be required to increase organic matter, improve soil structure and addition of organic or inorganic fertilizer to improve soil fertility.

11.4.5 Soil & land requirements for irrigated agriculture

The soil and land characteristics data obtained from field soil survey and laboratory analysis results are the major source of data for land suitability evaluation.

Table 11-3 & table 11-4 below summarize the minimum soil and land characteristics needed for surface and sprinkler irrigated agriculture. Land is suitable (S) if all the criteria are met but unsuitable (N1 or N2) if one or more of the criteria fail.

Table 11-3: Suitability class limits of land and soil characteristics for surface irrigated agriculture

Land characteristics and class determining factors	Land use requirement for different suitability classes				
	S1	S2	S3	N1	N2
Slope %	0-3	3-8	8-12	12-15	>15
Drainage	Well	Moderately well	Imperfect	Excessive, poor	v.poor
Depth (cm)	>200	150-200	60-150	30-60	<30
Texture	Silty loam - clay loam	Sandy loam - clay	Loamy sand - clay	Sand, clay	Sand, gravel
Stoniness %	<0.1	1-3	3-15	15-50	>50
Salinity (ms/cm)	<4	4-8	8-12	12-16	>16
CEC (meq/100g)	>20	5-20	<5	<5	
OM	3-5	1-3	<1	<1	
C/N	10-12	6-10	<6	<6	
pH	7-8.5	7-8.5	7-8.5	<9,>4.5	>9, <4.5
Structure	well blocky & granular/crumb	well prismatic and weak SAB	weak prismatic well platy	weak Platy, Massive	Massive
Consistency	Slightly st. Sl. pl	Sticky, plastic	Very st., very pl.	Very st., Vlpl	
Vegetation	No clearing req.	Scattered trees	Frequent	Dense Forest	
Erosion	None	Medium/slight	Severe	Very severe	
ESP	<10	10-15	15-20	>20	>20
IR (cm/hr)	0.7-3.5	3.5-6.5	0.1-0.7&12.5-25	>25	
HC (m/day)	>1.5	1.5-0.5	0.4-0.2	<0.2	
AWC (mm/m)	>180	180-100	99-60	<60	
Hard pan (cm)	>150	100-150	100-50	50 -30	<30

Table 11-4: Suitability class limits of land and soil characteristics for sprinkler irrigated agriculture1

Land and soil characteristics	suitability Class			
	S1	**S2**	**S3**	**N1**
Topography	Flat, almost flat plain		undulating	rolling, with conservation is feasible
Slope (%)	0-3		4-12	12 – 15, with conservation (>is feasible
Flooding	none	5 days < 3 / year	10 days < 5 / year	other, if flood protection is feasible
Soil depth (m); salinity risk; drainage need	> 2.0			
Soil depth (m); no salinity risk; good drainage	>2.0	> 1.5	0.6m, slopes <8%[2] > 1.0m, slopes >8%	
Topsoil (0-25 cm) stone, gravel (% vol	< 10	10 – 25	26 – 40	
Topsoil (0-25 cm) texture	C,CL	vertic clay, SC,SIC,SICL	L,SCL,SIL	
Infiltration rate (cm/hr)	1.0 – 3.5	0.5 – 1.0 3.5 – 9.0	0.3 – 0.5 > 9.0	
AWC, top 0.6m (mm)	> 100	71 – 100	30 – 70	
Hydraulic conductivity (permeability) rate (m/day)	> 1.5	0.6 – 1.5	0.2 – 0.5	< 0.2 if drainage is feasible
Soil drainage class [3]	Well moderate	imperfect	Poor	very poor, if drainage is feasible
Surface water logging (after drainage)	none	intermittent, few days, < 4 months	intermittent, several days, > 4 months	prolonged, if drainage is feasible
Water-table depth (m; wet season; after drainage)	> 10	>5	>2	< 2.0 if drainage is feasible
CEC, top 0.6 m (cmol (+) kg-1)	> 25	8 – 25	< 8	
pH, top 0.6 m	6.0 – 7.7	5.1 – 5.9 7.8 – 8.3	4.5 – 5.0 8.4 – 8.7	< 4.5 if liming is feasible > 8.7 if not sodic or gypsum can be added
Soil fertility, top 0.6 m	Moderate, High	Low	Low	
ECe, top 0.6m (dS/m)	< 2	2 – 4	5 – 8	>8bif reclamation is feasible
ESP, top 0.6m	< 8	8 – 15	16 – 25	> 25 if reclamation is feasible

Notes: 15-30% can be developed by drip irrigation with appropriate conservation structure.

An example of land suitability classes, sub-classes for individual soil and land characteristics & factor rating table for maize and land suitability map prepared for Rassa small scale irrigation project is shown in table 11-5 and figure 11-1 respectively.

Table 11-5: Land Suitability Classes, Sub-Classes for individual soil and land characteristics & factor rating for maize

Soil &Land characteristics		Factor Rating																	
		T	d	d'			m	R		W’			n		z		s		Final suitability class
SMU	Soil Type	Slope (%)	oxygen availability	infiltration	Hydraulic conductivity	Depth to ground water	moisture availability(AWC)	Soil Depth	Stone & rocks	Soil texture (0-50cm)	Topsoil (0-25cm) structure	Subsoil Structure (within 125cm)	Organic Carbon (0-60cm)	CEC (0-60cm)	Soil Reaction ((0-60cm))	texture	Sodicity (0-60cm	EC	
SMU1	EutricFluvisol	S1	S1	S2	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2d'm
SMU2	AndicCambisol	S1	S1	S2	S2	S1	S2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S2d'mz
SMU3	Chromic Cambisol	S3	S1			S1		S1	S1	S1	S1	S1				S1			S3t
SMU 4	Chromic Cambisol	S3	S1			S1		S1	S1	S1	S1	S1				S1			S3t
SMU5	Chromic Cam Chromic	N1	S1			S1		S1	S1	S1						S1			N1t
SMU 6	Lithic Leptosol	S3	S3					N2	N2	S1						S1			N2r
SMU7	Lithic Leptosol	N1	S3					N2	N2	S1						S1			N2r

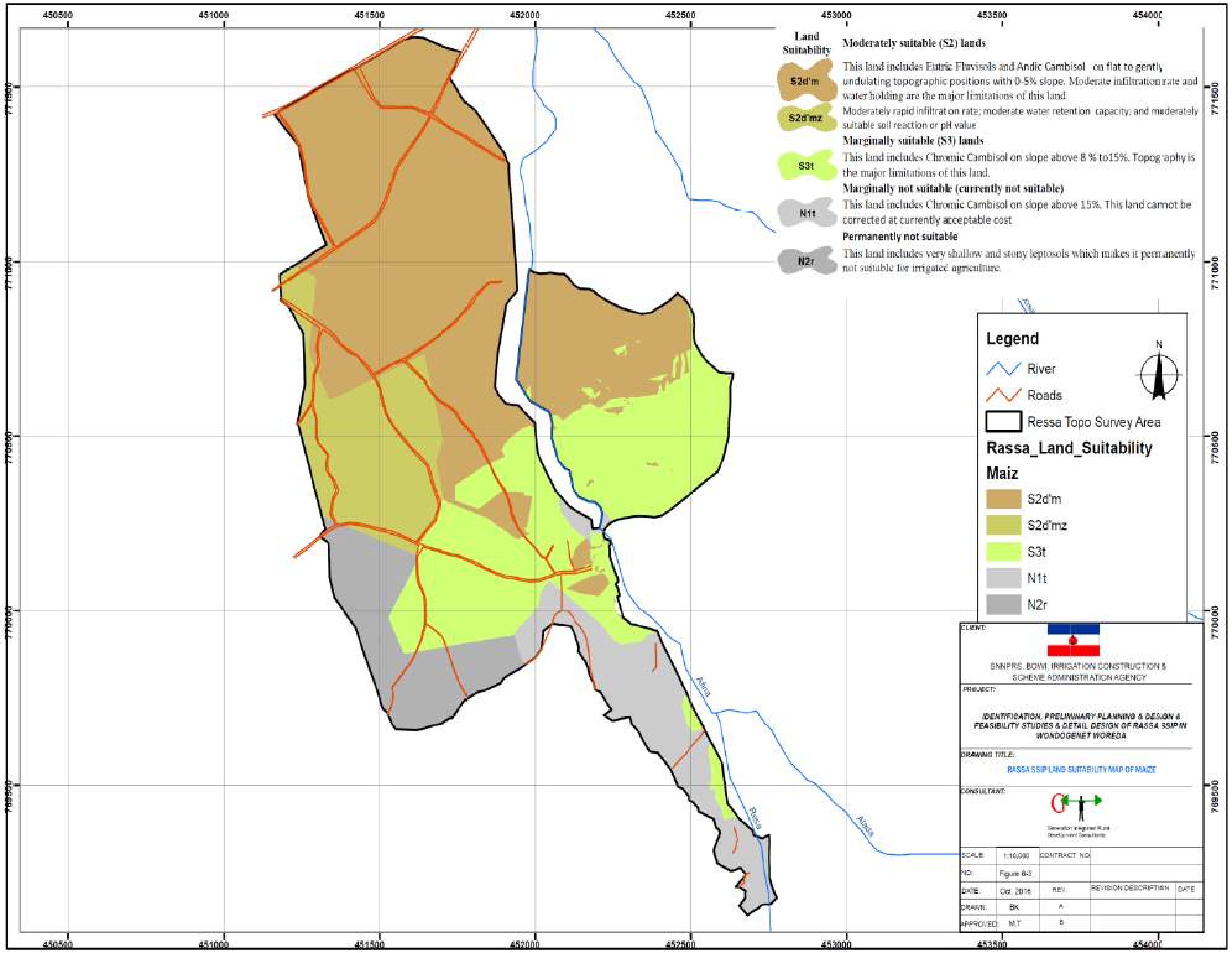


Figure 11-1: Land suitability map for irrigated maize

12 PROPOSED SOIL & LAND MANAGEMENT

The following soil and land management measures could be implemented if any of the problems below are identified.

12.1 DRAINAGE AND RECLAMATION

Signs of poor drainage include surface ponding, slow infiltration, or a soil that remains wet for prolonged periods of time.

Proper drainage ditch network should be implemented with careful design as an integral to the irrigation development planning. Drainage should ensure that surface water excess water is removed from the fields.

The main need is to ensure that excess rainfall and irrigation can be led off the land safely by careful contouring and surface drainage to existing water ways.

Drainage of irrigated soils is an essential complement to irrigation. Drainage, in combination with adequate irrigation scheduling, allows for the leaching of excess salts and water from the plant root zone in order to maintain the right soil nutrients and water balance.

12.2 MANAGEMENT OF SALINE AND SODIC SOILS

Development of the unfavorable properties of saline and sodic soils, continuing hazard in irrigation which can be prevented by adequate drainage and good irrigation and soil management practices.

These practices include (1) adequate irrigation to leach soluble salts below the root zone combined with (2) efficient distribution of water to prevent excessive deep percolation; (3) construction of a good surface drainage system to remove runoff water from each field; and (4) addition of gypsum where necessary to prevent or correct unfavorable sodic conditions.5.salt tolerant plants 6.sub surface drainage

Saline-sodic soils must be treated as sodic soils first. These soils require calcium to correct a sodium problem, followed by leaching to remove salts.

If salts are leached with clean water while sodium is insoluble, the result may be a sodic soil. Soils with a sodicity problem must have drainage to facilitate sodium removal from the root zone.

The principle of reclaiming sodic soils is to pass a solution high in dissolved calcium through the soil. From this soil solution, the calcium will replace the sodium on the soil exchange complex and the sodium will then be washed down.

Sodic soils are treated by replacing the sodium with calcium from a soluble source. Gypsum ($CaSO_4 \cdot 2H_2O$) is considered the cheapest, soluble calcium source for reclamation of sodic soils. Gypsum is used because it is calcium-rich, dissolves at high pH, and does not contain elements or compounds that might interfere with reclamation

Gypsum may be applied in broadcast and then ploughed into the soil or it may be dissolved in irrigation water. If the exchangeable sodium occurs in the subsoil then deeper placement of gypsum is desirable. This can be achieved by distributing the amendment behind a deep plough..

Once the gypsum is applied and incorporated, sufficient good quality water must be added to leach the displaced sodium beyond the root zone. Reclamation of sodic soils is slow because soil structure, once destroyed, is slow to improve.

Growing a salt-tolerant crop in the early stages of reclamation and disking in crop residues adds organic matter, which increases water infiltration and permeability, speeding up the reclamation process. Moreover, tillage often is necessary to physically break up sodium-rich layers and mix amendments in the soil. Coarse organic materials that decompose slowly (such as straw, cornstalks and sawdust) can help improve soil structure and infiltration when used with other reclamation practices.

Controlling Salinity with Irrigation Water

Where applicable, irrigation water can be used to maintain soil salinity at levels where maximum crop yields can be obtained by applying excess water to drain through the root zone and leach salts. For any given water, the lower the fraction of applied water that becomes drainage water, the higher the average root zone salinity. The amount of excess drainage water required to maintain salinity at sustainable levels is the leaching requirement (LR). LR can be estimated by the following equation:

$$LR = \frac{EC_{iw}}{(5 \times EC_t - EC_{iw})}$$

where ECiw is the EC of the irrigation water and ECt is the soil EC that should not be exceeded in order to minimize yield loss (Table 3). After determining LR, the total amount of water required (WR) by the crop can be estimated by knowing the crop's evapotranspiration (ET) rate: WR= ET/ (1-LR).

12.3 MANAGEMENT OF ACID AND TOXIC SOILS

Acidic soil environment (pH < 5.5) affects plant growth directly or indirectly by influencing the availability of plant nutrients, particularly phosphorus, secondary nutrients (Ca, Mg) and micronutrients (Mo, B and Zn), reducing microbial activity and creating toxicity of Fe and Mn (Al in some cases).

Lime or dolomite can be incorporated into the soil to neutralize and replace aluminum with calcium and magnesium. The dose of applied liming materials depends on the CaCO equivalent of the liming materials, soil texture and its cation exchange capacity (CEC), existing soil pH and desired soil pH to bring after soil amelioration.

When high concentrations of aluminum are found in the subsoil, it is more difficult to neutralize it due to the low solubility of lime and its slow movement into the deeper layers. In these cases, gypsum can be applied, or even better, gypsum mixed with lime because the gypsum is soluble and the calcium in the gypsum more rapidly replaces the aluminum in the lower layers.

Application of organic manure can also have a beneficial effect due to the formation of Aluminum-organic complexes, which reduces the activity of aluminum in the soil solution.

Management of vertisols

Drainage and reclamation have been mentioned above. For irrigating vertisols, water will only penetrate Vertisols via the cracks, and once these close any additional irrigation will pond or runoff.

The measures to be implemented are (i) to establish an irrigation regimen related to the drying cycle; and (ii) to provide adequate surface drainage both to control and remove surplus water (rainfall or irrigation).

An integrated approach to acid soil management comprises a spatially variable liming strategy, including addition of calcium rich material like dolomite and lime stones and use of acid-tolerant species, efficient use of fertilizers, suitable crop rotations and crop diversification. Soil testing needs to be carried out every two to three years to determine the lime requirements of the field. The buffering capacity needs to be assessed to work out the amount of lime needed to neutralize soil acidity to the desired level. The negative effects of soil acidity on physical and chemical soil conditions can be partly compensated by ensuring high organic matter content.

12.4 SLOPE/TOPOGRAPHY

Topography is one of the most important elements that affect the irrigation system selection process. Generally, surface irrigation systems require uniform field slopes within the 0-5%range. Land slopes may limit the selection of surface irrigation systems as it affects the length of run and the labor required for the operation of the system.

Steep lands are not favorable for surface irrigation and irrigation on slope above 5 % needs land leveling and bench terraces.

For rain fed and irrigated agriculture on steep slope, bench terraces are one of the most effective measures for erosion control.

The width of the bench (flat part) is determined by soil depth, crop requirements, tools to be used for cultivation, the land owner's preferences and available resources. It is important to check soil depths and inform farmers that wide benches require deep soils and higher construction costs.

The wider the bench, the more cut and fill needed and hence the higher the cost. The optimum width for handmade and manual-cultivated terraces range from 2.5 to 5 m; for machine built and tractor-cultivated terraces, the range is from 3.5 to 8 m are proper where depth of soil does not constitute a limit.

Bench terraces must be spaced with a vertical interval which is two and a half times the depth of rework able soil. If the soil is 1m deep, the vertical interval is 2.5 m. The width of cultivated area on a bench terrace is determined by the slope gradient and the soil depth as shown in Table12-1 below.

Table 12-1: Bench width (meter) based on soil depth and slope of the area

Slope	Soil depth(cm)			
	50 cm	75 cm	100 cm	125 cm
20%	5.63	8.44	11.25	14.05
30%	3.54	5.31	7	8.83
40%	2.5	3.25	5	6.25
50%	1.9	2.8	3.75	4.65

Source::Ministry of urban development &Housing, 2016

12.5 MANAGEMENT OF COMPACTED SOIL

Sub soiling should be considered as a practice for recuperating soils that have been degraded due to serious problems of compaction. Generally speaking, sub soiling is not a tillage operation that should be used routinely every year for soil preparation. Sub soiling has the effect of lifting, breaking and loosening the soil. This results in better root development and often in better soil drainage.

The main advantage of sub soiling is that it breaks up the compacted layers and loosens the soil without inverting it as occurs during ploughing. In this manner, the subsurface soil is not brought up to the surface and the majority of the residues remain on top of the soil surface

12.6 CONTROL OF SOIL EROSION

Any water development works such as weir, dam and water reservoir to be sustainable it should be integrated with soil and water conservation. In this regard, implementing intervention measures in the proposed irrigation command area or its catchment contribute to control soil erosion and maintain land productivity in the watershed and reduce sediment inflow to downstream areas and water resource infrastructures. This will also ensure equity of benefits from development interventions among upstream and downstream community.

There are a broad range of possible interventions and techniques including agronomic &biological and physical soil and conservation measures.

The following are some of proposed conservation measures to prevent erosion in an irrigated area or command areas of small scale irrigation schemes

- Never leave the soil at all bare in the rainy season
- Carefully construct contour drains, collector drains and roadside drains (all with drop-structures as required) as part of the estate infrastructure, before planting and irrigating
- Line all drains and waterways with grass, membrane, stone or cement as appropriate
- Ensure that drain outfalls discharge safely without causing erosion
- Do not over-irrigate, especially before a good canopy is established
- Do not cultivate right up to gully edges; leave a buffer zone and ensure that this zone remains well-vegetated
- Observe continually and make corrective measures immediately, before erosion worsens

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APPENDICES

APPENDIX I: Field guide for auger-hole & profile description &coding

ABBRIVATIONS USEFUL FOR SITE, /AUGER & PROFILE DISCRIPTION AND DATA ENCODING

A. Site description

Date (dd/mm/yyyy), author (s) name, auger/profile number, location (UTM E&N), Region, Zone and District should be recorded in the description sheet.

Hierarchy of major landforms

1stlevel2ndlevel		Gradient (%)	Relief intensity m/km	Potential drainage density
L	**Level land**			
LP	Plan	<10	<50	0–25
LL	Plateau	<10	<50	0–25
LD	Depression	<10	<50	16–25
LV	Valley floor	<10	<50	6-15
S	**Sloping land**			
SM	Medium-gradient mountain	15-30	150–300	0-15
SH	Medium-gradient hill	10 -30	100-150.	0-15
SE	Medium-gradient escarpment zone	10-30	50-100	<6
SP	Dissected plain	10-30	50-100	0-15
SV	medium-gradient valley	10–30	100–150	6–15
T	**Steep land**			
TM	High-gradient mountain	>30	>300	0–15
TH	High-gradient hill	>30	150–300	0–15
TE	High-gradient escarpment	>30	150–300	<6
TV	High-gradient valley	>30	>1506–15	

C Complex landforms

CU =Cuesta-shaped

DO =Dome-shaped

RI =Ridged

TE =Terraced

IN =Isenberg covered(occupying>1%oflevelland)

DU =Dune-shaped

IM =With intermundane plains(occupying>15%)

KA =Strong karst

WE =With wetlands(occupying>15%)

Regional slope

W	0 – 2 %	Flat, wet
F	0 – 2 %	Flat
G	2 – 5 %	gently undulated, gently sloping
U	5 – 8 %	undulating, sloping
R	8 – 15 %	rolling, strongly sloping
S	15 – 30 %	moderately steep
T	30 – 60 %	Steep
V	≥60 %	Very steep

Composite classes e.g:

FU	0 - 8	%	Flat to undulating/sloping
FG	0 - 5	%	Flat to gently undulating /gently sloping
GU	2 - 8	%	gently undulating to undulating/ sloping

Position in undulating to mountainous terrain

CR =Crest (summit)
UP =Upper slope (shoulder)
MS =Middle slope (back slope)
LS =Lower slope (foot slope)
TS =Toe slope
BO =Bottom (flat)

Position in flat or almost flat terrain

HI=Higher part(rise)
IN = Intermediate part (half)
LO = Lower part (and dip)
BO = Bottom (drainage line)

Slope gradient classes Form of slope

01	Flat	0 – 0.2 %	S straight
02	Level	0.2 – 0.5 %	V convex
03	Nearly level	0.5 – 1. %	C concave
04	Very gently slope	1.0 – 2 %	T terraced
05	Gently slope	2 – 5 %	X complex (irregular)
06	Sloping	5 – 10 %	Orientation
07	Strongly sloping	10 – 15%	N= north
08	Moderately steep	15 – 30%	S = south
09	Steep	30 – 60%	W = west
10	Very steep	> 60 %	E = east, etc.

*Slope gradient and slope length should be recorded on the description sheet

Local surface form

LE Level
GI Gilgai Micro-relief produced by expansion and contraction of montmorillonitic clay with changes in moisture; found in Vertisols; in nearly level areas a succession of micro-basins and micro-knolls; on sloping and micro-valleys and micro-ridges parallel to the direction of the slope.
GL Low gilgai Height difference (with 10 m) <20 cm
GM Medium gilgai Height difference (with 10 m) 20-40 cm
GH High gilgai Height difference (with 10 m) >40 cm
AT Animal tracks
TM Termite or ant mounds
AB Animal burrows
H Hummocks Meso-relief (2.5-2.5m) showing a very complex pattern of slopes, extending from somewhat rounded depressions of various sizes to irregular conical knolls or knobs.
R Ridges Coverage at least 5& by parallel, sub-parallel, or intersecting usually sharp-crested ridges or elongated narrow elevations more than 2.5m high.
K Towers Coverage at least 5% by isolated steep sided karst towers more than 2.5m high.
T Terraced Level areas <2% slope bounded on one side by a steep slope >2.5m high with another flat surface above it.
G Gullied Coverage ≥ 5% by steep sided gullies > 2.5m deep.

S	St.	Dissected Strongly dissected areas with a drainage density of ≥ 25km per km^2; depth of drainage lines
D	dissected	Areas with a drainage density of between 10 and 25 km per km^2; depth of drainage lines ≥ 2.5m.
L	Sl. dissected	Slightly dissected areas with a drainage density of < 10 km per km^2; depth of drainage lines ≥ 2.5 m.

Rock type (for in situ weathered/saprolite only) /Lithology/

Major class	Group	Type
I igneous rock	IA acid igneous	IA1 diorite
		IA2 grano-diorite
		IA3 quartz-diorite
		IA4 rhyolite
II intermediate igneous		II1 andesite, trachyte, phonolite
		II2 diorite-syenite
	IB basic igneous	IB1 gabbro
		IB2 basalt
		IB3 dolerite
	IU ultrabasic igneous	IU1 peridotite
		IU2 pyroxenite
		IU3 ilmenite, magnetite, ironstone, serpentine
	IP pyroclastic	IP1 tuff, tuffite
		IP2 volcanic scoria/breccia
		IP3 volcanic ash
		IP4 ignimbrite
M metamorphic rock	MA acid metamorphic	MA1 quartzite
		MA2 gneiss, migmatite
		MA3 slate, phyllite (pelitic rocks)
		MA4 schist
S sedimentary rock	SC clastic sediments	SC1 conglomerate, breccia (consolidated)
		SC2 sandstone, greywacke, arkose
		SC3 silt-, mud-, claystone
		SC4 shale
		SC5 Ironstone
	SO carbonatic, organic	SO1 limestone, other carbonate rock
		SO2 marl and other mixtures
		SO3 coals, bitumen and related rocks
	SE evaporites	SE1 anhydrite, gypsum
		SE2 halite
MB basic metamorphic		MB1 slate, phyllite (pelitic rocks)
		MB2 (green) schist
		MB3 gneiss rich in Fe–Mg minerals
		MB4 metamorphic limestone (marble)
		MB5 amphibolite
		MB6 eclogite
MU ultra-basic metamorphic		MU1 serpentinite, greenstone
U sedimentary rock (unconsolidated)		UR weathered residuum UR1 bauxite, laterite
	UF fluvial	UF1 sand and gravel
		UF2 clay, silt and loam
	UL lacustrine	UL1 sand
		UL2 silt and clay
	UM marine, estuarine	UM1 sand

	UM2 clay and silt
UC colluvial	UC1 slope deposits
	UC2 lahar
UE eolian	UE1 loess
	UE2 sand
UG glacial	UG1 moraine
	UG2 glacio-fluvial sand
	UG3 glacio-fluvial gravel
UK * kryogenic	UK1 per glacial rock debris
	UK2 periglacial solifluction layer
UO organic	UO1 rainwater-fed moor peat
	UO2 groundwater-fed bog peat
UA anthropogenic/	UA1 redeposited natural material technogenic
	UA2 industrial/artisanal deposits
	UU * unspecified deposits
	UU1 clay
	UU2 loam and silt
	UU3 sand
	UU4 gravelly sand
	UU5 gravel, broken rock

Materials (natural and anthropogenic/technogenic) deposited by humans are coded:

d... = dumped,

s... = spoiled

Parent materials, unconsolidated (Faices)

AU	Aeolian deposits	VA	Volcanic ash
AS	Aeolian sand	PY	Pyroclastic deposits
LO	Loess	GL	Glacial deposits
LI	Littoral deposits	OR	Organic deposits
LG	Lagunal deposits	CO	Colluvial deposits
MA	Marine deposits	WE	In situ weathered, residual
LA	Lacustrine deposits	SA	Saprolite
FL	Fluvial deposits	U	Unknown
AL	Alluvial deposits		

Effective soil depth

V	Very shallow	<25cm
S	Shallow	25 – 50 cm
M	Moderately deep	50 – 100cm
D	Deep	100 – 150cm
X	Very deep	≥ 150cm

Rock outcrops

Surface cover (abundance)			Distance	
N	None	0 %	1	> 50 m
V	Very few	0 – 2%	2	20 – 50 m
F	Few	2 – 5%	3	5 – 20 m
C	Common	5 – 15%	4	2 – 5 m
M	Many	15 – 40%	5	< 2 m
A	Abundant	40 – 80%		
D	Dominant	>80 %		

Surface coarse fragments
Surface cover (abundance): Classes as for Rock outcrops

Size

F	Fine gravel	0.2 – 0.6 cm	
M	Medium gravel	0.6 – 2 cm	
C	Coarse gravel	2 – 6 cm	
S	Stones	6 – 20 cm	
B	Boulders	20 – 60cm	
L	Large boulders	>60 cm	
FM	Fine and medium gravel	FC	Fine and coarse gravel
MC	Medium and coarse gravel	SB	Stones and boulders

Types of erosion /deposition

N No evidence of erosion
W Water erosion or deposition
WS Sheet erosion
WR Rill erosion
WG Gully erosion
WT Tunnel erosion
WD Deposition by water
WA Water and wind erosion
M Mass movement (landslides and similar phenomena)
NK Not known
A Wind (aeolian) erosion or deposition
AD Wind deposition
AM Wind erosion and deposition
AS Shifting sands
AZ Salt deposition

Area affected		Activity	
0	0		
1	0 – 5%	A	Active at present
2	5 – 10%	R	Active in recent past (previous 50–100 years)
3	10 – 25%	H	Active in historical times
4	25 – 50%	N	Period of activity not known
5	≥ 50%	X	Accelerated and natural erosion not distinguished

Degree of erosion

S	Slight	Some evidence of loss of surface horizons. Original biotic functions largely intact.
M	Moderate	Clear evidence of removal or coverage of surface horizons. Original biotic functions partly destroyed.
V	Severe	Surface horizons completely removed (with sub surface horizons exposed) or covered up by sedimentation of material from upslope. Original biotic functions largely destroyed.
E	Extreme	Substantial removal of deeper subsurface horizons (badlands). Original biotic functions fully destroyed.

SURFACE SEALING

Thickness	(mm)		Consistence	
N	None		S	Slightly hard
F	Thin	<2	H	Hard
M	Medium	2–5	V	Very hard
C	Thick	5–20	E	Extremely hard
V	Very thick	>20		

SURFACE CRACKS AND POTHOLES

F	Fine	< 1 cm	P Pothole (sinkhole)
M		1 - 2 cm	
W	Wide	2 - 5 cm	
V	Very wide	5 -10 cm	
E	Extremely wide	> 10 cm	

Distance between cracks (m)

C	Very closely spaced	< 0.2
D	Closely spaced	0.2–0.5
M	Moderately widely spaced	0.5–2
W	Widely spaced	2–5
V	Very widely spaced	> 5

Depth (cm)

S	Surface	<2
M	Medium	2–
D	Deep	10–
V	Verydeep	>20

Classification of salt characteristics (%)

0	None	0–2
1	Low	2–15
2	Moderate	15–40
3	High	40–80
4	Dominant	> 80

Thickness (cm)

N	None	
F	Thin	< 2
M	Medium	2–5
C	Thick	5–20
V	Very thick	> 20

Classification of bleached and characteristics

		%
0	None	0–2
1	Low	2–15
2	Moderate	15–40
3	High	40–80
4	Dominant	>80

Drainage classes

E Excessively drained Water is removed from the soil very rapidly. The soils are commonly very coarse textured or rocky. Shallow or on steep slopes.

S Somewhat exe. Drained Water is removed from the soil rapidly. The soils are commonly sandy and very pervious.

W Well drained — Water is removed from the soil readily but not rapidly. The soils commonly retain optional amounts of moisture, but wetness does not inhibit the growth of roots for significant periods.

M Mod. Well drained — Water is removed from the soil somewhat slowly during some periods of the year. The soils are wet for short periods within the rooting depth. They commonly have an almost impervious layer, or periodically receive heavy rainfall.

I imperfectly drained — Water is removed slowly so that the soils are wet at shallow depth for significant periods. The soils commonly have an almost impervious layer, a high water table, and additions of water by seepage, or very frequent rainfall.

P Poorly drained — Water is removed so slowly that the soil is commonly wet at a shallow depth for considerable periods. The soils commonly have a shallow waterable which is usually the result of an almost impervious layer, seepage or very frequent rainfall.

V Very poorly drained — Water is removed to slowly that the soils are wet at a shallow depth for long periods. The soils have a very shallow water table and are commonly in level or depressed sites or have very rainfall falling almost every day.

<u>External drainage</u>

E Extremely slow	Water ponds at the surface, and large parts of the terrain are waterlogged for continuous periods of more than 30 days.
S Slow	Water drains slowly, but most of the terrain dose not remain waterlogged for more than 30 days continuously.
W Well	Water drains well but not excessively; nowhere dose the terrain remain waterlogged for a continuous period of more than 48 hours.
R Rapid	Excess water drains rapidly, even during periods of prolonged rainfall.
V Very rapid	Excess water drains very rapidly: the terrain does not support growth of short-rooted plants, even if there is sufficient rainfall.

<u>Flooding</u>

<u>Frequency</u>

N	None	B	Biannually
D	Daily	F	Once every 2 – 5 years
W	Weekly	T	Once every 5 – 10 years
M	Monthly	R	Rare (less than once in every 10 years)
A	Annually	U	Unknown

<u>Duration</u>

1	Less than one day	5	90 – 180 days
2	1 – 15 days	6	180 – 360 days
3	15 – 30 days	7	continuously
4	30 – 90 days		

<u>Depth</u>

Classes as for Effective soil depth

<u>Ground water</u>

<u>Depth</u>

N Not observed

Other classes as for Effective soil depth

Moisture conditions of the profile

D Dry
S Slightly moist
M Moist
W Wet

Human influence

N =No influence PO =Pollution
NK =Not known MI =Mine (surface, including open pit, gravel and quarries)
VS =Vegetation slightly disturbed
VM =Vegetation moderately disturbed
VE =Vegetation strongly disturbed
VU =Vegetation disturbed (not specified)
IS =Sprinkle irrigation
IF =Furrow irrigation
ID =Drip irrigation MO =Organic additions (not specified)
IP =Flood irrigation MU =Mineral additions (not specified)
IB =Border irrigation
IU =Irrigation (not specified)
AD =Artificial drainage
FE =Application of fertilizers
LF =Landfill (also sanitary)
LV =Leveling
AC =Archaeological (burial mound, midden)
CR =Impact crater
BU =Bonding
BR =Burning SC =Surface compaction
TE =Terracing SA =Scalped area
PL =Ploughing MS =Sand additions
MP =PlaggenME =Raised beds (engineering purposes)
MR =Raised beds (agricultural purposes)
BP =Borrow pit
DU =Dump (not specified)

B HORIZON DESCRIPTION

Horizon boundary

Distinctness

A	Abrupt	0 - 2 cm
C	Clear	2 - 5 cm
G	Gradual	5 - 15 cm
D	Diffuse	> 15 cm

Topography

S	Smooth	Nearly plane surface
W	Wavy	Pockets less deep than wide
I	Irregular	Pockets more deep than wide
B	Broken	Discontinuous

Mottling

Abundance

N	None	0 %
V	Very few	0 – 2%

F	Few	2 – 5%
C	Common	5 – 15%
M	Many	15 – 40%
A	Abundant	40 – 80 %
D	Dominant	>80 %

Size

V	Very fine	< 2 mm
F	Fine	2 – 6 mm
M	Medium	6 – 20 mm
A	Coarse	>20 mm

Contrast

F Faint	The mottles are evident only on close examination. Soil colours in both the matrix and mottles have closely related hues, chromas and values.
D Distinct	Although not striking, the mottles are ready seen. The hue, chroma or values of the matrix are easily distinguished from those of the mottles. They may vary by as much as 2.5 units of hue or several units in chroma or value.
P Prominent	The mottles are conspicuous and mottling is one of the outstanding features of the horizon.. Hue, chroma and value alone or in combination are at least several units apart.

Boundary between mottle and matrix

S	Sharp	0 – 0.5 mm
C	Clear	0.5 – 2 mm
D	Diffuse	>2mm

Colour

WH	White	YE	Yellow
RE	Red	RY	Reddish yellow
RS	Reddish	GE	Greenish, green
YR	Yellowish red	GR	Gray
BR	Brown	GS	Grayish
BS	Brownish	BU	Blue
RB	Reddish brown	BB	Bluish-black
YB	Yellowish brown	BL	Black

Soil texture classes

C	Clay	CSL	Coarse sandy loam
L	Loam	LS	Loamy sand
CL	Clay loam	LVFS	Loamy very fine sand
SI	Silt	LFS	Loamy fine sand
SIC	Silt clay	LCS	Loamy coarse sand
SICL	Silt clay loam	VFS	Very fine sand
SIL	Silt loam	FS	Fine sand

		Granular/ platy (mm)	**Prismatic/columnar/ wedge-shaped (mm)**	**Blocky/crumbly/lumpy/cloddy (mm)**
VF	Very fine/thin	<1	<10	<5
FI	Fine/thin	1–2	10–20	5–10
ME	Medium	2–5	20–50	10–20
CO	Coarse/thick	5–10	50–100	20–50
VC	Very	>10	00–500	>50
EC	Extremely	–	>500	–

SC	Sandy clay	MS	Medium sand
SCL	Sandy clay loam	CS	Coarse sand
SL	Sandy loam	US	Sand, unsorted
FSL	Fine sandy loam	S	Sand, unspecified

Coarse fragments and artifact

Abundance (by soil volume): Classes as for Rock outcrops and
S Stone line any content, but concentrated at a distinct depth of a horizon

Size
Classes as for surface coarse fragments

Combination of classes
FM Fine and medium gravel/artifacts
MC Medium and coarse gravel/artifacts
CS Coarse gravel and stones
SB Stones and boulders
BL Boulders and large boulders

Artifacts (mm)

V Very fine artifacts< 2
F Fine artifacts 2–6
M Medium artifacts 6–20
C Coarse artifacts> 20

Shape of rock fragments
F Flat
A Angular
S Sub-rounded
R Rounded

Classification of weathering of coarse fragments

F Fresh or slightly weathered Fragments show little or no signs of weathering.

W Weathered Partial weathering is indicated by discolor action and loss of crystal form in the outer parts of the fragments while the centers remain relatively fresh and the fragments have lost little of their original strength.

S Strongly weathered All but the most resistant minerals are weathered, strongly discolored and altered throughout the fragments, which tend to disintegrate under only moderate pressure.

Codes for primary mineral fragments
QU Quartz
MI Mica
FE Feldspar

Structure

Grade

N Structure less No observable aggregation or no orderly arrangement of natural planes of weakness (massive or single grain).

W Weak Peds are barely observable inplace and there is only a weak arrangement of natural surfaces of weakness. When gently disturbed, the soil material breaks into a mixture of few entire peds, many broken peds, and much material without ped faces. Ped surfaces will differ in some way from the ped interior.

M Moderate Peds are observable and there is a distinct arrangement of natural surfaces of weakness. When disturbed, the soil material breaks into a mixture of many entire peds, some broken peds, and little material without ped faces. Ped surfaces generally show distinct differences with the ped interior.

S Strong Peds are clearly observable in place and there is a prominent arrangement of natural surfaces of weakness. When disturbed, the soil material separates mainly into entire peds. Ped surfaces generally differ from ped interiors.

Size of structure elements

Combined size classes for soil structure types

FF Very fine and fine
VM Very fine to medium
FM Fine and medium
FC Fine to coarse
MC Medium and coarse
MV Medium to very coarse
CV Coarse and very coarse

Type of structure

RS Rock structure
SS Stratified structure
SG Single grain
MA Massive
PM Porous massive
BL Blocky
AB Angular blocky
AP Angular blocky (parallelepiped)
AS Angular and subangular blocky
AW Angular blocky (wedge-shaped)
SA Subangular and angular blocky
SAB Subangular blocky
SN Nutty subangular blocky
PR Prismatic
PS Subangular prismatic
WE Wedge-shaped
CO Columnar
GR Granular
WC Worm casts
PL Platy
CL Cloddy
CR Crumbly
LU Lumpy

Combinations of soil structures

C+R Both structures present.

R → A Primary structure breaking into secondary structure.

P / R One structure merging into the other.

Consistence When Dry

LO Loose Non-coherent

SO Soft Soil mass is very weakly coherent and fragile; breaks to powder or individual grains under very slight pressure.

SHA Slight hard Weakly resistant to pressure; easily broken between thumb and forefinger.

HA Hard Moderately resistant to pressure; can be broken in the hands; not breakable between thumb and forefinger.

VHA Very hard Very resistant to pressure; can be broken in the hands only with difficulty.

EHA Extr.hard Extremely resistant to pressure; cannot be broken in the hands.

SSH Soft to slightly hard HVH Hard to very hard

SHH Slightly hard to hard.

Consistence When moist

LO Loose Non – coherent.

VFR Very friable Soil material crushes under very gentle pressure, but coheres when pressed together.

FI Firm Soil material crushes under moderate pressure between thumb and forefinger.

VFI Very firm Soil material crushes under strong pressure; Barely crushable between thumb and forefinger.

EFI Extr.firm Soil material crushes only under very strong pressure; cannot be crushed between thumb and forefinger.

VFF Very friable to friable FVF Firm to very firm

FRF Friable to firm

Consistence When wet:

Maximum stickiness and maximum plasticity

NST Non sticky After release of pressure, practically no soil material observed adheres to thumb and finger.

SST Slightly sticky After pressure, soil material adheres to both thumb and finger but comes off one or the other rater than other cleanly.

ST Sticky After pressure, soil material adheres to both thump and finger and tends to stretch somewhat and pull apart rather than pulling free from either digit.

VST Very sticky After pressure, soil material adheres strongly to both thumb and finger and is decidedly stretched when they are separated.

SSS Slightly sticky to sticky.

SVS Sticky to very sticky.

NPL Non plastic No wire is formable.

SPL Slightly plastic Wire formable but immediately breaks if bent into a ring; soil mass deformed by very slight force.

PL Plastic Wire formable but breaks if bent into a ring; slight to moderate force required for deformation of the soil mass.

VPL Very plastic Wire formable and can be bent into a ring; moderately strong to very strong required for deformation of the soil mass.

SPP Slightly plastic to plastic.

PVP Plastic to very plastic.

Cutanic features

Abundance		%
N	None	0
V	Very few	0–2
F	Few	2–5
C	Common	5–15
M	Many	15–40
A	Abundant	40–80
D	Dominant	>80

Contrast

F Faint Surface of cutan shows little contrast in colour, smoothness or any other property to the adjacent surface. Any lamellae are <2 mm thick.

D Distinct Surface of cutan is distinctly smoother or different in colour than the adjacent surface. Any lamellae are between 2 and 5 mm thick.

P Prominent Surface of cutan contrast strongly in smoothness or colour with the adjacent surface. Outlines of the sand grains are not visible. Any lamellae are more than 5 mm thick.

Nature

C Clay
S Sesquioxides
H Humus
CS Clay and sesquioxides
CH Clay and humus (organic matter)
CC Calcium carbonate
GB Gibbsite
HC Hypodermic coatings (Hypodermic coatings, as used here, are field-scale features, commonly only expressed as hydromorphic features. Micro-morphological hypodermic coatings include non-redox features [Bullock *et al.,* 1985].)
JA Jarosite
MN Manganese
SL Silica (opal)
SA Sand coatings
ST Silt coatings
SF Shiny faces (as in nitic horizon)
PF Pressure faces
SI Slickenside, predominantly intersecting (Slickenside are polished and grooved ped surfaces that are produced by aggregates sliding one past another.)
SP Slickenside, partly intersecting
SN Slickenside, non intersecting

Classification of the form of coatings

C Continuous
CI Continuous irregular (non-uniform, heterogeneous)
DI Discontinuous irregular
DE Dendroidal
DC Discontinuous circular
O Other

Location of coatings and clay accumulation

P Pedfaces
PV Vertical pedfaces
PH Horizontal pedfaces
CF Coarse fragments
LA Lamellae (clay bands)
VO Voids
BR Bridges between sand grains
NS No specific location

Cementation and Compaction

Degree

N Non-cemented and non-compacted: neither cementation nor compaction observed (slakes in water)
Y Compacted: compacted mass is appreciably harder or more brittle than other comparable soil mass (slakes in water)
W Weakly cemented: cemented mass is brittle and hard, but can be broken in the hands.
M Moderately cemented: cemented mass cannot be broken in the hands .but is discontinuous (less than 90% of soil mass).
C Cemented: cemented mass cannot be broken in the hands and is continuous (more than 90% of soil mass).
I Indurated: Cemented mass cannot be broken by body weight (75-kg standard soil scientist) (more than 90 percent of soil mass).

Structure

N None The structure is massive without recognizable orientation.
P Platy The compacted or cemented parts are plate like and have a horizontal or sub horizontal orientation
V Vesicular The layer has large, equidimensional voids which may be filled with uncommented material.
S Pisolithic The layer is constructed from cemented spherical nodules.
D Nodularthe layer is largely constructed from cemented bodies' of irregular shape.

Continuity of cementation/compaction

B Broken The layer is less than 50 percent cemented or compacted, and shows a rather irregular appearance.
D Discontinuous The layer is 50–90 percent cemented or compacted, and in general shows a regular appearance.
C Continuous The layer is more than 90 percent cemented or compacted, and is only interrupted in places by cracks or fissures

Nature

K Carbonates
Q Silica
KQ Carbonates–silica
F Iron
FM Iron–manganese (sesquioxides)
FO Iron–organic matter
I Ice
GY Gypsum
C Clay
CS Clay–sesquioxides
M Mechanical
P Ploughing
NK Not known

Mineral Nodules

Abundance (by volume): Classes as for Mottling

Colour:

Classes as for Mottling.

Hardness

H	Hard	cannot be broken in the fingers.
S	Soft	can be broken between forefinger and thumb nail.
B	Both hard and soft	

Nature

Mineral classes as for cementation

Kind

T	Crystal
C	Concretion A discrete body with a concentric internal structure, generally cemented.
SC	Soft concretion
S	Soft segregation (or soft accumulation) Differs from the surrounding soil mass in colour and composition but is not easily separated as a discrete body.
N	Nodule Discrete body without an internal organization.
IP	Pore infillings Including pseudo mycelium of carbonates or opal.
IC	Crack infillings
R	Residual rock fragment Discrete impregnated body still showing rock structure.
O	Other.

Size and shape

Size		**(mm)**		Shape
V	Very fine	<2	R	Rounded(spherical)
F	Fine	2–6	E	Elongated
M	Medium	6–20	F	Flat
C	Coarse	>20	I	Irregular
			A	Angular

Nature

K	Carbonates (calcareous)
KQ	Carbonates–silica
C	Clay (argillaceous)
CS	Clay–sesquioxides
GY	Gypsum (gypsiferous)
SA	Salt (saline)
GB	Gibbsite
JA	Jarosite
S	Sulphur (sulphurous)
Q	Silica (siliceous)
F	Iron (ferruginous)
FM	Iron–manganese (sesquioxides)
M	Manganese (manganiferous)
NK	Not known

Roots

Abundance

Classes as for pores

Size (diameter) (**mm)**

VF	Veryfine	<0.5
F	Fine	0.5–2
M	Medium	2–5
C	Coarse	>5

Biological features

Abundance

N	None	C	Common
F	Few	M	Many

Kind

B	Burrows (unspecified)	E	Earth worm channels
BO	Open large burrows	K	Krotovinas
BI	In-filled large burrows	T	Termite or ant channels & nests
C	Charcoal fragments	I	Unspecified insect activities

Pores, Abundance (per dm^2)

		<2mm (no.)	> 2mm
N	None	0	0
V	Very few	1 – 20	1 - 2
F	Few	20 – 50	2 - 5
C	Common	50 – 200	5 - 20
M	Many	>200	>20

Classification of porosity

		%
1	Verylow	<2
2	Low	2–5
3	Medium	5–15
4	High	15–40
5	Veryhigh	>40

Size (diameter) for elongate or tubular voids

V	Very fine	<0.5 mm
F	Fine	0.5-2 mm
M	Medium	2 – 5 mm
C	Coarse	5 – 20 mm
VC	very coarse	20-50 mm
FM	Fine and medium	
MC	Medium and coarse	
FC	Fine to coarse	

Classification of porosity

Classification of carbonate reaction in the soil matrix

Code	%	Description
N	0	Non-calcareous No detectable visible or audible effervescence.
SL	≈ 0–2	Slightly calcareous Audible effervescence but not visible.
MO	≈ 2–10	Moderately calcareous Visible effervescence.
ST	≈ 10–25	Strongly calcareous Strong visible effervescence. Bubbles form a low foam.
EX	≈ > 25	Extremely calcareous Extremely strong reaction. Thick foam forms quickly.

Classification of forms of secondary carbonates

SC	soft concretions
HC	hard concretions
HHC	hard hollow concretions
D	disperse powdery lime
PM	pseudo mycelia* (carbonate infillings in pores, resembling mycelia)
M	marl layer
HL	hard cemented layer or layers of carbonates (less than 10 cm thick)

Classification of salt content of soil

		EC_{SE}=dSm^{-1}(25 °C)
N	(nearly)Not salty	<0.75
SL	Slightly salty	0.75–2
MO	Moderately salty	2–4
ST	Strongly salty	4–8
VST	Very strongly salty	8–15
EX	Extremely salty	>15

**Any observation in the field related to this activity should be recorded on the description sheet

Land Uses

A=Crop agriculture(cropping)

AA	=Annual field cropping	
	AA1	=Shifting cultivation
	AA2	=Fallow system cultivation
	AA3	=Leysystem cultivation
	AA4	=Rainfed arable cultivation
	AA5	=Wet rice cultivation
	AA6	=Irrigated cultivation
AP	=Perennial field cropping	
	AP1	=Non-irrigated cultivation
	AP2	=Irrigated cultivation
AT	=Tree and shrub cropping	
	AT1	=Non-irrigated tree crop cultivation
	AT2	=Irrigated tree crop cultivation
	AT3	=Non-irrigated shrub crop cultivation
	AT4	=Irrigated shrub crop cultivation

Additionalcodesmaybeusedtofurtherspecifytheland-usetype.Forexample:

AA4	=Rainfed arable cultivation
AA4T	=Traditional
AA4I	=Improved traditional
AA4M	=Mechanized traditional
AA4C	=Commercial
AA4U	=Unspecified

M	**=Mixed farming**		
	MF	=Agroforestry	
	MP	=Agro pastoralism	
H	**=Animal husbandry**		
	HE	=Extensive grazing	
		HE1	=Nomadism
		HE2	=Semi-nomadism
		HE3	=Ranching
	HI	=Intensive grazing	
		HI1	=Animal production
		HI2	=Dairying
F	**=Forestry**		
	FN	=Natural forest and woodland	
		FN1	=Selective felling
		FN2	=Clear felling
	FP	=Plantation forestry	
P	**=Nature protection**		
	PN	=Nature and game preservation	
		PN1	=Reserves
		PN2	=Parks
		PN3	=Wildlife management
	PD	=Degradation control	
		PD1	=Without interference
		PD2	=With interference
S	**=Settlement, industry**		
	SR	=Residential use	
	SI	=Industrial use	
	ST	=Transport	
	SC	=Recreational use	
	SX	=Excavations	
	SD	=Disposal sites	
Y	**=Military area**		
O	**=Other land uses**		
U	**=Not used and not managed**		

<u>**Land Covers**</u>

Major Classes	Land Cover type	Mapping units
Settlement/Industries		S/I
Cultivated lands		CL
	State farm	CL1
	Intensively cultivated land	CL2
	Predominantly cultivated	CL3
	Moderately cultivated land	CL4
	Sparsely cultivated	CL5
	Perennial crop cultivation	CL6
Afro-Alpine and Sub- Alpine vegetation		AA
Forestlands		FL
	Dense coniferous high forest	FL1
	Dense mixed high forest	FL2
	Disturbed high forest	FL3
Woodlands		WL
	Dense woodland	WL1
	Open woodland	WL2
Riparian wood lands or Bush lands		RL
Bush land		BL
	Dense bush land	BL1
	Open bush land	BL2

Major Classes	Land Cover type	Mapping units
Shrub lands		SL
	Dense shrub land	SL1
	Open shrub land	SL2
Grass lands		GL
	Open Grass land	GL1
	Bushed shrub grass land	GL2
	Wood grass land	GL3
Wet lands		WE
	Perennial swamp	WE1
	Perennial marsh	WE2
	Seasonal swamp	WE3
	Seasonal marsh	WE4
Bare lands		BA
	Exposed rock surface	BA1
	Salt flats	BA2
	Exposed sand and soil surface	BA3
	Exposed sand and soil surface with cattered scrub and grass	BA4
Water body		WB
Other (specif		

Crop codes

Ce = Cereals

CeBa	= Barley
CeMa	= Maize
CeMi	= Millet
CeOa	= Oats
CePa	= Rice, paddy
CeRi	= Rice, dry
CeRy	= Rye
CeSo	= Sorghum
CeWh	= Wheat

Oi = Oilcrops

OiCc	= Coconuts
OiGr	= Groundnuts
OiLi	= Linseed
OiOl	= Olives
OiOp	= Oil-palm
OiRa	= Rape OiSe
	= Sesame
OiSo	= Soybeans
OiSu	= Sunflower

Fo = Fodder plants

FoAl	= Alfalfa
FoCl	= Clover
FoGr	= Grasses
FoHa	= Hay
FoLe	= Leguminous
FoMa	= Maize
FoPu	= Pumpkins

Ro = Roots and tubers

RoCa	= Cassava
RoPo	= Potatoes
RoSu	= Sugar beets
RoYa	= Yams

Fr = Fruits and melons

FrAp	= Apples
FrBa	= Bananas
FrCi	= Citrus
FrGr	= Grapes, Wine, Raisins
FrMa	= Mangoes
FrMe	= Melons

Fi = Fibre crops

FiCo	= Cotton
FiJu	= Jute

Ve = Vegetables

Pu = Pulses

PuBe	= Beans
PuLe	= Lentils
PuPe	= Peas

Lu = Semi-luxury foods and tobacco

LuCc	= Cocoa
LuCo	= Coffee
LuTe	= Tea
LuTo	= Tobacco

Ot = Other crops

OtSc	= Sugar cane
OtRu	= Rubber
OtPa	= Palm (fibres, kernels)

Vegetation classification

F =Closed forest

FE =Evergreen broad-leaved forest

FC =Coniferous forest

FS =Semi-deciduous forest

FD =Deciduous forest

FX =Xeromorphic forest

W =Woodland2

WE =Ever green woodland

WS =Semi-deciduous woodland

WD =Deciduous woodland

WX =Xeromorphic woodland

S =Shrub

SE =Evergreen shrub

SS =Semi-deciduous shrub

SD =Deciduous shrub

SX =Xeromorphic shrub

D =Dwarf shrub

DE =Evergreen dwarf shrub

DS =Semi-deciduous dwarf shrub

DD =Deciduous dwarf shrub

DX =Xeromorphic dwarf shrub

DT =Tundra

H =Herbaceous

HT =Tall grassland

HM =Medium grassland

HS =Short grassland

HF =For

M =Rainwater- fed moor peat

B =Groundwater-fed bog peat

APPENDIX II: Recommended Criteria for interpretation of soil physio-chemical analysis result

Texture/structure:

- Cm - Massive clay
- SiCm - Massive silt clay
- C+60,v- Fine clay, vertisols structure
- C+60,s- Fine clay, blocky structure
- C-60,v- Clay, vertisols structure
- C-60,s- Clay, blocky structure
- SiCs- Silty clay, blocky structure
- Co- Clay, oxisols structure
- SiCL - Silt clay loam
- CL- Clay loam
- Si – Silt
- SiC Silt clay
- SiL - Silt loam
- SC- Sandy clay
- L- Loam
- SCL- Sandy clay loam
- SL- Sandy loam
- Lfs- Loamy fine sand
- LS- Loamy sand
- LCS- Loamy coarse sand
- Fs- Fine sand
- S- Sand
- CS- Coarse sand
- C - Clay

Basic infiltration: Suitability for surface irrigation

Rates (cm/hr)

- < 0.1- Unsuitable (too slow) but suitable for rice
- 0.1-0.3- Marginally suitable (too slow), marginally suitable for rice
- 0.3-0.7- Suitable, unsuitable for rice
- 0.7-3.5- Optimum
- 3.5-6.5- Suitable
- 6.5-12.5- Marginally suitable (too rapid), small basin needed
- 12.5-25.0- Suitable only under special conditions, very small basin needs
- >25- Unsuitable (too rapid) over head irrigation method only.

Hydraulic conductivity: Permeability is a general term for the same ability to transmit water

K (m/day) **Classes**

- <0.2- Very slow
- 0.2-0.5- Slow
- 0.5-1.4- Moderately slow
- 1.4-1.9- Moderately rapid
- 1.9-3- Rapid
- >3- Very rapid

Available water holding capacity

AWC (mm/m) **Rating for irrigation suitability**

- Low - <120
- Medium - 120-180
- High - >180

Analysis	Range	Rating
PH	< 4.5	Extremely acid
	4.5 - 5.0	Very strongly acid
	5.1 - 5.5	Strongly acid
	5.6 - 6.0	Moderately acid
	6.1 - 6.5	Slightly acid
	6.6 - 7.3	Neutral
	7.4 - 8.0	Slightly alkaline
	8.1 - 9.0	Strongly alkaline
	>9.0	Very strongly alkaline
Electrical Conductivity (ms/cm)	0- 2	Salt free
	4-8	Slightly saline
	8-15	Moderately saline
	> 15	Strongly saline
CEC (me/100g)	>40	very high
	25- 40	high
	15-25	medium
	5-15	Low
	<5	very low
Base Saturation (%)	< 20	low
	20 - 60	medium
	>60	high
Exchangeable cations (Meq/100g of soil)		
Ca	>20	Very high
	10-20	High
	5-10	medium
	2-5	low
	<2	very low
Mg	>8	Very high
	3-8	High
	1.5-3	medium
	0.5-1.5	low
	< 0.5	very low
K	>1.2	Very high
	0.6-1.2	High
	0.3-0.6	medium
	0.1-0.3	low
	<0.1	very low
Na	>2	Very high
	0.7-2	High
	0.3-0.7	medium
	0.1-0.3	low
	<0.1	very low
Organic Carbon (%)	>20	Very high
	10-20	High
	4-10	medium
	2-4	low

Analysis	Range	Rating
	<2	very low
Organic matter (%)	>5	Very high
	3-5	High
	1-3	medium
	<1	low
Total N (%)	>1.0	Very high
	0.5-1	high
	0.2-0.5	medium
	0.1-0.2	Low
	<0.1	Very low
K: Mg Ratio	>2:1	Mg up take may be inhibited
Ca: Mg Ratio	>5:1	Possible Mg and p inhibition
	3-5:1	Normal range
	<3:1	Possible P inhibition and Ca deficiency
K: CEC Ratio	2%	Minimum level to avoid k deficiency
EX. Sodium Percent	<15	Non sodic
	> 15	sodic
• Available Phosphorus	>15	high
	5-15	medium
	<5	low
• Available Phosphoru	<10 ppm	Response expected
	11-31PPM	response probable
	>31ppm	response unlikely

Classification of carbonate reaction in the soil matrix

	%	
N	0	Non-calcareous
SL	0-2	slightly calcareous Audible effervescence
MO	2-10	moderately calcareous
ST	10-25	strongly calcareous
EX	>25	extremely calcareous

	Rating	**rages general**	**interpretation**
Al:CEC(%)	high	>85	tolerated only by few crops
	Medium	30-85	generally toxic
	Low	<30	sensitive crops affected

APPENDIX III: Profile description sheet

Soil Profile Description

Project Area:		**Profile number**: P	
Surveyor:		**Date:** / /	
Location:	**GPS E:**	**GPS N:**	**Elev.**
Slope class:		**Slope form:**	
Land form:		*Water erosion:*	
Topography:		*Position:*	
Surface crack:		*GravelA:*	
Land use/cover		**Rock out crop:**	
Major crop(s):			
Vegetation:	Species:		
Flooding F/D:	……./……	**Termitaria:**	
Soil drainage class:		*Water table, **cm:*** ***…… cm N***	
Soil parent material:	specify rock type if known:		
WRB soil class:		**Soil type**:	
Notes, observations, diagram:			
FAO-WRB:		**Soil unit:**	

Deep augering (from base of profile pit):

Boundary, cm				
Munsellcolour (moist)				
Colour code				
Mottles 0 F C M A F D P				
Texture class				
Coarse fragments 0 VF F C M A CS FG G S B				
HCl				
Fe-Mn nodules F C M				
Other features				

				Profile No:	P
Horizon	**1-**	**2-**	**3-**	**4-**	**5-**
Depth **cm**	**0 -**				
Moisture status					
Permeability					
Colour moist					
Colour code					
Mottles ab'nce: 0 F C M A					
size					
prominence: F D P					
colour					
Texture					
Coarse ab'nce: 0 F C M					
fragments size					
type					
Consistence dry					
moist					
wet					
Structure development					
size					
type					
Distinct common clay skins					
Slickenside/Pressure face					
Pores ab'nce: 0 VF F C					
size					
Fe-Mn ab'nce: 0 VF F C M					
size: F M C					
type					
CaCo3 ab'nce: 0 VF F C M					
size: F M C					
Type					
Roots ab'nce: 0 VF F C M					
size					
HCl					
Horizon boundary					
Sample No.					

Remark:

APPENDIX IV: Auger-hole description sheet

Name of Project--------------

Soil Auger Description Sheet

Surveyor:	Date: dd / mm /yr	Survey area:	GPS (E): GPS (N):	Elev.:	Auger No.:
Land form:	Topography:	Slope class:	Slope form:	Position:	Surface: Cracks
Gravels:	Rock out crop:	Vegetation (species):		Water table……...cm; N	
Drainage class:	Erosion:…..…….	Flooding F/D:…../…….	Land use/cover:…………………..	Crop(s):	
Micro-topography:	Termitaria:	Parent material:	Sampled: Y N	Soil type:	FAO soil class:
Between sites, notes:					

Depth (cm)	0 -					
Munsellcolour (Dry)						
(Moist)						
Colour code						
Mottles Abundance						
Distinctness						
Colour						
Texture class						
Consistence Dry						
Moist						
Wet						
Distinct common clay skins						
Distinct pressure faces, slickensides						
Coarse fragments Abundance						
Size						
HCl						
Nodules Abundance						
Nature						
Type						
Other features						

Remark:

Note: Dig a mini-hole to 60cm to observe clayskin, pressure faces and other profile development

APPENDIX V: Infiltration measurement sheet

Profile No: Replicate No:
Date: Measured by:
Surface feature Source of water:

Local Time (hr:mins)	Time intervals (mins)	Depth to water (cm)	Refill depth, (cm)	Intake (cm)	Cumulative intake (cm/hr)	Infiltration Rate (cm/hr) Instantaneous	Infiltration Rate (cm/hr) Mean

Diagram / comments:

APPENDIX VI: Hydraulic conductivity measurement sheet

Hydraulic Conductivity Measurement *(inverse auger-hole method)*

Profile No: Replicate No:

Date: Measured by:

Radius of hole, r (cm) Depth of hole, D (cm):

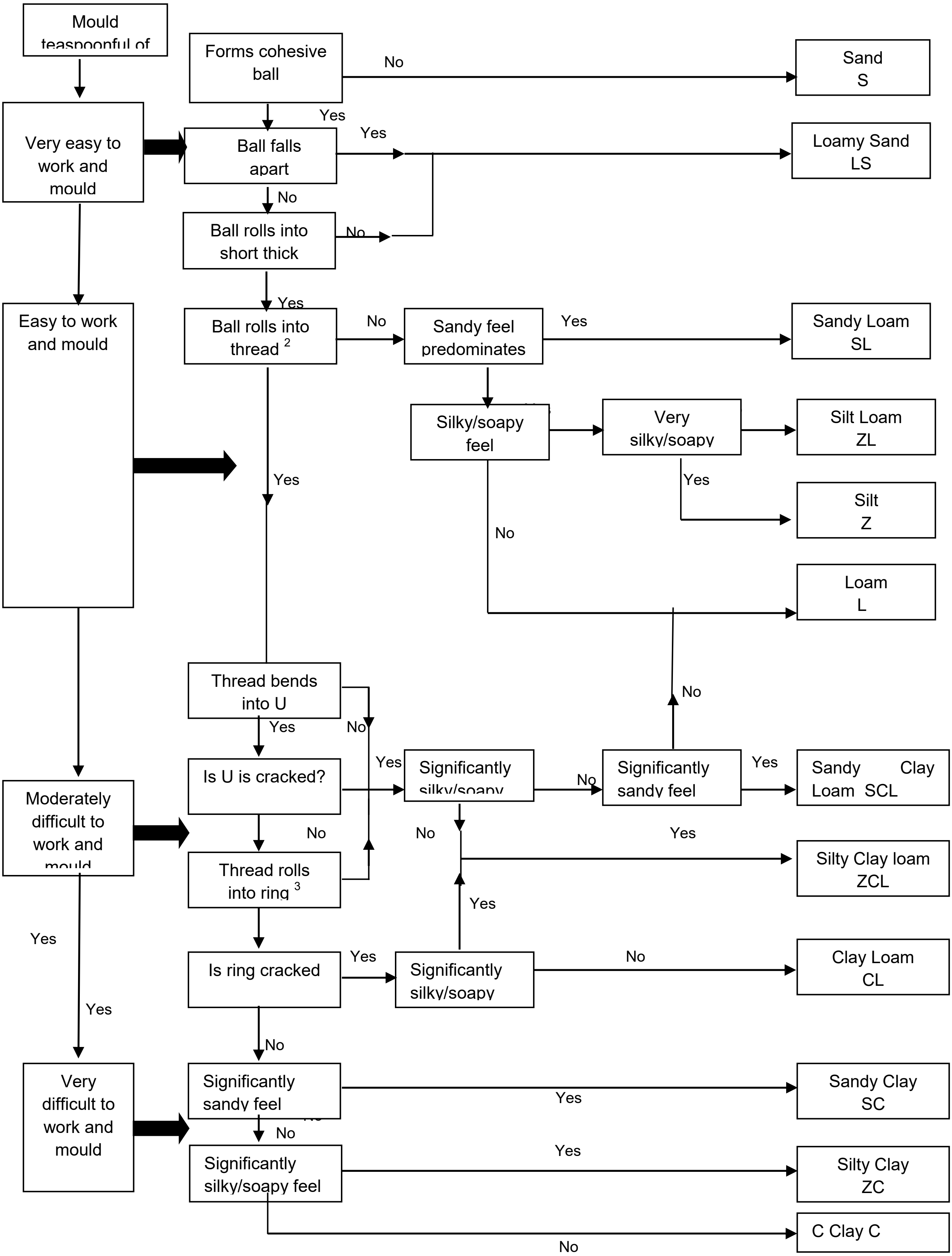
Source of water: Depth of GWT:

Site characteristics:

i	ti sec	h'(ti) cm	h(ti) cm	(hti+r/2) cm	Remarks
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					
17.					
18.					
19.					
20.					
21.					
22.					
23.					
24.					
25.					
26.					
27.					
28.					

Diagram / comments

APPENDIX VII: Flow chart for determining textural class by feel method



[1] Cylinder : Approximately 5cm long and 1.5 cm diameter
[2] Thread: Approximately 13 cm long and 0.5 cm diameter
[3] Ring: Approximately 2.5 cm diameter

Additional Explanatory Notes

Soil Textures	Predominant Features
Sand*	Gritty feel, no cohesion of particles, hardly sticks to fingers. Water squirted onto soil runs off relatively clear.
Loamy sand	Very sandy feel. Very little soil sticks to fingers. Water squirted onto soil runs off slightly muddy.
Sandy loam	Sandy/gritty feel. Sticks to at least one finger. Easily worked.
Silt loam	Smooth soapy feel, easily worked, wets up rapidly, sticks to at least one finger, does not take a polish.
Loam	No predominating feel equal amounts of sand silt and clay. Sticks to fingers and thumb, easily worked. Slightly sticky and plastic, but does not take a polish.
Sandy clay loam	Moderately difficult to work, gritty feel, moderately sticky, sticking to fingers and thumb. Smears but too gritty to take a polish.
Silty clay loam	Moderately difficult to work, very smooth and soapy feel. Sticks to fingers and thumb, smears and takes a slight polish.
Clay loam	Moderately hard to work, stickier than loam, sticks to fingers and thumb. Slightly soapy. Smears and takes a slight polish.
Sandy clay	Very hard to work and very sticky with gritty feel. Smears and takes a polish, but sand grains stand out on the surface.
Silty clay	Very hard to work and very sticky with very smooth soapy feel. Takes a marked polish.
Clay	Very hard to work and slow to wet up, very sticky and takes a very marked polish. Very hard when dry.

* Sand can be subdivided into:

Coarse: Majority of grains size of sugar grains and very visible (> 0.5 mm).

Fine: Particles just visible to naked eye, abrasive sound, feels relatively smooth but just feel sand grains.

ASSESSING SOIL TEXTURE

1. Pick up a small amount (teaspoonful) of soil and remove any stones or roots.
2. Moisten the soil using a small amount of water from a water bottle. **Do not saturate the soil**.
3. Rub and work the soil thoroughly between thumb and fingers to ensure uniform wetting and the complete breakdown of any harder lumps of soil. This operation may take a considerable length of time on heavy textured clayey soils. During this operation it may be necessary to add more water but again, **do not make the soil too wet**. Sufficient water should be used only to bind the soil particles together and to begin to stick to the fingers.
4. If the soil becomes too wet, progressively add drier soil and/or continue working the soil.
5. Once the soil has been thoroughly worked, carry out the tests as shown overleaf.

APPENDIX VIII: Soil &land Suitability Report Outline

a) SOIL AND LAND SUITABILITY REPORT OUTLINE

I. EXECUTIVE SUMMARY: The summary should cover and address the reliant section i.e the following chapters of the report

b) CHAPTER 1. INTRODUCTION

- Back ground
- Scope
- Objective
- Report structure

c) CHAPTER 2. THE ENVIRONMENT

a) Location: Latitude and longitude; relation to national or regional geography and administrative areas, main and local towns. altitude; major landforms and relative relief.
b) Communications:- Roads (and surfaces), tracks (motorable or not), seasonal closures; railways; air and river transport.
c) Human settlement and present economic activities population numbers, density, distribution; occupations; health and endemic diseases. Industry, agriculture and forestry; main crops, marketing and processing (more details of land use can go into main report).
d) Infrastructure: Local, regional and national government administrative institutions; agricultural stations; dispensaries and hospitals; schools and colleges; power and water supplies.
e) Climate : Rainfall quantity, intensity and distribution; wind speeds and directions; maximum, minimum and mean temperatures; bright sunshine hours; solar radiation; evaportanspiration; moisture surpluses/deficits; frost/storm action; seasonal trends; incidence of a typical but crop-damaging weather. Statistical analysis where appropriate; references to standard local works (if any).
f) Water resources: River flows and GWT levels (seasonal variation); water storage; water quality; regional drainage; flood risks, duration and depths.
g) Geology and geomorphology: Major terrain types, basic geology and geomorphology; specific landforms and their relationship with soils. References to standard local works, if any. Map, if appropriate, with text.
h) Natural vegetation and present land use - Overall pattern, especially as related to landscape features; major tree and shrub species and uses. Present land use - major crop and weed species, type(s) of cultivation, crop rotations, land management, livestock, problems (e.g. erosion), agricultural research. References and, if appropriate, map.

Diagrams: of general location; agro-climatic data; major geological/geomorphological units (locations and cross-sections); vegetation/ecology.

d) CHAPTER 3. SOIL SURVEY METHODS

a) Level of survey(s) made, grid spacing. Site intensity; how/why varied; area(s) covered at given intensity.
b) Numbers of auger and of pit sites and observation density.
c) Numbers of deep boring
d) Depths of all observations; method of description
e) Processing of data (keep brief and cross-reference to annex on details of calculations)
f) Details of AP cover used - Date(s), scale(s) and area(s) covered, quality, limitations.
g) Map compilation - Scale, base map(s), how boundaries drawn (

h) Special measurements - Numbers of sites, replicates and brief method descriptions regarding, e.g. infiltration rate, hydraulic conductivity, bulk density etc.; also laboratory methods

e) CHAPTER 4. SOIL CLASSIFICATION

a) Previous studies and classifications, including level of study, proportions of field-work and API, observations made (depths of profiles, properties recorded).
b) General description of soils (origin, morphology, chemical, physical) and classification adopted.
c) Summarized profile descriptions of soil units (in small type further details in annex).
d) Correlation's with any previous classification(s) - Tabulate grouping; soil names, soil symbols; local, FAO and/or USDA units.
e) Tabulated physical and chemical data, including means and/or medians, SD/SE, ranges.

<u>Diagrams</u>: Soil moisture curves; infiltration test graphs

f) CHAPTER 5 DESCRIPTION OF SOIL-MAPPING UNITS

- Methodology ,accuracy of soil boundaries; minimum mapped area
- Description of individual units (grouped by landscape unit or soil grouping, as appropriate) with tabulations of most important data; include data on slopes, micro topography, erodibility, drainage, potential crop yields etc.
- Table of areas and percentages; both of mapping units and individual soils.
- Purity of units; major impurities.

g) CHAPTER 6. WATER QUALITY FOR IRRIGATION

6.1. Background

6.2 Evaluation Of water quality for irrigation

h) CHAPTER 7 LAND SUITABILITY EVALUATION

- ➢ Objectives of classification and context - Data and assumptions in physical, social and economic terms. Present and proposed land usage with respect to land suitability.
- ➢ Management and improvements envisaged before, at and after the time during which the land suitability classification is expected to be applicable; agricultural methods; engineering installations.
- ➢ Basis of classification - FAO principles;
- ➢ Tabulated soil mapping unit descriptions
- ➢ specific, with quantified limits for subclasses (see below).
    - Criteria chosen for differentiating classes and subclasses.
    - Description of subclasses, with reference back to table given at d ii above.
    - Deficiencies/restrictions; effects on yields. Tabulation of symbols.
    - Tabulated subclass areas, percentages, estimated crop yields.
    - Details of subclasses including impurities (if long, this section could be put in small print).
    - social, financial and economic evaluation - assessment and comparison of alternatives. Normally handled by the team economist and/or financial analyst.
    - Source data - Maps, previous reports, local information, either as annex or accompanying documentation.
- ➢ Check following points on land suitability evaluation
    - Range of properties and values of class limits used as the basis for the classification should be relevant to the planned development, and not necessarily just standard systems.
    - Definitions of units should be unambiguous and related to the proposed land use(s).
    - Specific problems should adequately quantified and based on sufficient measurements.
    - Areas and locations of classes and subclasses should be given.
    - There should be adequate interpretation of survey results for practical users; e.g. management practices for the land units should be specified where appropriate.

CHAPTER 8 SOIL AND LAND MANAGEMENT

- Soil acdidity
- soil fertility -
- drainage
- salinity and sodicity.
- Topography /Land preparation -bench terrace design requirements for hill side irrigation

I. Sol MAPS

1. Map subjects - These will normally include:

a) Soils
b) land suitability (separate map set for each use envisaged);
c) specific soil parameters relevant to development, e.g. salinity, depth (separate set for each development)
d) Summary map of whole area (usually land suitability).

(i) to (iii) normally at same scale; (iv) smaller scale to allow presentation on one sheets. In surveys of single farms or other small areas, or where soil and land unit boundary configurations are simple, one map sheet may suffice for all the topics.

2. Map scales

i) scale of available base maps;
ii) allowing sufficient space for site numbers to be drawn in;
iii) scale that will be of most value to other users (
iv) Production of maps that are small enough to use comfortably in the field.

3. General map presentation

All maps (soil, land suitability, parameter or theme, summary) should usually include the following features:

a) title (including client, project, map number and subject, country);
b) date:
c) map or sheet code and number;
d) scale (linear scale, and numerically);
e) north-point (magnetic/true) and latitude and longitude reference points (or grid system and references);
f) index diagram to adjoining sheets;
g) compilation source(s) (e.g. aerial photographs, topographic maps-authors, reference numbers, scales and dates);
h) company and associates' names, addresses and logos; where other companies have provided technical inputs such as aerial photography/base maps or cartography they also require mention;
i) specific subject legend
j) conventional symbol legend to explain all general symbols (roads, rivers etc.);
k) indication of map reliability/intensity of survey;
l) cross-reference to accompanying report;
m) copyright attribution.

The maps should be a self-contained and as easy to interpret as possible.

4. Soil map legends

a) Keep as simple as possible.
b) Major I soil
c) WRB symbol/name
d) Composition of complexes (percent of each soil type), and 'reliability' of map (depth and intensity of observations; purity of units).
e) Possibly (where easily portrayed) diagrammatic cross-sections showing soil-topography-vegetation associations (or in report).

II. **Land suitability map legends**

a) Separate map for each land use envisaged

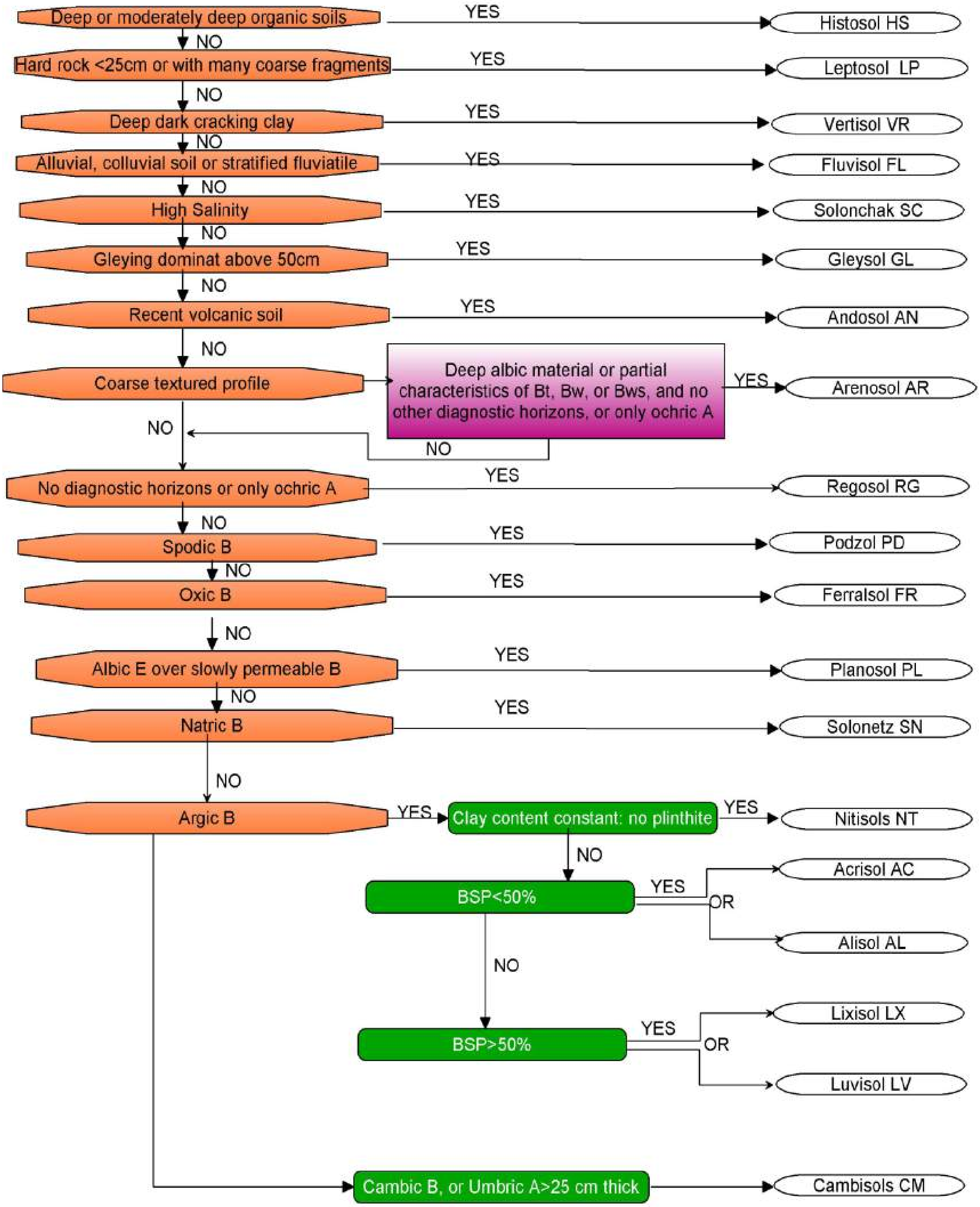
b) Keep as simple as possible, especially symbols.

c) Major limitations and/or use restrictions indicated.

Appendices: The following data should be compiled and appended

- soil physio-chemical analysis result
- Auger-hole & Profile description
- Infiltration & Hydraulic conductivity measurement
- soil moisture content

APPENDIX IX: Quick Classification Guide to for Reference Soil Groups in Ethiopia



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Prepared by

GIRDC