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SOIL CLASSIFICATION OF DUDHNAI REPRESENTATIVE BASIN (ASSAM/MEGHALAYA)

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ABSTRACT

The Dudhnai sub-catchment of about 500 km^2 on the south bank of the river Brahmaputra has been selected for long term representative basin studies. Under this broad objective, North Eastern Regional Centre undertook field investigations for classification of soils in the basin. This study aims at field and laboratory determination of soil classification properties under Dudhnai river basin.

Point infiltration tests using double ring infiltrometer were conducted at various locations (44 sites) in respect of different land use conditions. Soil samples were also collected from same infiltration testing sites. Field determination of saturated hydraulic conductivity was made using Guelph Permeameter for same site of infiltration tests. The undisturbed soil samples (from 44 locations) and disturbed soil samples (from 44 locations at 50 cm below surface) were collected and brought to the soil lab of the centre. Extensive laboratory measurements were made for each soil sample collected. Disturbed soil samples were used for textural and consistency analysis. Percentage of sand, silt and clays were determined through sieve analysis and pipette method. Different engineering and index properties like moisture content, bulk density, dry density, sp. gravity, plastic limit, liquid limit, void ratio, saturated density, degree of saturation, uniformity coefficient, coefficient of curvature etc. were obtained for each soil sample. Soil suction was also measured using Tensiometer at field. Grain size curves were plotted and particle size distribution ranges have been identified using USDA criteria. Textural classification was identified using triangular classification system of USDA and Bureau of Indian Standards method (IS:1498-1970) also. Hydrologic soil groups were identified on the basis of infiltration characteristics using SCS method.

The report presents a thorough soil investigation results for the Dudhnai river basin.

1.0 INTRODUCTION

Soils can be classified employing various methods that are in use in different parts of the world. The engineer classifies soil on the basis of those characteristics which determine how a soil will behave as an engineering construction material. Hydrologic classification of soils considers particle size, shape, density and consistency among other characteristics for grouping the soil. The hydrologist is concerned with the surface and subsurface percolation of water through soil and the effects of forces of nature on them. The systems of soil classification differ from country to country and all the systems have a number of common points in the method of classification.

Soils may be generally classified as coarse or fine, cohesive, or non-cohesive, inorganic or organic, and so on. But these descriptions are general and cover a wide variety of soils in a group. A more meaningful grouping is therefore necessary to establish criterion in terms of measurable characteristics. Soil classification groups together soils of like characteristics and are designated by group name in order to simplify the procedure of identification. Such a grouping of soils, with the sole purpose of engineering application, is known as *engineering soil classification*. Prerequisite to the classification of soils is the concept that the soil mantle consists of natural geographic bodies with their own genesis. Such a concept became possible after the science of geology was born, even though the first theory of soil genesis as rock weathering was found inadequate later. Present systems of soil classifications reflect many more aspects of soil and theories of genesis in requirement of improved soil and water management practices.

Quantitative measurements of soil physical properties are required for many purposes. In the area of land management, one may wish to know whether a particular management scheme will increase or decrease infiltration, runoff, erosion, leaching, salinization etc. We may need to predict material transport, such as the depth to a wetting front, position of a seepage face, time of arrival of a tracer plume, cumulative evaporation etc.

Hydrological soil classification is essential for accurate estimation of runoff from a catchment. The soil characteristics of the watershed play an important role in the hydrological soil classification. The main soil parameters generally considered for analysis are effective soil depth, soil texture, clay content in surface and sub-surface layers, soil structure, infiltration rate, soil permeability, and soil drainability.

Hydrological soil classification refers to a group of soil series that can be considered homogeneous in respect of soil characteristics that influence the runoff. Soil characteristics of watershed play an important role in its runoff potential. The surface runoff, soil moisture storage and deep percolation due to infiltration from a storm are influenced by the soil characteristics of the watershed. Such response is affected by the characteristics of soils both on the surface and sub-surface horizons. The characteristic of the soil on the surface is the infiltration capacity and characteristic of the soil in the sub surface is the percolation or transmission rate. Hydrological soil classification is useful for estimation of runoff. The soil characteristics of watershed play an important role in the hydrological soil classification.

Prediction of infiltration is important in the design of irrigation areas and for the estimation of runoff in catchment management studies. Many predictive models exist and various methods have been employed in measuring infiltration behavior. The proper evaluation of infiltration behavior depends on knowledge of the hydrological soil properties.

Physically based hydrological models, soil water balance, groundwater flow and transport models require saturated and unsaturated hydraulic conductivity to solve the sub-surface flow and transport equations. Saturated hydraulic conductivity and unsaturated hydraulic conductivity are related to the degree of resistance from soil particles when water flows in pores. The forms, sizes, branching, jointing of pores as well as viscosity of water affect these resistances. In addition, unsaturated hydraulic conductivity is affected markedly by the volumetric water content of soil.

Selection of the optimum drainage plan and the design and construction of adequate and successful drainage facilities depend upon the reliability and adequacy of the basic drainage data. The basic data provide the knowledge of soil texture, saturated hydraulic conductivity of the soil and topography of the area under consideration.

Hydrological soil properties constitute the basic data for carrying out groundwater, irrigation and drainage studies. Design and construction of adequate and successful subsurface drainage system depend upon the reliability and adequacy of the hydrological soil properties. The basic data must provide the knowledge of soil texture, saturated hydraulic conductivity and the soil moisture of the soil and topography of the area under consideration. Soil texture is a characteristic, which has a general relationship with hydraulic conductivity and water retention. It is difficult to measure the saturated hydraulic conductivity of the soil in the field where water table is at large depth. If the soil classification of the area is available then the saturated hydraulic conductivity can be determined by the Johnson's graph. The soil moisture relationship is another important parameter. Wilting point, field capacity and available moisture can be found from the characteristic relationship.

Once the soil has been identified, its suitability for specific engineering use for planning any developmental activities in the field of agriculture, irrigation, forestry and general land use planning can be evaluated. Efforts were made during the 19th century to classify the soils of a few states. With the setting-up of National Land Resources Commission at the Centre and Landuse Boards in the States, works for preparing soil resources maps for different regions are going on to provide rational approach for land use planning. For a few States of India, Agricultural Atlas have also been prepared by certain agencies for visual presentation of data on agricultural sectors. For the states of the north-east India, no such Atlas has so far been prepared.

The Dudhnai sub-catchment of about 500 km^2 on the south bank of the river Brahmaputra has been selected for long term representative basin studies. Under this broad objective, North Eastern Regional Centre undertook field investigations in the basin. Point infiltration tests, Guelph Permeameter tests for hydraulic conductivity & flux potential etc. were conducted at various locations in respect of different land uses. Soil samples were also collected from test sites and tested in laboratory to relate the results to soil types.

In the present study, field and laboratory investigations have been carried out to determine the soil characteristics (Particle size distribution, hydraulic conductivity, soil suction, index properties etc.) at various locations along the uppermost part of Dudhnai river.

The results of the study would be used in the subsequent hydrologic studies to model the basin. It is hoped that this study will be of great use for users of different departments and organizations in their watershed management program.

2.0 REVIEW

Soil classification needs knowledge of various soil properties and the extent to which the soil groups exist in a watershed. This necessitates mapping the basin after detailed soil survey. The monitoring of soil resources information is imperative, especially in areas where problems of degradation, such as rising ground water table resulting in development of soil salinity, sodicity, water-logging, erosion. etc. are encountered.

Many soil and landform attributes can be observed and classified. The choice depends upon the purpose for which classification is to be made. Generally, parameters which control or influence plant growth, soil texture, depth, profile development, drainability, soil infertability, permeability, temperature, pH etc.

2.1 Soil Surveys in India

The need and importance of soil survey in agricultural development in India have been recognized for many years. The scientific study of soils of the country was taken up as early as 1898 when four major soil groups occurring extensively were differentiated (National Commission on Agriculture, 1972).

With the initiation of agricultural research in the country the emphasis was on soil fertility. Soil profile studies started receiving attention only during the 1930s when soil genesis and development came to be recognized as significant factors for the purpose of soil classification. The standard comprehensive soil survey was started in 1956 when the All India Soil Survey and Land Use Organization was established. The modern system developed by the United States Department of Agriculture has been in use since 1969. A task of carrying out and coordinating the soil survey work in the counts, is done by the National Bureau of Soil Survey and Land Use Planning, Nagpur. The survey in progress is designed to furnish data about all important soil characteristics and associated features for the largest variety of users.

Using the legend based primarily on geologic origin of parent material, soil scientists at the National Agricultural Research Institute made a Soil Map of India in the mid 1950's at a scale of one inch equals 250 miles (Fig. 2.1). This early map has been useful in broad land-use planning. In the 1970's a soil map of India at the Great Group level was made based on the United States System of Soil Taxonomy. The Scale is one centimeter to 100 kilometers (Fig. 2.2).

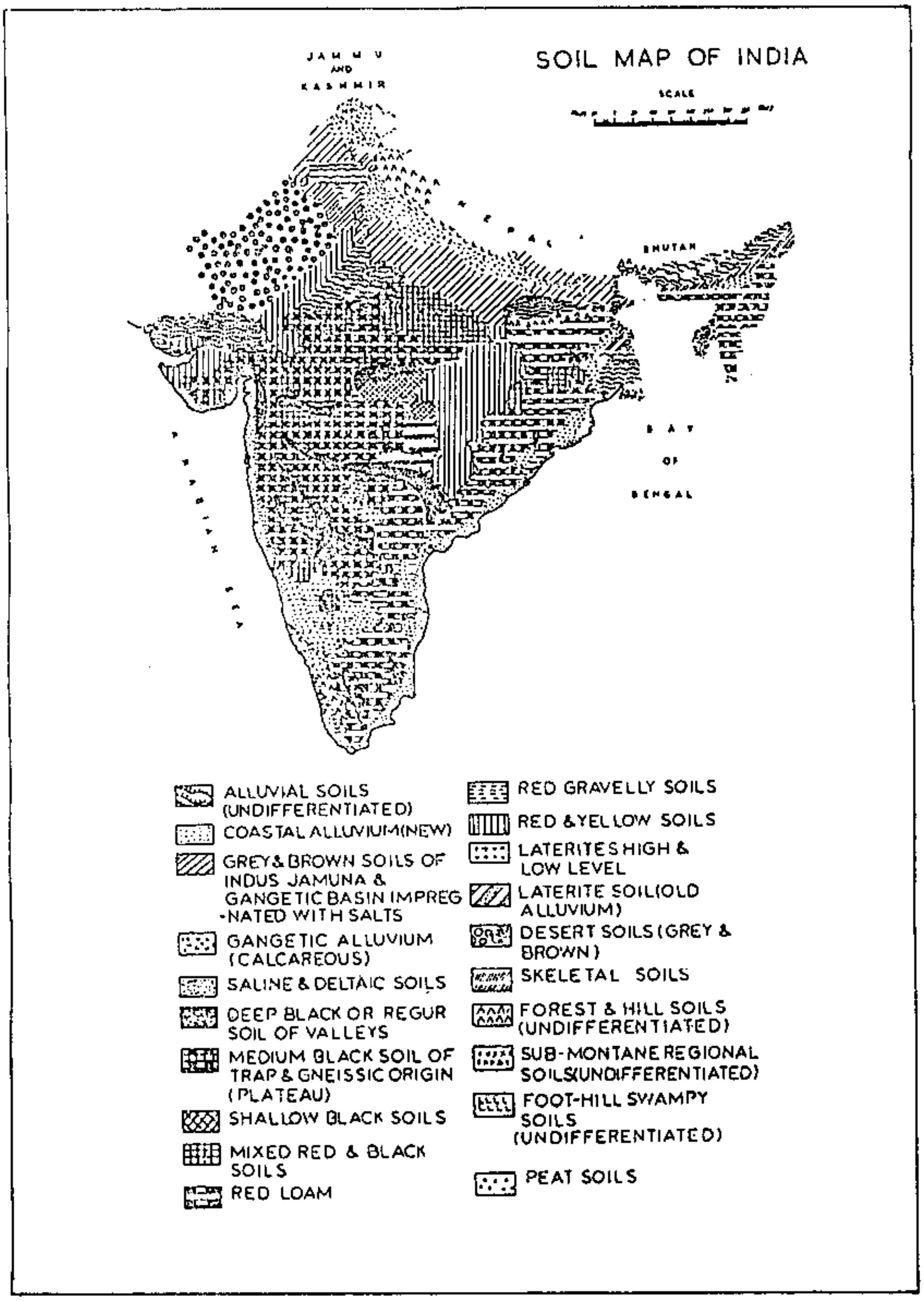


Fig. 2.1 : One of the earliest (in the mid 1950's) soil map of India (Source : India Council of Agricultural Research)

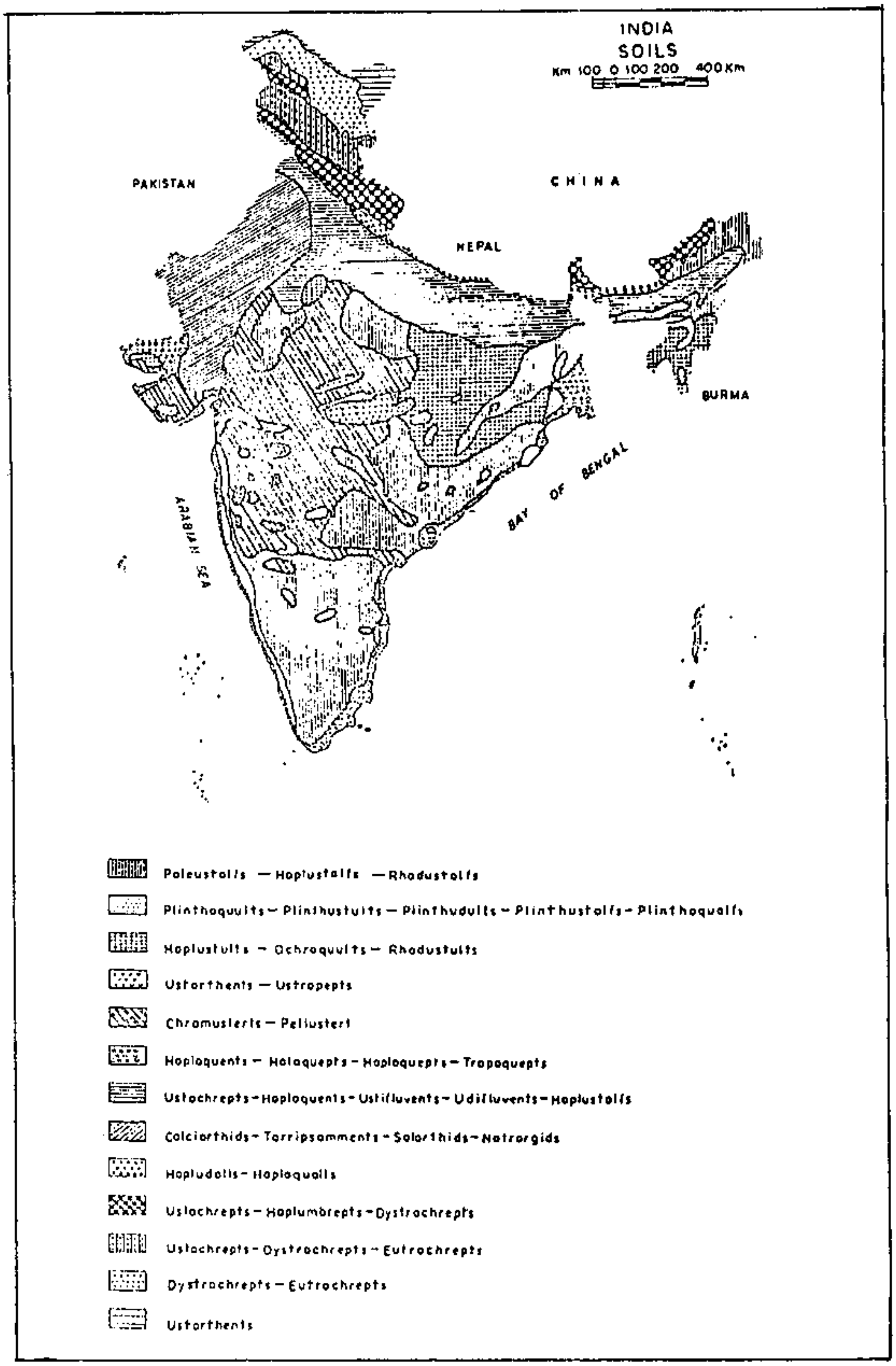


Fig. 2.2 (a): The most recent soil map of India based on U.S. system of soil taxonomy (Source : India Council of Agricultural Research, New Delhi)

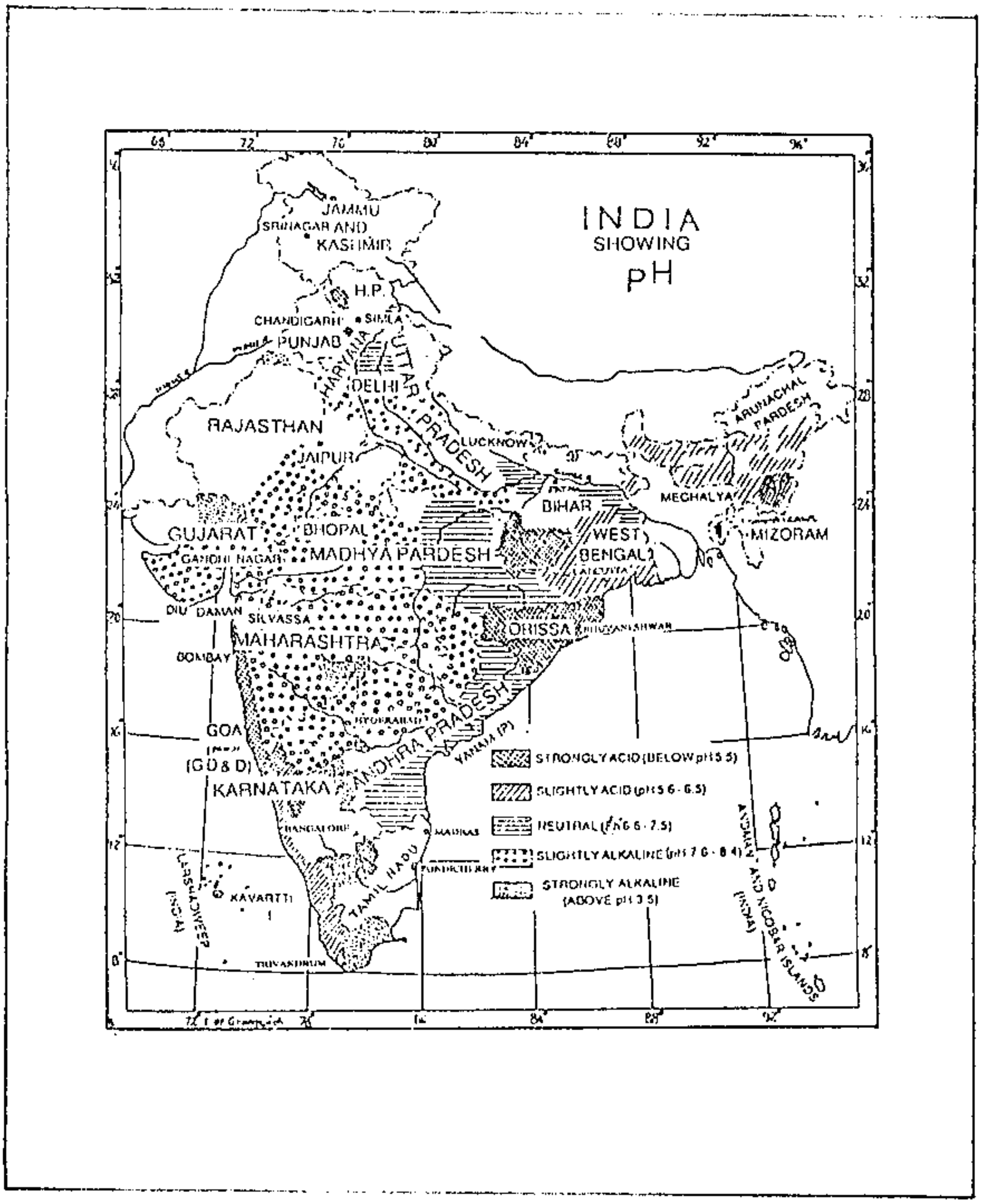


Fig. 2.2 (b) : Soil pH map of India (Source : Survey of India)

2.2 Soil Deposits of India

Under different conditions of climate, topography and action of various weathering agents, several soil types have been encountered in India. Figure 2.3 is a map indicating major soil deposits.

The marine deposits of India are mainly in tidal flats along the coast. Cochin area on the west coast and the Vishakapatnam harbour area on the east coast are important regions. These clays are slightly sensitive and are essentially inorganic in nature. One of the major regional deposits of soils, commonly designated as Black Cotton soils cover an extensive area of 300,000 sq. km. which is one fifth of total land area. The underlying bed rock of black cotton soils is to a large extent basaltic. Due to high active clay fraction present in such soils and the prevailing tropical environment, unacceptable volume changes due to heave or shrinkage can take place. Such expansive soils inevitable problematic geotechnical materials, are encountered in many parts of the world. In India Laterites form another important regional deposit covering an area of about 100,000 sq. km. They are formed by the decomposition of rock, removal of silica and bases in solution and accumulation of aluminum and iron sesquioxides, titanium, magnesium, calcium and other amorphous products. In large parts of Indo-Gangetic river plains, alluvium deposits are encountered. The thickness of such deposits in many places is more than 100 meters with alternating layers of sand, silt and clay deposits. Most of the soils found in large parts of Rajasthan are wind blown deposits formed under and conditions with hardly any rain-fall.

2.3 Systems of Soil Classification

The first systematic soil survey was launched in 1899 in the United States before any method for classification of soils was developed. The early system of soil classification was a direct reflection of the prevailing concept of soil as the weathered mantle of rock. The system was followed in United States with little change for about 30 years . Despite this frame of reference for the classification of soils, however , attention was given to soil profile characteristics that were not directly related to weathering or to source rocks. Those characteristics were being introduced as series criteria within the first 10 years of the century, well before a different approach had been proposed (Simonson,1964).

The important soil classification systems can be divided into two categories. The first category is based on grain size of the soils and is essentially useful for classifying soils in which single grain properties are of importance, such as cohesionless soils e.g. gravels and sands. The other category is one which is more

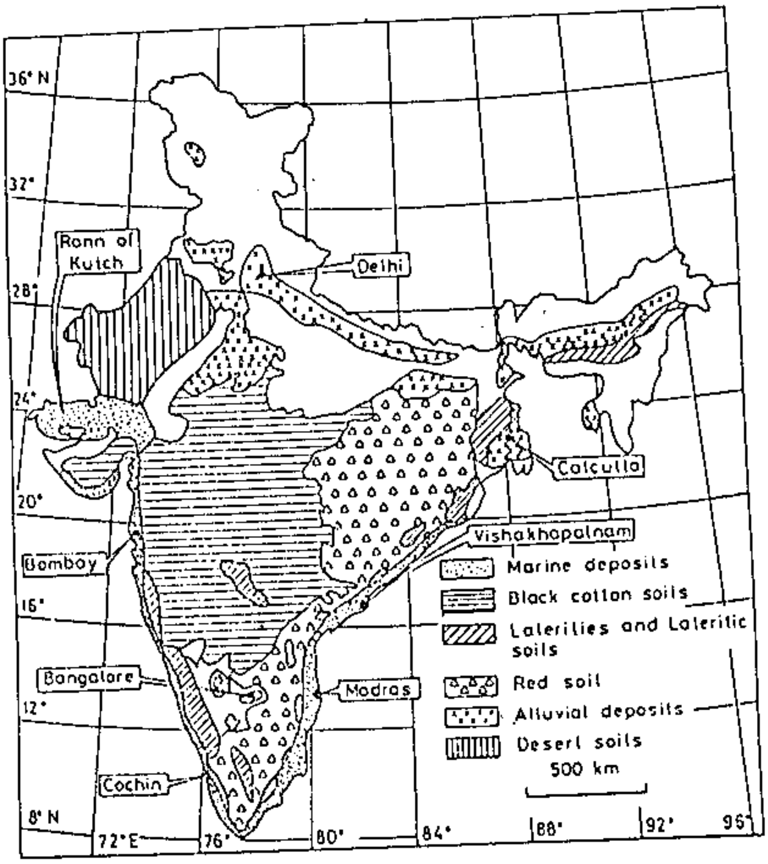


Fig. 2.3 : India map indicating major soil deposits

general in nature and is employed for classification of both the coarse as well as fine grained soils. These systems are based both on structure and texture of the soil.

2.3.1 Soil Structure and Composition

The original parent material of soil which is the solid rock of the earth's outer skin on weathering and erosion breaks down the surface layers of the solid geological strata and remains as deposits of unconsolidated material. Thus a soil may be a direct product of underlying weathered rocks or may be formed from loose deposits unrelated to the solid rocks below. Soil depths and their composition can therefore be variable along the subsurface.

Soil structure is the most important physical property in relation to plant growth, because it influences the amount and nature of porosity. The best structure for favourable physical properties of soil are spheroidal type of soil structure. Some structures are mechanically stable and strong but when they absorb moisture and are wet they become soft and lose their shape and size. Soils high in water stable aggregates are more permeable to water and air.

Soils tend to puddle under the condition of less stability of aggregation. Soil structure can be changed easily under different management practice namely ploughing, draining, liming, fertilizing and manuring etc. The application of organic matter also improves the soil structure. Grasses are most effective in promoting granulation as well as soil aggregation.

Soil structure has a profound influence on plant growth especially on root and top growth of plants. The structure of soil also determines the bulk density of a soil. As a rule, the higher the bulk density, the more compact the soil, the more poorly defined soil structure and the smaller the amount of pore space and therefore, the plant growth is restricted. High bulk densities inhibit the emergence of seedlings and also offer increased mechanical resistance to root penetration. Bulk density also influence the rate of diffusion of oxygen into the soil pore spaces and root respiration which in turn affect the plant growth to a great extent. The oxygen supply at the root absorbing surface is critical. Hence not only is the gross oxygen level of the soil air important, but also the rate at which oxygen diffuses through the soil to maintain an adequate partial pressure at the root surface. So it may be concluded that good soil structure and aeration are imperative for maximum yields of most agricultural crops (excepting rice) and the limiting effect is an inadequate root oxygen supply which can influence the plant growth.

2.3.2 Particle Size Classification

This system classifies soils on the basis of their grain size. Accordingly soils are termed as gravel, sand, loamy sand, silt, silty loam, clay, sandy clay loam, clayey fine etc depending on their grain size. Sieving and sedimentation analysis are used to determine grain sizes of soils.

In Sieve test gravel fraction of the soil is removed by sieving on the 2.00 mm sieve. The sample of soil which passes 2.00 mm sieve are dried and then shaken through a series of sieves ranging from coarse to fine and the amount (% of sample dry weight) retained on each sieve is weighed and recorded.

Sedimentation test is conducted for the finer fractions of the soil which passes the 75 micron sieve. Then this soil is shaken up in a test tube with water and allowed to settle. Different proportions of finer material can be seen at the top of the test tube and coarseness of grain size increases towards bottom of the test tube. Particle size is determined by observing the rate at which the grains settle through a liquid. Hydrometer or a pipette is used to determine this. As discussed above soils are grouped according to their grain size and many of them are in use. The important and commonly used particle size classifications are as follows.

i) Highway Research Board (HRB) Classification

Highway research board classification system, also known as Public Road Administration (PRA) classification system is based on both the particle size composition as well as the plasticity of the soil. The classification was extensively revised in 1945, 1949 and in 1966. It has also been designated as American Association of State Highway Officials (AASHO) classification. According to the revised system, soils are classified into seven groups, designated as A-1, A-2...A-7 as shown in Table 2.1. Group A-1 is divided into two sub-groups and A-2 is divided into four sub-groups. The Group Index(GI) is determined from the following equation,

$$GI= (F-35)[0.2+0.005(LL-40)] + 0.01(F-15)(PI-10)$$

where, F = That portion of percentage passing US.no.74 micron expressed as a positive whole number.

LL= Liquid limit

PI= Plasticity index

Table 2.1 – HRB Classification of soils and soil aggregate mixtures

General Classification	Granular Material (35 per cent or less Passing No. 74μ)*							Silt-Clay Materials (More than 35 per cent Passing No. 74μ)*			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7 A-7-5 A-7-6
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				
Sieve analysis, per cent passing											
2.00 mm*	50 max										
$420\ \mu$*	30 max	50 max	51 min								
$74\ \mu$*	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing $420\ \mu$*											
Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	Stone fragments —gravel and Sand		Fine sand	Silty or clayey gravel and sand				Silty Soils		Clayey Soils	
General rating as subgrade	Excellent to good							Fair to poor			

Classification procedure : *With required test data in mind, proceed from left to right in chart; correct group will be found by process of elimination. The first group from the left consistent with test data is the correct classification. The A-7 group is subdivided into A-7-5 or A-7-6 depending on the plastic limit. For P.L.* < 30*, classification is A-7-6; for P.L.* $\geqslant 30$*, A-7-5.*

N. P. denotes, non-plastic.

**Old numbers corresponding to new designation are 74* μ *— no. 200, no. 420* μ *— no. 40, 2.00mm — no. 10.*

Classification procedure: With required test data available, proceed from left to right on the chart and elimination process is used to find out the correct group. The first group from left into which the test data will fit is the correct classification.

The group index is always reported to the nearest whole number unless its calculated value is negative. In that case, it is reported to be zero. The group index is appended to the group and sub-group classification. For example, a clay soil having a group index of 22 may be classified A-7-6 (22).

ii) Unified Soil Classification System

A. Casagrande in 1942 developed a soil classification system for the United States Crops of Engineers which was termed as Airfield Classification (A.C) System, popularly known as "Arthur Casagrande's Classification system. After some modifications U.S. Bureau of Reclamation adopted this system in 1946. Airfield Classification system was renamed as Unified Soil Classification System after once again it was revised in 1952, with A.Casagrande acting as consultant. In 1969 the unified system was adopted by the 'American Society for Testing Materials' as a standard method for classification of soils for engineering purposes. The system is based on both grain size and plasticity properties of the soil and is therefore applicable to any use is shown in Table 2.2.

According to this system the coarse grained soils are classified by their grain size and fine grained soils are classified according to their indices. The names and symbols used to distinguish between the typical and boundary soil groups are as follows.

Soil Components:

Gravel-G, Sand-S, Silt-M, Clay-C, Organic-O, Peat-Pt.
Gradations: Well graded-W, Poorly graded-P
Liquid limits: High liquid limit-H, Low liquid limit- L

These are combined to form the group symbols which correspond to the names of typical soils in Table2.3 which is self explanatory and deserves careful study. The plasticity chart Fig.2.4 gives the relationship of Atterberg limits of the various fine grained soils of the system. If all the particles of a soil represent fairly well it is said to be well graded soil and a soil is poorly graded if there is excess or deficiency of certain sizes. To determine the soil as well graded or poorly graded, its coefficient of uniformity and coefficient of curvature are to be calculated, which are explained as follows.

Table 2.2 - US Bureau of Reclamation - General Land Classification

	Class 1 arable	*Class 2, arable*	*Class 3 arable*
Texture	Sandy loam to friable clay loam	Loamy sand to very permeable clay	Loamy sand to permeable clay
Depth to sand or gravel	90 cm plus or free working fine sandy loam or heavier, or 105 cm of sandy loam	60 cm plus or free working fine sandy loam or heavier, or 75-50 cm in sandy loam	45 cm plus or free working fine sandy loam or heavier, or 60—90 cm of lighter soil
Depth to impermeable shale or raw soil	150 cm plus or 115 cm with 150cm of gravel over impervious material, or sandy loam throughout	120 cm plus or with 15 cm of gravel over impervious material, or loamy sand throughout	105 cm plus or 90cm with 15cm of gravel over impervious material, or loamy sand throughout
Depth to penetrable lime zone	45 cm with 150 cm penetrable	35 cm with 120 cm penetrable	25 cm with 90 cm penetrable
Alkalinity at equilibrium*	Exchangeable sodium generally less than 15% for all land classes, butmay be higher or lower depending on the type of clay minerals		
Salinity at equilibrium*	Electrical conductivity of saturation extract less than 4 millimhos per cm	Electrical conductivity of saturation extract less than 8 millimhos per cm	Electrical conductivity of saturation extract less than 12 millimohs per cm
Slopes	Smooth slopes up to 4% with large areas in same plane	Smooth slopes up to 8% in large areas in the same plane, or rougher slopes less than 4% in general gradient	Smooth slopes up to 12% in large areas in the same plane or rougher slopes less than 8% in general gradient
Surface	Requires little levelling and no heavy grading	Moderate grading required, but in amounts found feasible in comparable areas	Heavy and expensive grading required in spots, but in amounts found feasible in comparable irrigated areas
Cover (rocks and vegetation)	Insufficient to affect productivity, or clearing cost small	Sufficient to reduced productivity and interfere with farming; clearing possible at moderate cost	Requires expansive but feasible clearing
Drainage	No drainage requirement expected	Some drainage expected, but at reasonable cost	Considerable drainage required. Considered expensive but feasible

Class 4, limited arable

Includes irrigable lands which are adaptable to a narrow range of crops

Class 5, nonarable

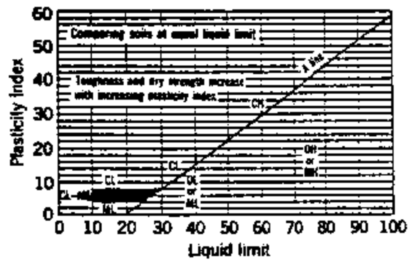
Includes lands which require additional studies to determine their irrigability and lands reclassified as temporarily non-productive pending construction of corrective works and reclamation through application of these works

Class 6, nonarable

Includes lands which do not meet the minimum requirements and small areas of arable land lying within larger bodies of nonarable land

*Equilibrium conditions based on projected use of a specific irrigation water supply.

Table 2.3 - Unified Soil Classification

Field Identification Procedures (Excluding particles larger than 75 µm and basing fractions on estimated weights)						Group Symbols [a]	Typical Names	Information Required for Describing Soils	Laboratory Classification Criteria			
Coarse-grained soils More than half of material is *larger* than 75 µm sieve size[b] (The 75 µm sieve size is about the smallest particle visible to naked eye)	Gravels More than half of coarse fraction is larger than 4 mm sieve size	Clean gravels (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes			*GW*	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name: indicate approximate percentages of sand and gravel: maximum size: angularity, surface condition, and hardness of the coarse grains: local or geologic name and other pertinent descriptive information: and symbols in parentheses For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics Example: *Silty sand*, gravelly: about 20% hard, angular gravel particles 12 mm maximum size: rounded and subangular sand grains coarse to fine, about 15% non-plastic fines with low dry strength; well compacted and moist in place: alluvial sand: (*SM*)	Use grain size curve in identifying the fractions as given under field identification	Determine percentages of gravel and sand from grain size curve Depending on percentage of fines (fraction smaller than 75 µm sieve size) coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP More than 12% GM, GC, SM, SC 5% to 12% *Borderline* cases requiring use of dual symbols	$C_U = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			Predominantly one size or a range of sizes with some intermediate sizes missing			*GP*	Poorly graded gravels, gravel-sand mixtures, little or no fines				Not meeting all gradation requirements for *GW*	
		Gravels with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see *ML* below)			*GM*	Silty gravels, poorly graded gravel-sand-silt mixtures				Atterberg limits below "A" line, or *PI* less than 4	Above "A" line with *PI* between 4 and 7 are *borderline* cases requiring use of dual symbols
			Plastic fines (for identification procedures, see *CL* below)			*GC*	Clayey gravels, poorly graded gravel-sand-clay mixtures				Atterberg limits above "A" line, with *PI* greater than 7	
	Sands More than half of coarse fraction is smaller than 4 mm sieve size	Clean sands (little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			*SW*	Well graded sands, gravelly sands, little or no fines				$C_U = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			Predominantly one size or a range of sizes with some intermediate sizes missing			*SP*	Poorly graded sands, gravelly sands, little or no fines				Not meeting all gradation requirements for *SW*	
		Sands with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures, see *ML* below)			*SM*	Silty sands, poorly graded sand-silt mixtures				Atterberg limits below "A" line or *PI* less than 5	Above "A" line with *PI* between 4 and 7 are *borderline* cases requiring use of dual symbols
			Plastic fines (for identification procedures, see *CL* below)			*SC*	Clayey sands, poorly graded sand-clay mixtures				Atterberg limits below "A" line with *PI* greater than 7	
Fine-grained soils More than half of material is *smaller* than 75 µm sieve size	Identification Procedures on Fraction Smaller than 380 µm Sieve Size											
			Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)							
	Silts and clays liquid limit less than 50		None to slight	Quick to slow	None	*ML*	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; colour in wet condition, odour if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions Example: *Clayey silt*, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (*ML*)		 Plasticity chart for laboratory classification of fine grained soils		
			Medium to high	None to very slow	Medium	*CL*	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays					
			Slight to medium	Slow	Slight	*OL*	Organic silts and organic silt-clays of low plasticity					
	Silts and clays liquid limit greater than 50		Slight to medium	Slow to none	Slight to medium	*MH*	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts					
			High to very high	None	High	*CH*	Inorganic clays of high plasticity, fat clays					
			Medium to high	None to very slow	Slight to medium	*OH*	Organic clays of medium to high plasticity					
Highly Organic Soils			Readily identified by colour, odour, spongy feel and frequently by fibrous texture			*Pt*	Peat and other highly organic soils					

From Wagner, 1957.

[a] *Boundary classifications*. Soils possessing characteristics of two groups are designated by combinations of group symbols. For example *GW–GC*, well graded gravel-sand mixture with clay binder.

[b] All sieve sizes on this chart are U.S. standard.

Field Identification Procedure for Fine Grained Soils or Fractions

These procedures are to be performed on the minus 380 µm sieve size particles. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (Reaction to shaking):

After removing particles larger than 380 µm sieve size, prepare a pat of moist soil with a volume of about 8000 mm³. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (Crushing characteristics):

After removing particles larger than 380 µm sieve size, mould a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (Consistency near plastic limit):

After removing particles larger than the 380 µm sieve size, a specimen of soil about 12 mm cube in size, is moulded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about 3 mm in diameter. The thread is then folded and re-rolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

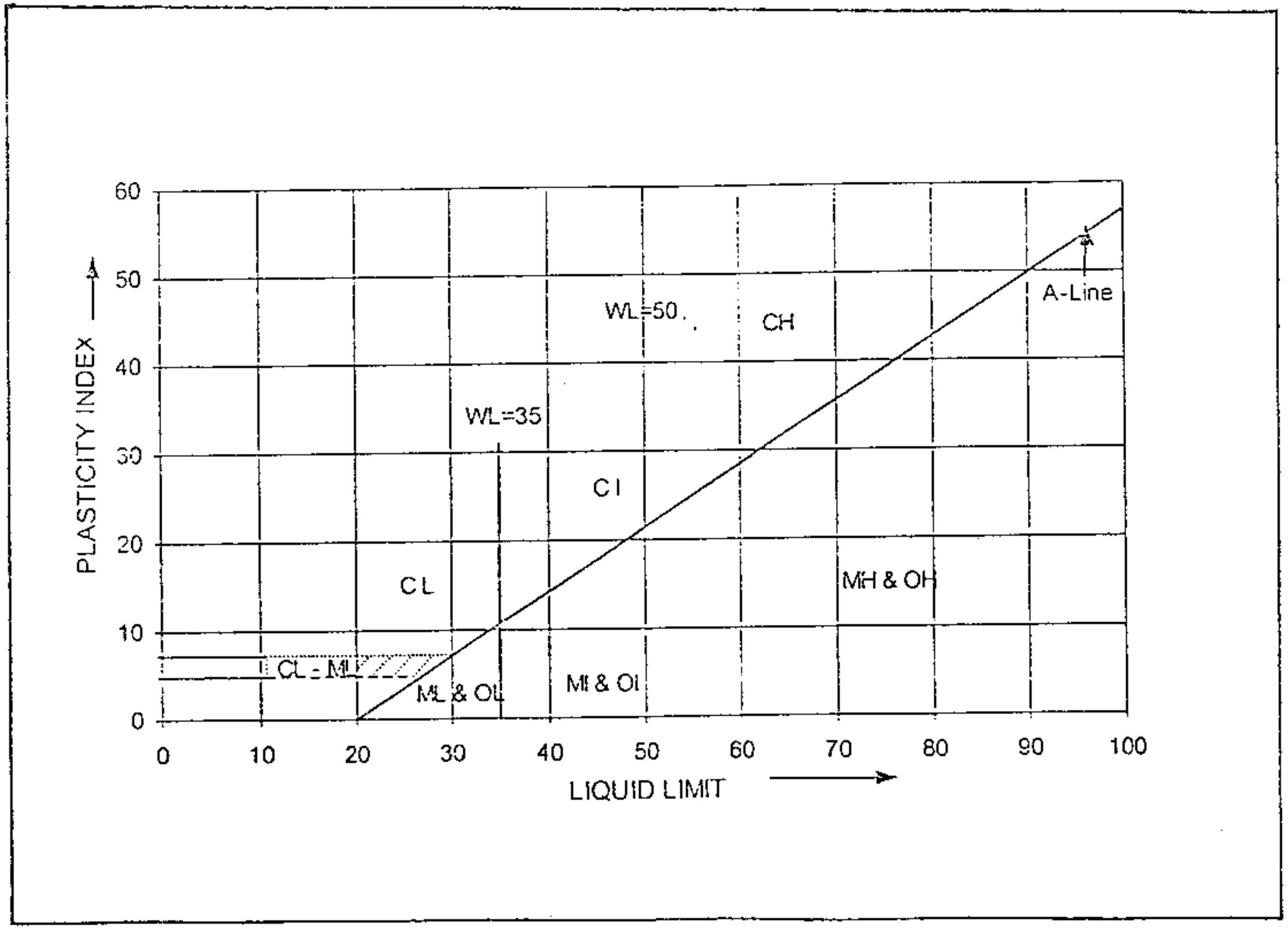


Fig. 2.4 : Plasticity chart for laboratory classification of fineaggregates (Bureau of Indian Soil Classification System)

Co-efficient of Uniformity $C_U = D_{60}/D_{10}$

Co-efficient of Curvature $C_C = (D_{30})^2/(D_{10} x D_{60})$

For a well graded soil co-efficient of curvature must be between 1 to 3 and the co-efficient of uniformity must be greater than 4 for gravels and 6 for sands.

The system has the following advantages:

(i) The classification is based on physical properties inherent in the soil and the soil behavior. It may be used for classifying soils for all varieties of engineering problems.

(ii) The system defines 15 soil groups each of which has distinct engineering properties. Soils having properties common to two groups can be defined as border line cases.

(iii) The system incorporates field identification and basis of classification in laboratory or field is simple.

iii) M.I.T classification proposed by Massachusetts Institute of Technology

M.I.T. Classification divides the soils into various main groups as sand, silt and clay and further subgroups them as coarse, medium and fine on the basis of standard grain size intervals as given in the following chart,

Coarse Sand	2.0	-	0.6	mm
Medium Sand	0.6	-	0.2	mm
Fine Sand	0.2	-	0.06	mm
Coarse silt	0.06	-	0.02	mm
Medium Silt	0.02	-	0.006	mm
Fine Silt	0.006	-	0.002	mm
Clay			<0.002	mm

iv) Indian Standard Classification (IS:1498-1970) based on M.I.T System

The Indian Standard (IS:1498-1959) on classification of soils for general engineering purposes was issued in 1959. It was revised in 1970 (IS:1498-1970). IS classification is given in Table 2.4. Fine grained soils are classified with the help of plasticity chart as in Fig.2.4. In IS system of classification soils are classified into three ranges of liquid limit, where as in the system of unified soil classification there is only two ranges of liquid limit. It is recommended that on all important projects soils be classified according to IS:1498.

Table 2.4 – BIS Soil Classification

Division	*Sub-Division*		*Group Letter Symbol*	*Hatching*	*Mapping Colour*	*Typical Names*	*Field Identification Procedures (Excluding Particles Larger than 80 mm and Basing Fractions on Estimated Weights)*			*Information Required for Describing Soils*
1	2		3	4	5	6	7			8
Coarse-grained soils (more than half of material is larger than 75-micron IS Sieve size) The smallest particle visible to the naked eye	*Gravels* More than half of coarse fraction is larger than 4.75-mm IS Sieve size (For visual classification the 5-mm size may be used as equivalent to the 4.75-mm IS Sieve size)	Clean gravels (Little or no fines)	GW	▨	Red	Well graded gravels, gravel-sand mixtures; little or no fines	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			For undisturbed soils add information on stratification; degree of compactness, cementation, moisture conditions and drainage characteristics. Give typical name; indicate approximate percentages of sand and gravel; maximum size, angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses. *Example* Silty sand, gravelly; about 20 percent hard angular gravel particles; 10 mm maximum size; rounded and subangular sand grains; about 15 percent non-plastic fines with low dry strength; well compacted and moist; in place; alluvial sand (SM).
			GP	▨	Red	Poorly graded gravels or gravel-sand mixtures; little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing			
		Gravels with fines (Appreciable amount of fines)	GM	▨	Yellow	Silty gravels, poorly graded gravel-sand-silt mixtures	Non-plastic fines or fines with low plasticity (for identification procedures, see ML and ML below)			
			GC	▨	Yellow	Clayey gravels, poorly graded gravel-sand-clay mixtures	Plastic fines (for identification procedures, see CL and CI below)			
	Sands More than half of coarse fraction is smaller than 4.75-mm IS Sieve size (For visual classification the 5-mm size may be used as equivalent to the 4.75 mm IS size)	Clean sands (Little or no fines)	SW	▨	Red	Well graded sands, gravelly sands; little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes			
			SP	▨	Red	Poorly graded sands or gravelly-sands; little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing			
		Sands with fines (Appreciable amount of fines)	SM	▨	Yellow	Silty sands, poorly graded sand-silt mixtures	Non-plastic fines or fines with low plasticity (for intermediate procedures, see ML and MI below)			
			SC	▨	Yellow	Clayey sands, poorly graded sand-clay mixture	Plastic fines (for identification procedures, see CL and CI below).			
							Identification Procedures (on Fraction Smaller than 75-Micron IS Sieve Size)			
							Dry Strength	*Dilatancy*	*Toughness*	
Fine-grained soils (more than half of material is smaller than 75-micron IS Sieve size). The 75-micron IS Sieve size is about the smallest particle visible to the naked eye	Silts and clays with low compressibility and liquid limit less than 35		ML	▨	Blue	Inorg. silts & very fine sands, rock flour, silty, clayey fine sands & silts with none to low plasticity	None to low	Quick	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; colour in wet condition; odour, if any; local or geologic name and other pertinent descriptive information and symbol in parentheses *Example* : Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess (ML)
			CL	▨	Green	Inorg., gravelly, sandy, silty, lean clays of low plasti.	Medium	None to very slow	Medium	
			OL	▨	Brown	Organic silts and organic silty clays of low plasticity	Low	Slow	Low	
	Silts and clays with medium compressibility and liquid limit greater than 35 & less than 50		MI	▨	Blue	Inorg. silts, silty clayey fine sands, clayey silts of med. plasti.	Low	Quick to slow	None	
			CI	▨	Green	Inorg., gravelly, sandy, silty, lean clays of med. plast.	Medium to high	None	Medium	
			OI	▨	Brown	Organic silts and org. silty clays of medium plasticity	Low to medium	Slow	Low	
	Silts and clays with high compressibility and liquid limit greater than 50		MH	▨	Blue	Inorganic silts of high compressibility, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Low to medium	Slow to None	Low to medium	
			CH	▨	Green	Inorganic clays of high plasticity, fat clays	High to very high	None	High	
			OH	▨	Brown	Organic clays of medium to high plasticity	Medium to high	None to very slow	Low to medium	
Highly Organic Soils			Pt	▨	Orange	Peat & other highly organic soils with very high compressibility	Readily identified by colour, odour, spongy feel and frequently by fibrous texture			

NOTE – *Boundary classification* : Soil possessing characteristics of two groups are designated by combinations of group symbols, for example, GW-GC, Well-graded, gravel-sand mixture with clay binder.

2.4 Soil Classification based on Hydrologic Soil Properties

Hydrologic soil classification is essential for the evaluation of runoff. The main parameters used commonly in hydrologic soil classification are :

1. Effective soil depth,
2. Soil texture/average clay content in the surface and subsurface layers
3. Soil structure in the surface and subsurface layers
4. Infiltration rate, and
5. Soil permeability and drainability

2.4.1 Effective Soil Depth

The depth of soil that can be effectively exploited by the plant roots is an important criterion in selecting land for irrigation. Effective depth includes the column thickness plus adjusted or corrected thickness of the disintegrated and weathered permeable rock material where the soil rests on such a material. In case of soils with hard pan, the effective depth is the thickness of soil overlying such a layer. When the soils are laying over disintegrated and weathered rock material, the effective soil depth will consist of soil depth plus the percentage soil equivalent of the weathered substratum. The adjusted and corrected thickness for such a disintegrated layer can be calculated by multiplying thickness of this layer with the percent soil material contained in it. For example, if the disintegrated substratum is 50 cm thick and contains about 30 percent soil materials and this substratum is overlain by a soil column of 30 cm., then the effective depth will be 30 + 15 = 45 cm. In case of soils with hard pans, indurated or permanently saturated moisture zone that prevents the entry of water through it, the effective depth signifies the thickness of the soil overlying such layer. The significance of effective soil depth to runoff potential is given in Table 2.5.

Table 2.5 - Effective soil depth and runoff potential

Thickness (cm)	Soil depth class*	Runoff potential
Above 100	d5	Low
51 - 100	d4	Moderately low
26 - 50	d3	Moderately high
11 - 25	d2	High
0 - 10	d1	High

*As used by the All India Soil and Land Use Survey Organization

2.4.2 Soil Texture/Average Clay Content

Soil texture refers to relative proportion of various soil separates in a soil material and is related to soil water interrelationships. On the basis of relative proportion of this basic separates, as shown in Table 2.6, various soil textural groups are recognized. Clay, being the most active and reactive fraction, is used as a single factor index in deciding hydrologic group of a series. Clay content of the surface layer and the average clay content of the whole profile are considered for this purpose. In order to compute average clay content of the profile, the clay content of each of the soil horizon is multiplied by its respective thickness and the summation of these is divided by the total thickness of the profile.

Clay content of the surface layer is more important with respect to infiltration. The relationship between clay content, textural class and runoff potential are given in Table 2.6.

Table 2.6 - Clay content and runoff potential

Clay content (%)	Qualifying Textural Class	Runoff potential
0 - 8	Sand, loamy sand	Low
9 - 25	Sandy loam, silt	Low to moderately Low
26 - 40	Silt, sandy clay loam, clay loam, silty clay loam	Moderately high to high
>41	Sandy clay, silty clay, Clay	High

2.4.3 Soil Structure

Soil structure refers to the arrangement of soil particles in the soil profile. Soil structure governs the moisture and air regimes in the soil. The movement of water in the soil and its transmission is affected by soil structure and texture. The influence of structure on runoff potential is given in Table 2.7.

Table 2.7 - Soil structure and runoff potential

Soil structure	Runoff potential
1. Single grain	Low
2. Granular, Crumb	Moderately low to low
3. Subgranular blockyColumnar	Moderately low to moderately high
4. Strong angular blocky prismatic	Moderately high to high
5. Strong platy compact massive	High

2.4.4 Infiltration

Infiltration is the term applied to the process of water entry into the soil, generally by downward flow through all part of the surface. The rate of this process determines how much water will enter the root zone and how much, if any, will runoff. The infiltration rate is defined per unit of soil surface area. The maximum rate at which the soil can absorb water through the soil surface is termed as infiltration capacity. This is a function of soil moisture condition. At saturation, infiltration capacity is minimum and is the characteristics of the soil i.e. texture, structure, organic matter content, type of clay mineral, antecedent soil moisture etc. The relationship between infiltration classes and runoff potential is given in Table 2.8 as per the studies conducted by All India Soil and Land Use Survey Organization of Ministry of Agriculture.

Table 2.8 - Infiltration rate and runoff potential

Infiltration Class	Basic Infiltration Rate (cm/hr)	Runoff Potential
1. Very high	> 8.0	Low
2. High	5.0 - 8.0	Low to moderately Low
3. Medium	3.1 - 5.0	Moderate low to moderately high
4. Low	1.60 - 3.1	Moderately high to high
5. Very low	< 1.6	High

Infiltration is a major component in the hydrologic cycle and plays a major role in the estimation of runoff from rainfall. Accurate estimation of infiltration is essential for better understanding of the rainfall-runoff relationship of a basin. The hydrologic properties of soils govern their infiltration characteristics. These properties include the tension-moisture content (ψ-θ) relationship, saturated hydraulic conductivity (Ks) and hydraulic conductivity-moisture content (K-θ) relationship of the soil.

Water infiltration is rapid into large, continuous pores in the soil. It is reduced by anything that decreases either the size or amount of pore space or wettability, such as structure breakdown, pore clogging by lodged particles, and the slower movement of deeper water as it reaches denser sub-soils. The factors that control the rate of water movement *into* the soil include these:

1. The percentage of sand, silt, and clay. Coarse sands permit rapid infiltration.
2. The soil structure. Fine-textured soil with large water-stable aggregates (granular structure) have higher infiltration rates than massive (structureless) soils.
3. The amount of organic matter in the soil. The greater the amount of organic matter and the coarser it is, the more water that enters the soil. Organic surface mulches are especially helpful in keeping infiltration high because they protect soil aggregates from breakdown by reducing the impact of raindrops and by continuing to supply the cementing agents for aggregates, such as gums, as they decompose.

4. The depth of the soil to hardpan, bedrock, or other impervious layers. Shallow soils do not permit as much water to enter as do deep soils, if they are similar in other respects, such as texture and structure.
5. The amount of water in the soil. Wet soils do not have as high an infiltration rate as do moist or dry soils. This is partly because pores or cracks are fewer or smaller because clays have already wetted and swelled.
6. Soil temperature. Warm soils take in water-faster than do cold soils. Frozen soils may or may not be capable of absorbing water, depending upon the kind of freezing that has taken place.
7. Compaction, which usually reduces pore space, slows infiltration.

With increased time, which also increases depth of wetted soil, the infiltration *rate* decreases because (1) clays swell, which makes pores smaller and reduces water movement; (2) loose particles that flow with water become lodged in "bottleneck" pores and plug them; (3) resistance to flow increases as water passes deeper through long pores. A dry, cracked, clayey soil may take up a large amount of water during the first hour but very little during each succeeding hour, particularly if rainfall is dispersing the soil particles that move downward to plug pores.

Four infiltration rates have been classified by the National Cooperative Soil Survey (Donahue, 1990).

1. <u>Very low</u>. Soils with infiltration rates of less than 0.25 cm (0.1 in.) per hour; soils in this group are very high in percentage of clay.
2. <u>Low</u>. Infiltration rates of 0.25-1.25 cm (0.1-0.5 in.) per hour; most of these soils are shallow, high in clay, or low in organic matter.
3. <u>Medium</u>. Infiltration rates of 1.25-2.5 cm (0.5-1.0 in.) per hour; soils in this group are loams and silts.
4. <u>High</u>. Rates of greater than 2.5 cm (1.0 in.) per hour; these are deep sands, deep well-aggregated silt loams. and some tropical soils with high porosity.

Effect of Surface Soil Conditions on Infiltration

Infiltration is the movement of water into the soil surface. The nature of the pores and water content are the most important factors determining the amount of precipitation that infiltrates and the amount that runs off. High infiltration rates, therefore, not only increase the amount of water stored in the soil for plant use, they also reduce flood threats and erosion resulting from runoff.

Raindrop impact on bare soil breaks up soil aggregates and causes the average pore size in the surface soil to decrease, this decreases infiltration. Infiltration is also decreased by overgrazing, deforestation, and soil completion resulting from traffic. The presence of a vegetative cover that absorbs raindrop impact is effective in maintaining a high infiltration rate in a given situation.

The presence of crop residues or other organic matter on the surface of the soil has the same effect as a living vegetative cover.

Many farmers modify the soil surface with contour tillage and terraces that hold water on the land for a longer time, which produces a greater opportunity for infiltration.

Effect of Internal Soil Properties on Infiltration

Typically, when water infiltrates in the field, the immediate surface of the soil is water saturated. After infiltration, the water moves downward as unsaturated flow that is dependent on water potential gradients and soil conductivity. Soils with a high content of expanding clay develop large cracks in the dry season that permit water from intense storms to move quickly as saturated flow deep into the dry soil without runoff. When these soils become wet in the rainy season however, infiltration approaches zero and nearly all the rainfall runs off.

Many Great Plains soils have well-developed argillic horizons that limit the downward movement of water. The use of deep tillage to disrupt these horizones would increase infiltration.

2.5 Soil Permeability and Hydraulic Conductivity

Permeability is the case with which liquids, gases, and roots pass through the soil. The permeability of the soil for water is the hydraulic conductivity. Permeability is one of the most important properties and its significance is increasingly realised with renewed interest seeking acceptable solutions for environmental problems. Soil permeability refers to the ease with which water can move in the soil profile. It is a measure of drainability of the soil in cm/hour or cm/day. Soil properties such as texture, structure, management practices, land cover, land use all control the total water intake in a soil profile at a given time. The various hydraulic conductivity classes for vertical water movement in water saturated soils with their run-off potentials are shown in the Table 2.9 below:

Table 2.9 – Hydraulic Conductivity Classes and Runoff Potential

Conductivity Class	Water Intake Rate, cm/hr.	Runoff Potential
Very slow	< 0.13	High
Slow	0.13 - 0.5	High
Moderately slow	0.51 - 2.0	Moderately high
Moderate	2.01 - 5.0	Moderately high to moderately low
Moderately rapid	5.01 - 13.0	Moderately low
Rapid	13.01- 25.0	Low
Very rapid	>25.0	Low

Hydraulic conductivity is the measure of the ability of a soil to transmit water under a unit hydraulic gradient. For a particular soil, It represents its average water transmitting properties, which depends mainly on the number and the diameter of the pores present. In Darcy's law, hydraulic conductivity is the proportionality constants K. This K usually stands for the hydraulic conductivity of a saturated soil. Under unsaturated conditions, the hydraulic conductivity varies with the soil moisture suction. Hydraulic conductivity decreases as the soil water suction increases. This relationship is called the conductivity pressure head relationship.

Factors Influencing the Hydraulic Conductivity of Saturated Soils

Any factor affecting the size and configuration of soil pores will influence hydraulic conductivity. The texture and structure of soils are the properties to which hydraulic conductivity is most directly related (Table 2.10). Sandy soils generally have higher saturated conductivities than finer textured soils. Likewise, soils with stable granular structure conduct water much more rapidly than do those with unstable structural units, which break down upon being wetted. Fine clay and silt can clog the small connecting channels of even the larger pores. Fine-textured soils that crack during dry weather at first allow rapid water movement; later the cracks swell shut, thereby drastically reducing water movement.

Soil texture, structure, and organic matter content have significant influence on hydraulic conductivity. Hydraulic conductivity is more in coarse textured. sandy soil - but, capillary conductivity is higher in loam, sandy loam and clay loam soils than sandy soil, due to better continuity of pores in fine textured soils. Particle size distribution affects the continuity of capillary pores and appears as a dominant factor affecting water transmission characteristics. Macropores conducts better, when they forms a continuous path through soil body. If, however, macropores are distributed spatially at random with micropores as under natural condition, conductivity may be lower.

Unsaturated water transmission characteristics of soil is influenced by texture and aggregate size of the soil pores. In soils of different textures, hydraulic conductivity follows the order, loamy sand, sandy loam, clay loam. Increase in soil water content increases of both hydraulic conductivity and soil water diffusivity but the value decreases with rise in soil water tension.

Changes of bulk density in soil cause variation in pore geometry. It influences pathways of water flowing through the soil. Reduced hydraulic conductivity with high bulk density has been reported by several workers. Increase in bulk density due to puddling and compaction under field condition decreases saturated conductivity drastically.

Important decisions that are based on a knowledge of soil hydraulic conductivity include: (1) determination of the distance between lines of drainage tile, (2) size of area of seepage beds for septic tank system, (3) size of terrace ridges and Disc slope of terrace channels for erosion control, and (4) length and gradient of irrigation furrows.

The hydraulic conductivity is a measure of the ability of the soil to transmit water. To evaluate the potential use of soil for many agricultural and non-agricultural uses, the hydraulic conductivity of the soil need to be known. In practice, hydraulic conductivity need to be measured at several places because of its spatial variability.

Table 2.10 – Hydraulic conductivity as per USDA soil classification

Soil Textural Class	Saturated Hydraulic Conductivity (cm/hr)
Sand	23.56
Loamy Sand	5.98
Sandy loam	2.18
Loam	1.32
Silty loam	0.68
Sandy clay loam	0.30
Clay loam	0.20
Silty clay loam	0.20
Sandy clay	0.12
Silty clay	0.10
Clay	0.06

Significance of Hydraulic Conductivity

Hydraulic conductivity is needed to describe how soil solution moves through the soil. This is useful for studying irrigation, water logging and drainage, erosion, soil water balance studies and other sub-soil problems. It is also an important parameter for studying the sub- surface flow and transport problems.

Thus, hydraulic conductivity is an important parameter frequently used to assess the following:

- Estimation of subsurface drain spacing, size of drain and volume of water that may be removed from water logged areas.
- Assessing the quantity of ground water recharge.

Movement of water also takes place in unsaturated soil condition. Had there been no water movement under the unsaturated condition, there would probably be no plant growth on the earth surface. Soil in the unsaturated zone exists in the saturated condition so long as either irrigation or rainfall continues. Immediately thereafter, an unsaturated condition develops. It is known that plants respond to water application at a particular soil suction and yields are maximum. Thus it is important that the suction should not go beyond the critical suction limits.

2.6 Hydrologic Soil Groups Classification based on SCS

Soil Conservation Service of the U.S Department of Agriculture has classified the soils into following four hydrologic soil groups namely Group A, B, C and group D respectively in the increasing order of runoff potential. All the four groups alongwith their grouping criterion and descriptions are given in Table 2.11.

A: (Low Runoff Potential)

These are soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep to very deep, well to excessively drained sands or gravels. These soils have a high rate of transmission throughout the profile and ground water table is usually below 5 meters.

B: (Moderately Low Runoff Potential)

These are soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission throughout the profile. The depth of ground water table is usually 3 to 5 meters or more.

C: (Moderately High Runoff Potential)

These are soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures. These soils have a slow rate of water transmissions. The depth of water table is usually 1.5 to 3.0 meters or more.

D: (High Runoff Potential)

These are soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils (vertisols and vertic subgroups) with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a slow rate of water transmission.

The SCS soil group can be identified at a site using one of the three ways :

1. Soil Characteristics
2. Soil Survey, and
3. Minimum infiltration rate.

Table 2.11 - Hydrologic Soil Classification based on Soil Conservation Service

HYDROLOGIC SOIL GROUP

Soil Characteristics	A	B	C	D
Effective Depth (cm)	> 100	51 - 100	26 - 50	< 25
Texture	S, LS	SL, SiL, L	Si, SCL, CL, SiCL	SC, SiC, C
Clay (%)	0 - 8	9 – 25	26 - 40	> 40
Structure	Single grained, Granular crumb	Granular crumb, Sub angular, Blocky	Sub-angular blocky, Columnar prismatic	Platy, Massive
Infiltration Rate (cm/hr)	> 8.0	5.1 – 8.0	1.6 - 5.0	< 1.6
Permeability (cm/hr)	High >13	Mod. High 2 – 13	Mod. Low to Mod. High 0.5 - 2.0	Low <0.5
Depth to Gr. Water (m)	> 5	3 – 5	1.5 – 3	< 1.5

S-sand, LS-loamy Sand, SL-Sandy Loam, SiL-Silty Loam, L-Loam, Si-Silt, SCL-Sandy Clay Loam, CL-Clay Loam, SiC-Silty Clay, C-Clay, SiCL- Silty Clay Loam.

The soil characteristics associated with each group are presented in Table 2.11. Soil survey gives a detailed description of the soils at a given location. These surveys are usually the best means of identifying the soil group. Soil analysis can be used to predict the minimum infiltration rates, which can be used to classify the soil into various hydrologic soil groups. The SCS cover complex classification consists of three factors namely, land use, treatment or practice and hydrologic condition. There are approximately fifteen different land uses that are identified for estimating curve number. Agriculture land use are often subdivided by treatment or practices, such as contoured or straight row. The hydrologic condition reflects the level of land management and it is classified into three classes, namely poor, fair and good.

The SCS developed an index which is termed as the runoff curve number (CN), to represent the combined hydrologic effect of soil, land use, agriculture land treatment classes, hydrologic condition and antecedent soil moisture. These factors can be assessed from soil surveys, site investigation, and land use maps.

2.7 Classification Based on Consistency Limits of Soils

Soil consistency is an important physical and dynamic properties which varies with the variation of soil moisture and applied stress. Consistency is the behaviour of soil under stress. This stress is commonly evidenced by feeling the soil, manipulating it by hand, or by tillage operation. Soil consistency is considered a combination of soil properties dependent upon the forces of attraction between soil particles as influenced by soil moisture. Soil consistency is defined as the manifestations of the physical forces of cohesion and adhesion acting within the soil at various moisture constants. These manifestation include the behaviour toward gravity, pressure, thrust and pull; the tendency of the soil mass to adhere to foreign bodies or substances; the sensations which are evidenced as feel by the fingers of the observer. Soil consistency depends on the texture, nature and amount of inorganic and organic colloids, structure and moisture content etc. With decreasing moisture content, the soils lose their stickiness and plasticity and become friable and soft and finally when dry become hard and coherent.

Soil consistency describes how well a soil sticks together or resists fragmentation. It is of value to predict cultivation problems and adaptation to engineering qualifications, such as the ability to bear building weight. It has been demonstrated by Casagrande (1932) that in the case of coarse grained soils, gradation of particles is adequate for characterization of specific properties, whereas for fine grained soils additional parameters are required to account for physico-chemical interactions between soil and water. Consistency limits of soils satisfy this requirement. In 1911, the Swedish soil scientist Atterberg (1911) reported an extensive study on the plasticity of soils, dividing the range from solid to the liquid into five stages by setting arbitrary limits. In the progressive transition from liquid state to solid state, the soil undergoes dramatic changes in consistency. Fig. 2.5. Schematically indicates the changes in volume of the soil with changes in water content together with the limits of different states of engineering significance. All limits are expressed as water contents. Atterberg limits are used extensively by soil Scientists. Atterberg, a well-known scientist suggested three values namely upper plastic limit, lower plastic limit and plasticity number or plasticity index and so they are called Atterberg limits.

Upper Plastic Limit (W_L)

It is also called liquid limit. It represents the moisture content of soil at a point where the soil-water mass just flows under an applied force and fails to retain its shape. The liquid limit is essentially a measure of a constant value of viscous shearing resistance, as the soil approaches the liquid state.

Lower Plastic Limit (W_P)

Lower plastic limit refers to the moisture content of a soil at a point where its consistence changes from plastic to friable and the soil-water mass is unable to change continuously under the influence of an applied force, and ultimately the mass breaks into fragments. Basically, plastic limit of fine grained soils is a reflection of both strength and deformability.

Plasticity Number /Index (Ip)

If refers to the difference between moisture contents of a soil at its upper plastic limit and lower plastic limit. Different soils are characterized by a specific plastic number or index of plasticity. It is the range of water content over which the soil remains plastic. In soils containing negligible clay fraction it's value is relatively low, whereas in the case of highly active clay minerals, it's value may even exceed 500. Plasticity index, apart from being used in engineering property correlations, has been extensively used in the classification of fine grained soils.

Relative Consistency and Liquidity Index

Analogous to the relative density of cohesionless soils, the state of fine grained soil was identified by relative consistency of the soil, C_R. This is the ratio of the difference between the liquid limit of the soil and the natural water content to the plasticity index and is expressed as

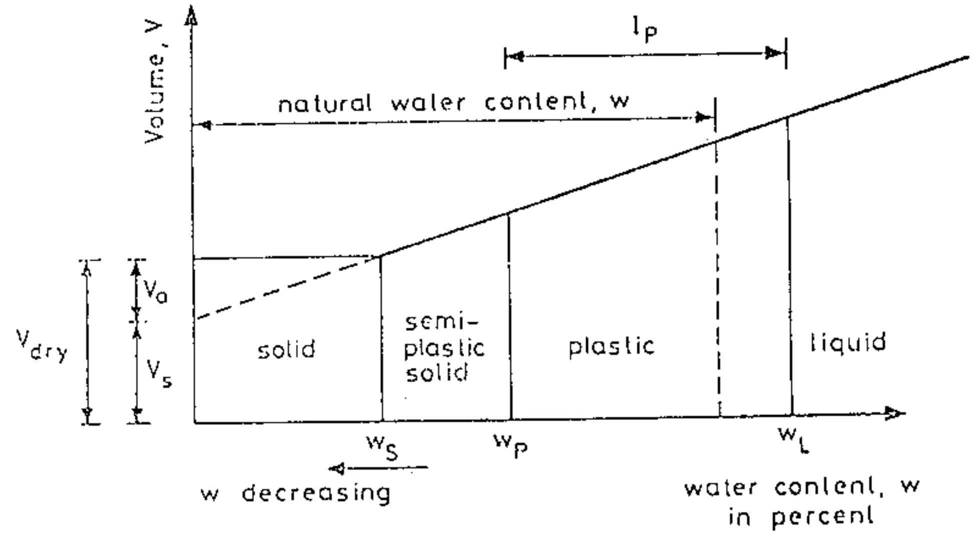


Fig. 2.5 : Consistency relationship of clays

$$C_R = (W_L - W)/(W_L - Wp)$$

This parameter was found to be deficient to the extent that in-situ water content more than liquid limit water content could not be accounted for.

The modified form of expression is liquidity index I_L, which is the ratio of difference between natural water content and plastic limit to the plasticity index. and is expressed as

$$I_L = (W - Wp)/(W_L - Wp)$$

The value of liquidity index reflects the stress history of in-situ soil. The normally consolidated clays at shallow depths have values closer to unity, while the value decreases and approaches zero for heavily over consolidated clays. The liquidity index values can be far greater than unity for highly sensitive clays or can be negative for in-situ weathered stiff clays.

Activity Number

The plasticity of the soil depends on the type of city, mineral as well as on the amount of clay present. Soil samples taken over an identified geographical area are likely to have a common geological history. Although, there could be variations in the clay fraction in different batches of samples, the nature of the clay mineral is not likely to show much variability.

Skempton (1953) observed that a plot of Ip versus percent clay content, C for soil samples from a given site, with a particular geological formation generates into a straight line passing through the origin. Such lines were distinctly different for sites with different geological formations. Skempton defined activity number, 'A' of soil as the slope of that line:

$$A = Ip/C$$

For soils from the same geological origin, with increase in clay content both plasticity index, Ip and percentage finer than 2 μm increase maintaining a constant value of activity number. Presently it has become a practice, to indicate activity number, 'A' along with other consistency limits in the soil investigation reports.

The liquid limit water content, could serve as a reference parameter generalising stress-strain behaviour because of the same order of effective stress existing at that state for all soils. If this parameter is to serve as a reference even for generalising permeability behaviour, all soils should posses the same pattern of microstructure at their liquid limit states.

Consistency in Relation to Different Moisture Regimes

Soil consistency is described on the basis of three moisture levels wet, moist and dry. In addition, soil consistency is also expressed based on the degree of cementation.

Sticky	After pressure, soil material adheres to both thumb and finger and tends to stretch somewhat and pull apart rather than pulling.
Plasticity	Plasticity is the ability to change shape continuously under the influence of an applied stress and retain the impressed shape on removal of the stress.
Non-sticky	After release of pressure, practically no soil material adheres to thumb or finger.
Slightly sticky	Slight adherence to thumb and finger.
Sticky	After pressure, soil material adheres to both thumb and finger and tends to stretch somewhat and pull apart.
Very sticky	After pressure, soil material adheres strongly to fingers.
Non-plastic	No wire is formable when the soil material is rolled between thumb and fore finger.
Slightly plastic	Wire is formable, but soil mass is easily deformable.
Plastic	Wire is formable, moderate pressure is required for deformation.
Very plastic	Wire is formable, sufficient pressure is required for deformation.
Moist soils	Moist consistency when soil is moist is determined at a moisture content approximately midway between air-dry and field capacity, The consistency of moist soils is most important since it best describes the condition of soils when they are tilled in the field. Consistency of a moist soil is described strating from the least coherence material to the strongly adherence material.

Another important character of soil consistency is the scouring point. This point represents that moisture content at which the soil no longer sticks to; foreign object. With highly plastic soils, the scouring point lies slightly below the liquid limit, with slightly plastic soils it occurs above the liquid limit.

Significance of the Atterberg Limits

The different Atterberg limits as stated above represents the moisture content of the change from the friable to the plastic consistency. It represents the minimum moisture percentage at which the soil can be puddled. Orientation of particles and their subsequent sliding over each other takes place at this point, since sufficient water has been added to provide a film around each particle. The moisture content of Atterberg limits depends upon the amount and nature of the soil colloids present. In the upper plastic limit the film of oriented water molecules becomes so thick that cohesion is decreased and the entire soil water mass flows freely under an applied force. The tensions of the water at the lower plastic limit and upper plastic limit are equivalent to pF values 2.8-3.3 and about 0.5 respectively.

The plasticity number or index of plasticity is an indirect measure of force required to mold the soil. It is a function of the number of the films and represents the amount of water that must be added to the soil system to increase the distance between the particles of maximum tension and the tension at which flow is produced. So there is a direct relationship between the plasticity index and the liquid limit or upper plastic limit.

2.8 Classification Based on Temperature of Soils

Soil temperatures determine seed germination, microbial decomposition of organic residues, nutrient availability and plant growth. Soil temperatures are also used in describing soil families in the United States system of soil taxonomy. Soil temperature, being an important soil property, is used to classify soils. Every increase in temperature of 10°C increases the rate of chemical reactions two to three times. Increased weathering and clay content occur with an average increase in soil temperature. Early soil warming can be encouraged by the use of clear plastic mulches and drying of wet soil. Wet soil and organic mulch covers keep the soil cool longer in late spring than do dry soils and no mulch cover. Many methods are used to alter the soil and the above-soil temperature to aid plant growth. Generally, existing temperatures have just been "lived with" and agricultural activities modified to fit them. Temperature restrictions can be mitigated usually only by expensive measures. Acknowledging the limitations and planning for them is wise soil and crop management. Some examples follow:

1. To get maximum germination and growth of seeds, soil temperatures must be correct; 4-10°C (40-50°F) for wheat and peas; 10-29°C (50-85°F) for corn; 16-21°C (60-70°F) for potatoes; about 27°C (80°F) or above for sorghums and melons. Optimum emergence temperatures for other plants: 8-11°C (46-52°F) for cabbage and spinach; 11-18°C (52-64°F) for beets and cauliflower; and 18-25°C

(64-72^{O}F) for asparagus, carrots, celery, endive, lettuce, onion, radish, and tomato."Direct planting of onion seeds in cool spring soil (a recent change from transplants; done because of labor costs) produces late plants. When pregerminated seeds were planted, they emerged in 1.7-7.3^{O}C soil within 7 days; regular seeds required 30 days. Maturity of onions from pregerminated seeds was 10-12 days earlier. Geranium seeds have most rapid germination at about 27^{O}C (80^{O}F).

2. When applying anhydrous ammonia in the fall, it is best to wait until the soil at a depth of 10 cm (4 in.) is 10^{O}C (50^{O}F), or less. Below this temperature nitrification of ammonium to nitrate is slow and therefore leaching losses of nitrate will be minimal.

3. Freezing and thawing of bare, saturated, fine-textured soils in cold areas, such as the intermountain West and the Northern United States, may cause heaving and then death of shallow-rooted crops.

4. Alternate freezing and thawing under conditions of moderate soil moisture improves the structure of cloddy soils, but with excess moisture destroys structure.

5. Cold soils tend to retard the absorption by the plant of phosphorus from the soil. To increase phosphorus absorption in cold periods, soils should be "warmed" by draining them and/or more easily solubilized phosphorus fertilizer should be added.

6. Hollow heart, or brown center, of potatoes is a brownish area in the potato tuber, often forming a hollow area. It is believed to be from dead cells caused by a cool period of a week or mores. The extent of damage increases as the cold period lengthens after tuber initiation. Four weeks at 18^{O}C (65^{O}F) days and 10^{O}C (50^{O}F) nights. A drop of only 5^{O} to 8^{O}C from normal growing temperature, caused 27 percent of the crop to have brown centers.

Optimum Temperatures for Microbial Activity

Microbial activity accelerates rapidly as temperature rises. Just as plants are nearly dormant at freezing, so are most microbes. There are exceptions that can exist fairly well at very cold temperatures (psychrophiles-cold lovers), and others that exist at relatively high temperatures (thermophiles-heat lovers), but the majority of soil bacteria actinomycates have optimum activity temperatures similar to those of the mesophiles (middle group). The temperature tolerances of these three general groups are :

1. Psychrophiles : can grow at temperatures below 5°C (41°F), but have optimum temperature near that of mesophiles.
2. Mesophiles : grow slightly near 0°C (31°F), but little if any growth above 40°C (104°F). Many die at this higher temperature. Optimum temperature is usually between 25' and 37°C (77-99°F).
3. Thermophiles : can tolerate 45-75°C (113-167°F) with optima between 55° and 65° (131-149°F) (e.g. some compositing microbes).

Soil Temperature Classes for Family Groupings

Soil temperature classes are based on mean annual soil temperature and the difference between mean summer and mean winter temperatures. Mean annual soil temperature is determined by measurement mostly in the deep root zone and can be estimated in most of the United States by adding 1°C to the mean annual air temperature. Soil temperature classes, as named and defined here, are used as family differentiae in all orders. The class names are used as family name modifiers unless the name of a higher taxon carries the same limitation. Thus, frigid is implied in all boric suborders and cryic great groups and is redundant in the name of a family. The Celsius (centigrade) scale is the standard. Approximate Fahrenheit equivalents are indicated parenthetically. It is assumed that the temperature is that of a soil that is not being irrigated.

The soil temperature classes for temperate region soils are defined in terms of mean annual soil temperature as

Pergelle	<0°C(32°F); permafrost present (unless dry)
Cryic	0-8°C(32-47°F); summer soil temperature below about 15°C
Frigid	0-8°C(32-47°F); summer soil temperature above about 15°C
Mesic	8-15°C(47-59°F)
Thermic	15-22°C(59-72°F)
Hyperthermic	>22°C(72°F)

For soils in which the difference is less than 5°C (9°F) between mean summer and mean winter soil temperature at a depth of 50 cm or at a lithic or paralithic contact, whichever is shallower, the following classes, defined in terms of the mean annual soil temperature are used.

Isofrigid	Less than 8°C (47°F).
Isomesic	From 8 - 15°C (47° to 59°F).
Isohyperthermic	More than 22°C (72°F).

Soil temperature regulates all physiological functions such as seed germination, microbial activity, root and shoot growth, and nutrient availability. Especially where growing seasons are short, it is important to plant a crop as early in the spring as possible. For this reason, some enlightened farmers use a soil thermometer to measure temperature at seeding depth to determine when the soil has warmed sufficiently to germinate the seed. In temperate countries for fall-seeded winter wheat, the soil should cool to the critical temperature indicated. Soil temperatures are so important that they are used as one criterion for differentiating soil family classes. Variation in soil temperature (very low to high temperature) affects the absorption of soil water by the plant roots. The effect of temperature in reducing the rate of water uptake may be important in spring time resulting strong transpiration. Soil structure is greatly influenced by the temperature. The temperature has a great influence on the aggregation of the soil as well as on the binding materials present in it.

The activity of micro-organisms having thermophobic and thermophilic nature is influenced by the variation in soil temperature. certain amount of heat is necessary, for the proper functioning of various types of soil micro-organisms. Various microbiological processes like mineralization of nitrogen, nitrogen fixation,. pesticide degradation etc. influenced by the temperature. The activity of micro-organisms is lowest when soil temperature is below 5°C and above 54°C. The optimum temperature for the activity of most of the micro-organisms is in the range of 25-35°C.

Earthworms and Soil Temperature

Earthworms are probably the most important soil macroanimals. Earthworms are important in many ways, especially in the upper 15-35 cm of soil. They ingest organic matter as well as soil. As these materials pass through the earthworm's body, they are subjected to digestive enzymes as well as to a grinding action within the animal. The weight of the material passing through their bodies (casts) each day may equal the weight of the earthworm. In the tropics, as much as 250 Mg/ha (110 tons/acre) of casts may be produced annually. Although figures only one tenth of those values are more common in the cultivated soils of temperate regions, the casts are evidence of extensive earthworm activities. Compared to the soil itself, the casts are definitely higher in bacteria, organic matter, and available plant nutrients. The rank growth of grass around earthworm casts is evidence of the favorable effect of earthworms on soil productivity.

Earthworms are important in other ways also. The holes left in the soil serve to increase aeration and drainage, an important consideration in crop production and soil development. Moreover, the worms mix and granulate the soil by dragging into their burrows quantities of undecomposed organic matter such as leaves and grass, which they use as food. In some cases the accumulation is surprisingly large. This action is more important in uncultivated soils (including those where reduced tillage is practiced) than in plowed land, where organic matter may be turned under in quantity. Without a doubt, earthworms increase both the size and stability of the soil aggregates.

Earthworms prefer a well-aerated but moist habitat. Therefore they are found mostly in medium-textured upland soils where the moisture capacity is high rather than in droughty sands or poorly drained lowlands. Earthworms must have organic matter as a source of food. Consequently, they thrive where farm manure or plant residues have been added to the soil. A few species are reasonably tolerant of low pH, but most earthworms thrive best where the soil is not too acid.

Each group of soil microorganisms has its critical temperature. For example, the actinomyces involved in decomposing manure compost are most abundant at 55 to 65^{O}C. However, most species proliferate abundantly at 25 to 37^{O}C. This is also the optimum temperature for most species of bacteria. Fungi are more abundant when the soil is about 37^{O}C. Nitrogen- fixing organisms grow and reproduce fastest at a soil temperature of about 36^{O}C (Alexander, 1977). Soil temperature affects earthworm numbers and their distribution in the soil profile. For example, a temperature of about 10^{O}C (50^{O}F) appears optimum for Lumbricus terrestris. The temperature sensitivity and soil moisture requirements probably account for the maximum earthworm activity noted in spring and autumn in temperate regions.

Some earthworms burrow deeply into the profile, thereby avoiding unfavorable moisture and temperature conditions. Penetration as deep as 1-2 m is not uncommon. Soil cover is important in maintaining a high earthworm population where sudden frosts are common. Earthworms are responsible for mechanically incorporating residues into the soil, and they leave open channels through which water and air can flow.

Factors influence the soil temperature :

There are various factors that influence the soil temperature which are as follows:

Soil structure: Soil structure influence soil temperature by controlling pore spaces resulting from the different types of arrangement of soil particles like open and close systems of packing etc. Soils having spheroidal type of structure warm up more quickly because there is no prevailing conditions of waterlogging.

Soil texture : A light textured sandy soils, in general, absorb heat very quickly than heavy textured clayey soils. A heavy soils carry a greater quantity of water and due to this reason it warms up very slowly.

Soil moisture : Soil moisture plays a vital role in controlling its thermal regime. The specific heat of water is high then the soil. Moist soils have a higher specific heat then dry soils. Consequently a moist soil has a lower temperature than dry soil. Moist Soil gets heated very slowly and it is cooler than the dry soils.

Soil colour : In a dark soil where colour is caused by large amounts of humus, the larger amounts of water held by the humus may offset the increased heat absorption due to the dark colour.

Vegetation : Soils covered with different types of vegetation absorb less heat compared to soils without vegetation cover. Vegetation acts as an intercept of beat on the soil surface and thereby reduces the thermal regime of the soil.

Composition of the soil : The thermal regimes of the soil depend upon its volumetric composition, the size and arrangement of the solid particles and also interface relationship between the solid and liquid phases. Among the solid materials, the soil is composed of partly mineral matter and partly organic matter. The specific heat of mineral matter like iron (sp. heat 0.11) is less than that of organic matter, humus (sp. heat 0.44). So soils containing much more mineral matter get heated very easily than those soils containing higher amount of organic matter.

Irrigation and drainage : Irrigation raises the humidity of the air, lowers the air temperature over the soil and reduces the daily soil temperature variations. Drainage decreases the heat capacity of wet soils, which raises the soil temperature. This plays an important role in warming up the soil in the spring.

Topography : The slope of the land especially ground slope also influence the soil temperature. The temperature of the ridged fields is higher than those that are level.

Compactness of the soil : Compactness of the soil surface increases the, density and the thermal conductivity. Compacted soils have better heat conductivity than loosened soil. Tillage, on the other hand, cereals a surface mulch which reduces heat flux from the surface to the sub-surface layers.

Climate and Season : Soil in temperate climate are cooler than those soils in tropical climate. Soil temperature differs with the seasonal variations of the year. The summer months (June to July) in the northern hemisphere like midday represent the peak of the global radiation and the maximum temperatures. The winter months have an effect similar to daily night temperatures which is much lower. The temperature of the surface soil is always higher than the air temperature.

2.9 Classification Based on Soil pH

The term pH is from the French pouvoir Hydrogene or "Hydrogen power." Soil reaction (pH) is an indication of the acidity or basicity of the soil and is measured in pH units. The scale goes from 0 to 14 with pH 7 as the neutral point. At pH 7, hydrogen ion concentration (H+) equals the hydroxyl ion concentration (OH-). From pH 7 to 0 the soil is increasingly more acidic; from pH 7 to 14 the soil is increasingly more alkaline (basic). The H+, concentration, which is the substance measured when determining pH, has a tenfold change between each whole pH number. Thus, a soil of pH 5 has 100 times more H+ in solution than a soil solution with a pH of 7. Fig. 2.6 shows some pH relations among various materials and environments. Soil pH is easily measured and indicates much about a soil. A strongly acid soil has been intensively leached, is low in exchangeable basic cations, has mostly kaolinite and sesquioxide clays, and has slow microbial activity. Metal nutrients are soluble; Al and Mn may even occur in toxic concentrations. In contrast, soils of pH 7.5 to 8.5 have mostly Ca and Mg with lesser amounts of K and Na exchangeable cations. Soluble salts and/or carbonates (lime) may accumulate in many of these soils.

Two classes, calcareous and noncalcareous, are used in selected taxa. The definitions follow.

Calcareous-The fine-earth fraction effervesces in all parts with cold dilute HCl.

Noncalcareous-The fine-earth fraction does not effervesce in all parts with cold dilute HCl. The term "noncalcareous" is not used as a part of a family name.

It should be noted that a soil containing dolomite is calcareous and that effervescence of dolomite, when treated with cold dilute HCI, is slow.

Reaction classes are applied to the control section that is defined for particle-size classes. Two classes, acid and nonacid, are used in selected taxa. The definitions follow.

Acid-The pH is< 5.0 in 0.01 M $CaCl_2$, (2:1) throughout the control section (about 5.5 in H_2O, 1:1).

Nonacid-The pH is 5.0 or more in 0.01 M $CaCl_2$ (2:1) in at least some part of the control section. The term "nonacid" is not used in family names of calcareous soils.

Reaction-class modifiers are used only in names of families of Entisols and Aquepts; they are not used in names of sandy, sandy-skeletal, and fragmental families of these taxa, nor are they used in names of sulfaquepts and Fragiaquepts and families that have carbonatic or gypsic mineralogy.

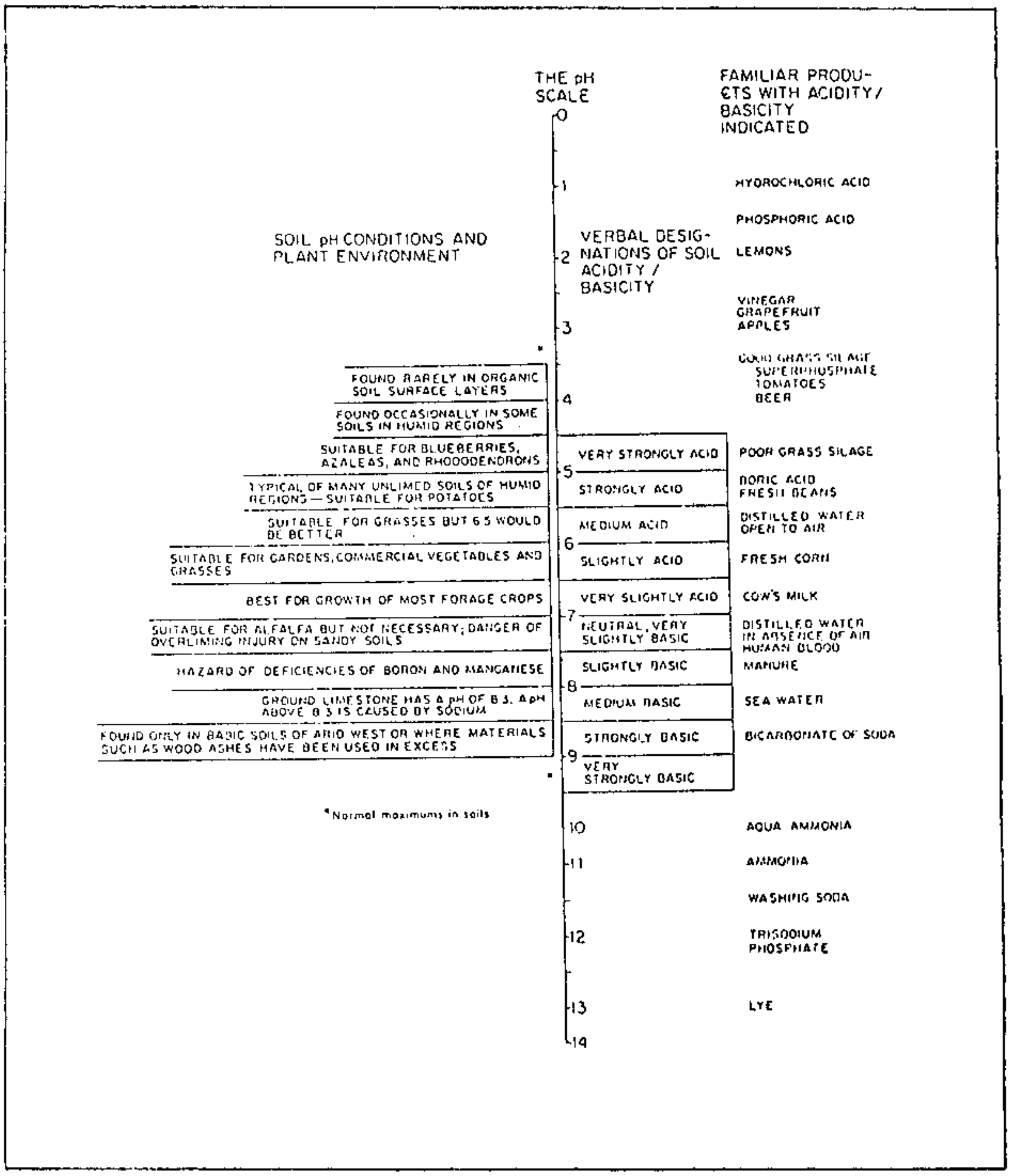


Fig. 2.6 : pH relations among various materials and environments

Calcareous-class modifiers are used, if appropriate, in the names of the same taxa as reaction-classes and, in addition, are used in families of Aquolls except for Calciaquolls and for Aquolls that have an argillic horizon. Calcareous reaction-class modifiers are not used in family names of soils that have carbonatic or gypsic mineralogy. A calcareous soil is never acid. Calcareous therefore implies nonacid, and both modifiers are not used in the family name because nonacid would be redundant. Similarly, noncalcareous would be redundant in family names of acid soils.

The soil pH is easily determined and provides various clues about other soil properties. The soil pH greatly affects the solubility of minerals. Strongly acid soils (pH 4-5) usually have high and toxic concentrations of soluble aluminum and manganese. Azaleas, tea, rhododendrons, cranberries, pineapple, blueberries, and several conifer timber species tolerate a strong acidity and grow well. In contrast, alfalfa, beans, barley, and sugar beets only do well in slightly acid to moderately basic soils because of a high calcium demand or inability to tolerate soluble aluminum. Most minerals are more soluble in acid soils than in neutral or slightly basic solutions.

The soil pH can also influence plant growth by the pH effect on activity of beneficial microorganisms. Most nitrogen-fixing legume bacteria are not very active in strongly acid soils. Bacteria that decompose soil organic matter and thus release nitrogen and other nutrients for plant use are also hindered by strong acidity. Fungi usually tolerate acidity better than do other microbes.

On mineral soils most agricultural crops do best in slightly acidic soils (pH 6.5); on organic soils, about pH 5.5. Soils become acidic, even from basic parent materials, by the leaching away by rainwater of the basic cations (Ca++, Mg++, K+, Na+) and replacement of many of them by H+ from carbonic acid (H_2CO_3) formed from water and dissolved carbon dioxide.

Soil basicity, although more difficult to alter than soil acidity, may be just as undesirable for plants. Non leached soils or those high in calcium (low rainfall areas) may have pH values to 8.5. With increased exchangeable sodium, soils may reach values of over pH 10. Plants on soils of pH greater than about 9 usually have reduced growth, or even die. Some plants (halophytes) are tolerant of high salt or pH.

The major effect of a basic pH is to reduce the solubility of all micronutrients (except chlorine and molybdenum), especially those of iron, zinc, copper, and manganese. Also, phosphate is often not readily available to some plants because of its precipitation in the soil solution by calcium or precipitation on solid calcium carbonate. Iron deficiency, associated with wet clayey soils high in carbonates, has long been known (although not well understood); it is referred to as lime-induced iron chlorosis. Solutions have low solubilities of iron, zinc, manganese. and copper at high pH; the addition of phosphorus often further decreases the availability of those metals at the root surface or just inside the root by precipitating them as insoluble phosphates.

Most micronutrient problems caused by high soil pH are solved by adding special fertilizers such as water-soluble chelates (key-lates), which are "stable". (although susceptible to microbial decomposition) but soluble complexers of the metal ions. If excess exchangeable sodium exists in the soil, it is usually removed by adding gypsum, followed by irrigation to leach the exchanged Na+ ions.

The majority of soil microorganisms grow best at pH 7, which is the pH of microbial cytoplasm (the cell material). Bacteria and actinomycetes are usually less tolerant of acid soil conditions than are fungi, and few grow well at soil pHs below pH 5. An exception is the sulfur oxidizing genus Thiobacillus, which produces sulfuric acid; it tolerates soil pHs even down to pH 0.6. Many fungi exist in forested and organic soils with pHs as low; is 3.0. Localized micro-environments near roots or decomposing residues can produce locales of lower pH than that of the soil as a whole, differences of as much as 1 or 2 pH units. Most common microorganisms grow best at pH 6-8, but are severely inhibited below pH 4.5 and above pH 8.5. Strongly acid soils are even more inhibiting to microbe growth than are strongly alkaline ones. (Plants tolerate pH extremes more readily than do microbes.)

Some organisms have a rather small tolerance to variations in pH, but other organisms can tolerate a wide pH range. Studies have shown that the actual concentrations of H+ or OH- are not very important, except under the most extreme circumstances. It is the associated conditions of a certain pH value that is most important.

Nutrient Availability and pH Relationships

Perhaps the greatest general influence of pH on plant growth is its effect on the availability of nutrients (Fig. 2.7). Soil pH is related to the percentage of base saturation is less than 100 percent, an increase in pH is associated with an increase in the amount of calcium and magnesium in the soil solution, since they are usually the dominant exchangeable bases. Many studies have been conducted that relate increases in plant growth with increases in the percentage of calcium in plants, and with increasing pH or percentage base saturation.

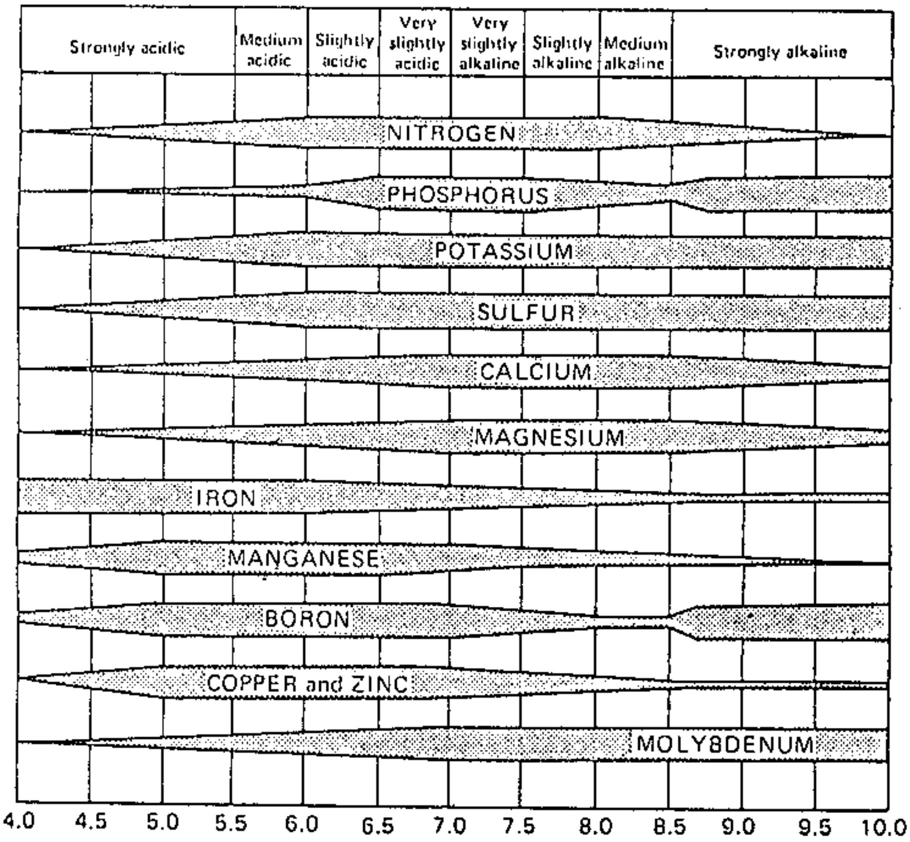


Fig. 2.7 : General relationship between soil pH and availability of plant nutrients (the wider the bar, the more availability)

Another nutrient whose availability is increased as the pH is increased on the low end of the pH range in soils is molybdenum. At low pH, molybdenum forms insoluble compounds with iron, and it is rendered unavailable. Under these conditions, plants susceptible to molybdenum deficiency, such as cauliflower, closer, and citrus, will show a growth response to an increase in pH. The fact that increased availability of molybdenum occurs as the pH increases is responsible for molybdenum toxicity for plants in some soils.

Potassium availability is usually good in neutral and alkaline soils that reflects the limited leaching of exchangeable potassium (Fig. 2.7).

The availability or solubility of some plant nutrients decreases with an increase in pH. Iron and manganese are two good examples (Fig. 2.7). Iron and manganese are commonly deficient in calcareous soils. Phosphorus and boron also tend to be unavailable in calcareous soils that result from reactions with calcium. Phosphorus and boron also tend to be unavailable in very acidic soils. Copper and zinc have reduced availability in both highly acidic and alkaline soils. For the plant nutrients as a whole, good overall nutrient availability is found near pH 6.5 in high base-status soils. Soil pH in low base-status soils generally never exceeds 6.0 or 6.2.

Effect of pH on Soil Organisms

The pH requirements of some disease organisms can be used by soil management practices as a means to control diseases. One of the best-known cases is that of the maintenance of acidic soils to control potato scab. Damping off disease in nurseries is controlled by maintaining the pH at 5.5 or less. Nitrifying organisms also become inhibited when the pH is less than 5.5. The availability of nitrogen in soils is related mainly to the effect of pH on decomposition of organic matter. High soil acidity has also been shown to inhibit earthworms in soils.

Iron and manganese are most available in highly acidic soils. Manganese toxicity may occur when the pH is about 4.5 or less. Evidence indicates that the high exchangeable aluminum in many acidic soils of the south-eastern United States restricts root growth in sub-soils. Plants (even varieties of the same species) exhibit differences in tolerance to high levels of aluminum, iron, or manganese, as well as to other soil conditions associated with soil pH. This gives rise to pH preferences of plants.

pH Preferences of Plants

Blueberries are well known for their highly. acidic soil requirement. In a study, it was shown that poor blueberry growth occured when calcium saturaration exceeded 10 percent. Normally this would mean that the soil had a very low base saturation and pH. Other plants preferring a pH of 5 or less include azaleas, orchids, sphagnum moss, jack pine, black spruce, and cranberry. Most field and vegetable crops prefer a pH of about 6 or higher.

The fact that plants have specific soil pH requirements gives rise to the need to alter soil pH for successful growth of many plants.

Alteration of Soil pH

There are two approaches to assure that plants will grow without serious inhibition from unfavorable soil pH : (1) plants can be selected that will grow well with the existing soil pH, or (2) the pH of the soil can be altered to suit the preference of the plants. Considerations for altering soil pH will be examined first.

Soil pH can be lowered and soil acidity increased by the addition of sulfur or sulfur-containing compounds. The sulfur is converted into sulfuric acid. Most changes in soil pH are directed toward increased pH and reduced soil acidity. Lime ($CaCO_3$) is commonly used; it hydrolyzes to produce OH^-, and the calcium increases base saturation.

Benefits of Liming

The benefits of lime depend on the soil and crop conditions. In Mollisols, there is little or no aluminum saturation and no danger of aluminum toxicity. Therefore, liming will not produce a benefit by reducing the amount of aluminum in the solution. However, some crops (such as alfalfa) may benefit from the increased nitrogen fixation that results from increased pH and calcium availability. By contrast, the major benefit of liming Oxisols is the inactivation of aluminum and manganese in the soil solution, which reduces or prevents aluminum and manganese toxicity.. In addition, lime acts as a fertilizer to supply calcium when it is in very short supply. Overliming soils can either produce adverse problems associated with deficiencies of zinc, manganese, iron, boron and copper or increase molybdenum sufficiently to produce molybdenum toxicity. The major benefits of liming and the adverse effects of overliming, as well as the desirable pH range for high base- (and permanently charged) and low base-status soils (with high pH-dependent charges) is summarized in Table 2.12.

Table 2.12 – **Benefits of Liming, the Adverse Effects of Overliming and the Desirable pH Range for High and Low Base-Status Soils**

Soil	Benefits of Lime	Detrimental Effects of Overliming	Desirable pH Range
High base-status and permanent charge	Increase : Soil pH Calcium availability Nitrogen fixation	Decrease: Zinc availability Manganese availability Increase Molybdenum to toxic levels	6.0-6.8
Low base-status and high pH-dependent charge	Inactivate Aluminum and Manganese Add Calcium (and Magnesium)	Decrease availability of : Zinc Manganese Copper Boron Increase Molybdenum to toxic levels	5.0-6.2

2.10 Soil Textural and Structural Classification

Natural soils are comprised of soil particles of varying sizes. The soil particle-size groups, called soil separates, are sands (the coarsest), silts, and clays (the smallest). The relative proportions of soil separates in a particular soil determine its soil texture.

Texture is an important soil characteristic because it will, in part, determine water intake rates (absorption), water storage in the soil, the ease of tilting the soil, the amount of aeration (vital to root growth), and will influence soil fertility. For instance, a coarse sandy soils easy to till, has plenty of aeration for good root growth, and is easily wetted, but it also dries rapidly and easily loses plant nutrients, which are drained away in the rapidly lost water. High-clay soils (over 30 percent clay) have very small particles that fit tightly together, leaving little open pore space, which means there is little room for water to flow into the soil. This makes high-clay soils difficult to wet, difficult to drain, and difficult to till.

Soil Textural Classes

Textural names are given to soils based upon the relative proportions of each of the three soil separates-sand, silt, and clay. Soils that are preponderantly clay are called clay (textural class); those with high silt content are silt (textural class); those with a high sand percentage are sand (textural class). A soil that does not exhibit the dominant physical properties of any of these three groups (such as a soil with 40 percent sand, 20 percent clay, and 40 percent silt) is called loam. Loam does not contain equal percentages of sand, silt, and clay. It does, however, exhibit approximately equal properties of sand, silt, and clay.

Since the soil's textural classification includes only mineral particles and those of less than 2 mm diameter, the sand plus silt plus clay percentages equal 100 percent. (organic matter is not included.) Knowing the amount of any two fractions automatically fixes the percentage of the third one. In reading the textural triangle, any two particle fractions will locate the textural class at the point where those two intersect.

Mineral fragments in the soil larger than 2 mm in diameter but less than 25 mm (gravels and cobbles) must be considered a part of the soil because they greatly influence its use. In the classification and mapping of soil, the names of these fragments precede the textural name of the soil. For example, if a sandy loam contains over 20 percent gravel, the textural name becomes gravelly sandy loam; if the large fragments comprise more than 50 percent of the soil weight, "very" is added to the soil textural name-very gravelly sandy loam.

Some Physical Characteristics of Soil Textural Classes

Sandy Soil

This soil is open and friable; grains remain generally separated from one another ; when rubbed with fingers the grains can be felt distinctly, when dry if a handful of such soil is pressed it does not cake ; when semidry it cakes slightly and tends to form a ball but on release of pressure the grains tend to separate out. When wet pressure very nicely leaves the impression of fingers on it; on release of pressure the ball breaks and the grains again separate out. Water holding capacity is very low and the soil dries very quickly.

Loamy Soil

This soil type contains sand, silt and clay almost in equal proportions. When felt with fingers it may give presence of small grits; slightly plastic when semidry, if pressed in hand impression of fingers can be easily inflicted on it forms a ball ; but on release of pressure the ball does not break ; when wet it easily forms a ball and the soil in it can be pressed; on release of pressure the soil does not disintegrate. It breaks when thrown from a height but the grains do not separate out.

Silt Loam

This soil contains medium quantities of fine sand and relatively less clay. Percentage of silt is generally more than 50. On drying, this soil forms hard clod but the clod breaks easily. On pulverization the soil becomes soft and powdery. When wet, it gets muddy quickly and flows. This soil forms good ball even when slightly wet. The ball does not break quickly. On kneading the soil does not give fine ribons, it breaks.

Clay Loam

This soil contains proportionately more clay. The particles are very fine. On drying the soil forms hard clods. Wet soil on kneading gives good ribons but ribons break when 1 to 1.5 cm long; wet soil is quite plastic, the ball does not break easily; cakes well.

Clay Soil

Clay content in this soil is more than 50%. On drying the soil gives very hard clods and clods do not break easily. Clods become pointed and become difficult to work upon the pointed edges prick. On wet the soil becomes very sticky, very plastic, gives good ribons on kneading, after slight drying the ribons break ; if clay % increases more than 70-80 the soil loses its plasticity.

Particle-Size Classes

particle-size refers to grain-size distribution of the whole soil and is the same as texture, which refers to the fine-earth fraction. The fine-earth fraction consists of the particles that have a diameter <2 mm. Particle-size classes are a kind of compromise between engineering and pedologic classification In engineering classifications, the limit between sand and silt is a diameter of 74 microns; in pedologic classifications, the limit is a diameter of either 50 or 20 microns. Engineering classifications are based on percentage weight in the fraction <74 mm in diameter, and textural classes are base percentages by weight in the fraction <2 mm in diameter.

The two dominant systems for classifying soil particles were developed-by the International Society of Soil Science and the United States Department of Agriculture. Each followed by the Soil Survey Staff's classification of coarse fragments; i.e., particles larger than 2 mm in diameter, the upper limit for clay in both systems.(Fig. 2.8 and 2.9)

The International Society of Soil Science recognizes five classes of soil separates (soil particles) based on size. These are, in millimeters (mm) in diameter: clay,<0.002; silt, 0.002-0.02; fine sand, 0.02-0.2; coarse sand, 0.2-2.0; and gravel, >2.0 (Fig. 2.8). In contrast, the United States Department of Agriculture has adopted eight classes, as follows (in mm in diameter): clay,< 0.002; silt, 0.002-0.5; very fine sand,0.05-0.10; fine sand,0.10-0.25; medium sand, 0.25-0.5; coarse sand 0.5-1.0; very coarse sand 1.0-2.0; and gravel, >2.0 (Fig. 2.9).

It can thus be observed that both systems of soil particle classification define gravel as particles

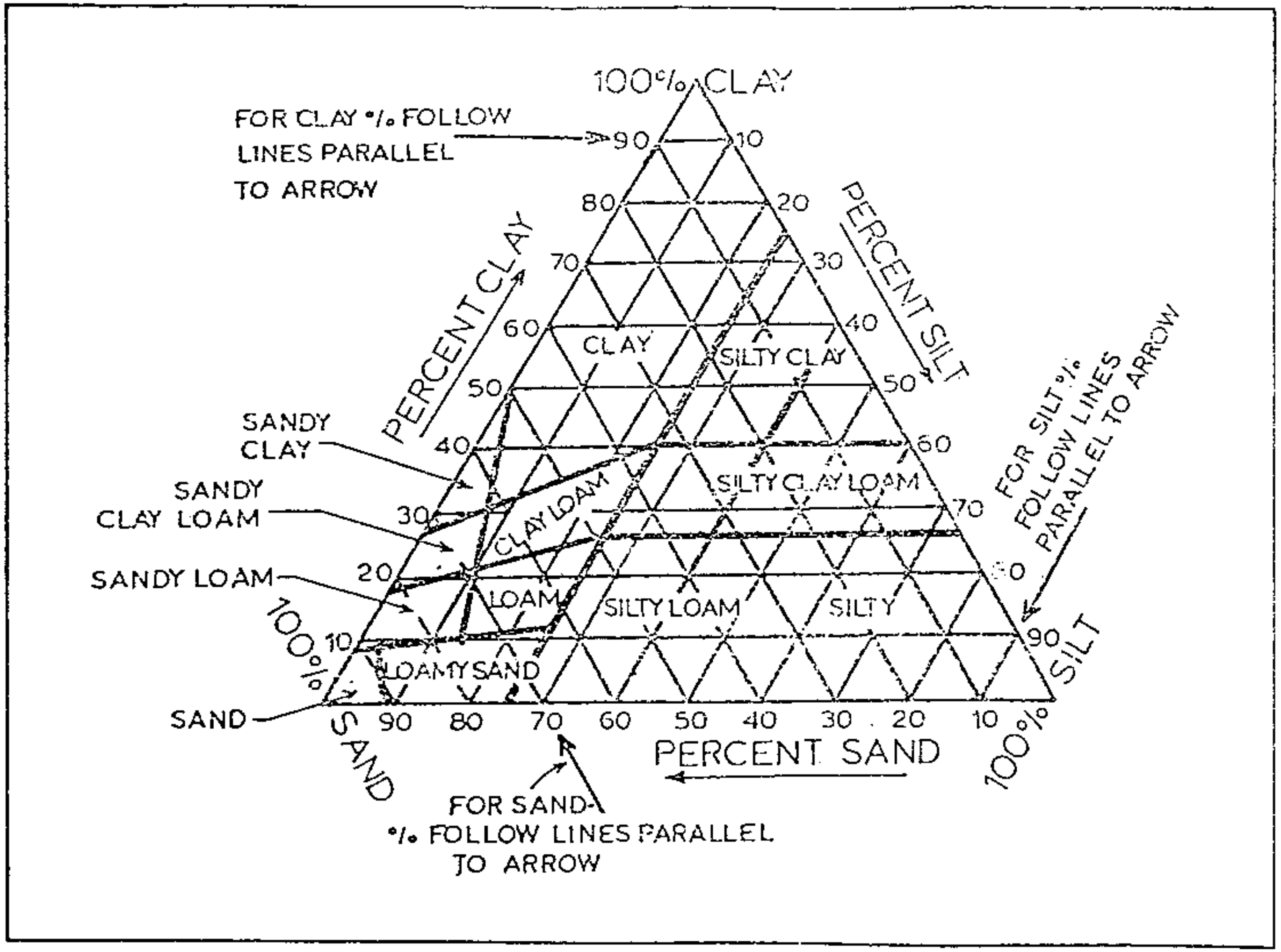
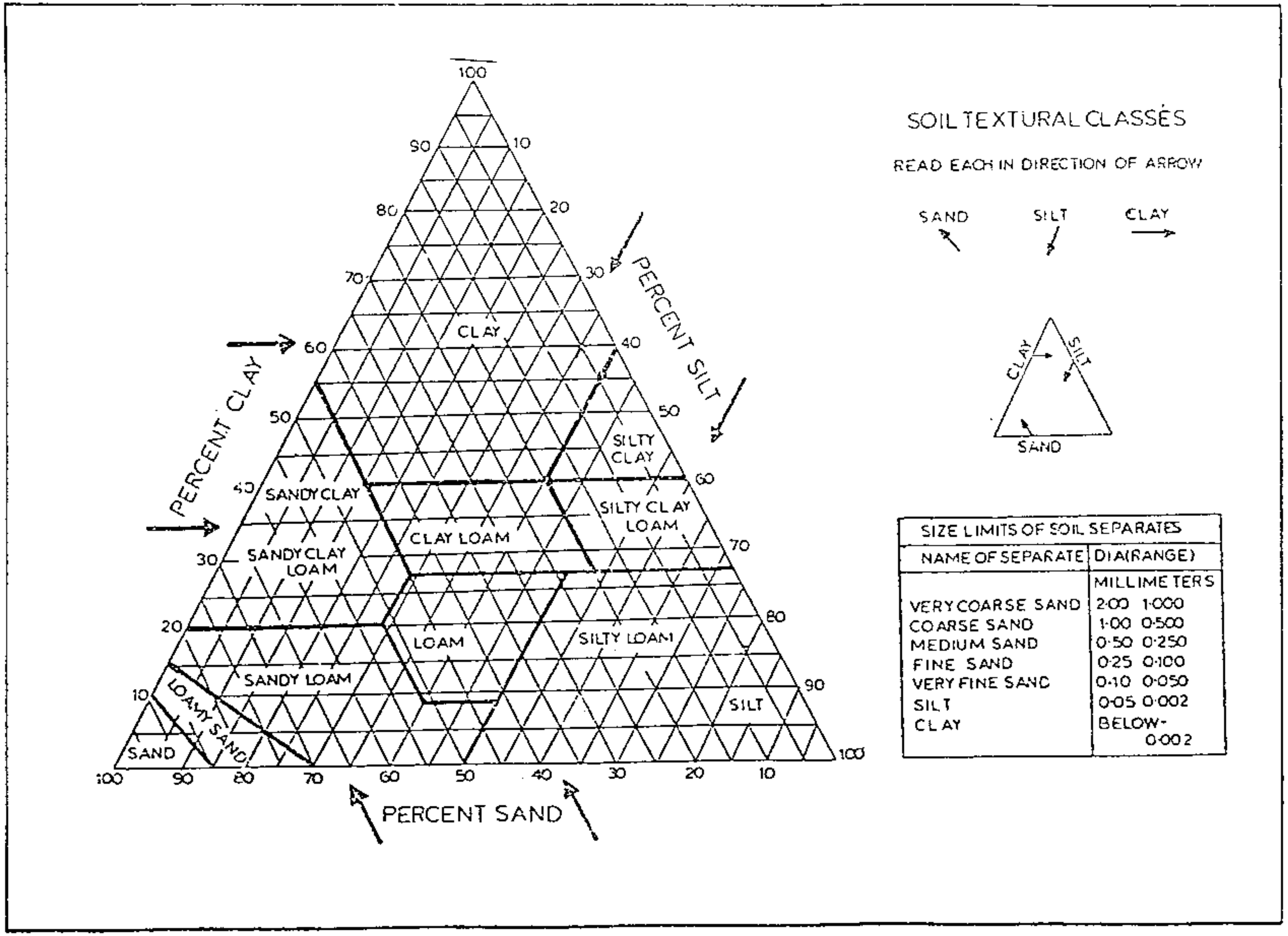


Fig. 2.8 : Guide for textural classification by the International system for textural designation



SIZE LIMITS OF SOIL SEPARATES	
NAME OF SEPARATE	DIA(RANGE)
	MILLIMETERS
VERY COARSE SAND	2·00 1·000
COARSE SAND	1·00 0·500
MEDIUM SAND	0·50 0·250
FINE SAND	0·25 0·100
VERY FINE SAND	0·10 0·050
SILT	0·05 0·002
CLAY	BELOW- 0·002

Fig. 2.9 : Guide for textural classification by the United States system for textural designation

larger than 2mm in diameter. It is obvious that these classification systems are laboratory techniques because field soils often contain coarse fragments too large to be called gravel.

Soil Textural Classes

Soils throughout the world contain an infinite combination of sands, silt, and clays. For this reason, various names are assigned to soils with specific percentages of each of these soil particles.

There are several techniques for determining the percentages of sands, silt, and clay in a sample of soil. Such a determination is called particle size analysis (formerly known as mechanical analysis). Particle-size analysis may be conducted by sedimentation, sieving, and/or micrometry. The sedimentation or micrometric method gives the percentages of total sand, silt, and clay. The five grades of sand in the USDA system or the two in the international system must then be determined by sieving.

The principal soil textural classes recognized, ranked according to increasing amounts of fine particles are: sand, loamy sand, sandy loam, loam silt, silt loam, sandy clay loam, clay loam, silty clay loam, sandy clay, silt, clay, and clay. The classes of sand, loamy sand, and sandy loam may be further modified by the terms coarse, fine, or very fine inserted before the word, "sand". When the fineness of the sand is not specified, it is assumed to be "medium". The textural triangle can be used to designate the principal texture classes from a mechanical analysis. However, in the United States system the sand, loamy sand, and sandy loam classes are further subdivided, bases on the fineness of the sand. Since this detail is beyond the limits of the triangle in Figure 2.9, it will be set forth here.

Sand

Soil material that contains 85 percent or more of sand; percentage of silt plus 1.5 times the percentage of clay, shall not exceed 15.

Coarse sand :	25 percent or more very coarse and coarse sand, and< 5 percent any other one grade of sand.
Sand :	25 percent or more very coarse, coarse, and medium sand, and < 50 percent fine or very fine sand.
Fine sand :	50 percent or more fine sand (or) < 25 percent very coarse coarse, and medium sand and < 50 percent very fine sand.
Very fine sand :	50 percent or more very fine sand.

Loamy sand

Soil material that contains at the upper limit 85 to 90 percent sand, and the percentage of silt plus 1.5 times the percentage of clay is not less than 15; at the lower limit it contains not less than 70 to 85 percent sand, and, the percentage of silt plus twice the percentage of clay does not exceed 30.

Loamy coarse sand :	25 percent or more very coarse and coarse sand, and <50 percent any other one grade of sand.
Loamy sand :	25 percent or more very coarse, coarse, and medium sand, and < 50 percent fine or very fine sand.
Loamy fine sand :	50 percent or more fine sand (or) < 25 percent very coarse, coarse, and medium sand and < 50 percent very fine sand.
Loamy very fine sand :	50 percent or more very fine sand.

Sandy loam

Soil material that contains either 20 percent clay or less, and the percentage of silt plus twice. the percentage of clay exceeds 30, and 52 percent or more sand; or < 7 percent clay, < 50 percent silt, and between 43 percent and 52 percent sand.

Coarse sandy loam :	25 percent or more very coarse and coarse sand and < 50 percent any other one grade of sand.
Sandy loam :	30 percent or more very coarse, coarse, and medium sand, but < 25 percent very coarse sand, and < 30 percent very fine or fine sand.
Fine sandy loam :	30 percent or more fine sand and <30 percent very fine sand (or) between 15 and 30 percent very coarse, coarse, and medium sand.
Very fine sandy loam :	30 percent or more very fine (or) >40 percent fine and very fine sand, at least half of which is very fine sand and <15 percent very coarse, coarse, and medium sand.

Field soil textural class names may be further modified based on the relative proportion and kinds of coarse fragments present. These terms usually precede the textural class name; for example, Gravelly fine sandy loam, cobbly loam, or stony clay.

Effect of Texture on Available Water

The water present in the soil between field capacity and wilting point is known as available water.

It is generally considered to be matrix potential in the range of -0.6 to –15 bars. The capacity of the soil to hold water is related to both surface area and pore space volume. Water-holding capacity is therefore related to structure as well as to texture. Fine-textured soils have the maximum total water-holding capacity, but maximum available water is held in medium-textured soils. Research has shown that available water in many soils is closely correlated with the content of silt and very fine sand (Fig. 2.10). As the texture becomes finer, a smaller percentage of the water at field capacity is available, about 40 percent for clays.

It is generally known that sandy soils are more droughty than clayey soils. One reason is that the finer-textured soils are able to retain more available water. An other important difference between sands and clays is related to the differences in the slope of the soil-moisture characteristic curves shown in Fig. 2.11. The flatness of the curve for the fine sandy loam at water matric potential that is less than -4 bars means most of the available water in the sandy soil has relatively high potential, it can be rapidly used by transpiring plants. Since more of the available water in the clay loam has a lower matric potential, plants use this water less rapidly, conserving the available water supply. In areas of limited rainfall, sandy loam soils may out-produce clay soils due to the greater infiltration and lesser runoff on the sandy loam soils. The soil types differ in their available water as given in table 2.13.

Table 2.13 - Textural Class and Available Water (cm/m)

Textural class	Available water
Sand	1.5
Loamy sand	7.4
Sandy loam	12.1
Loam	19.1
Silt loam	23.4
Silt	25.6
Sandy clay loam	20.9
Silt clay loam	20.4
Sandy clay	8.5
Silty clay	18.0
Clay	15.6

Many red tropical soils (Oxisols) with high iron oxide contents are rich in clay; however, the soils exhibit moisture characteristics of sands. That is, a modest amount of water is held at "high" potential. Such soils may be composed of very stable sand-sized aggregates. The aggregates act as sand particles for water retention. Moisture within the aggregates is held in a matrix that is high in clay. It is mostly held at potentials less than the wilt point.

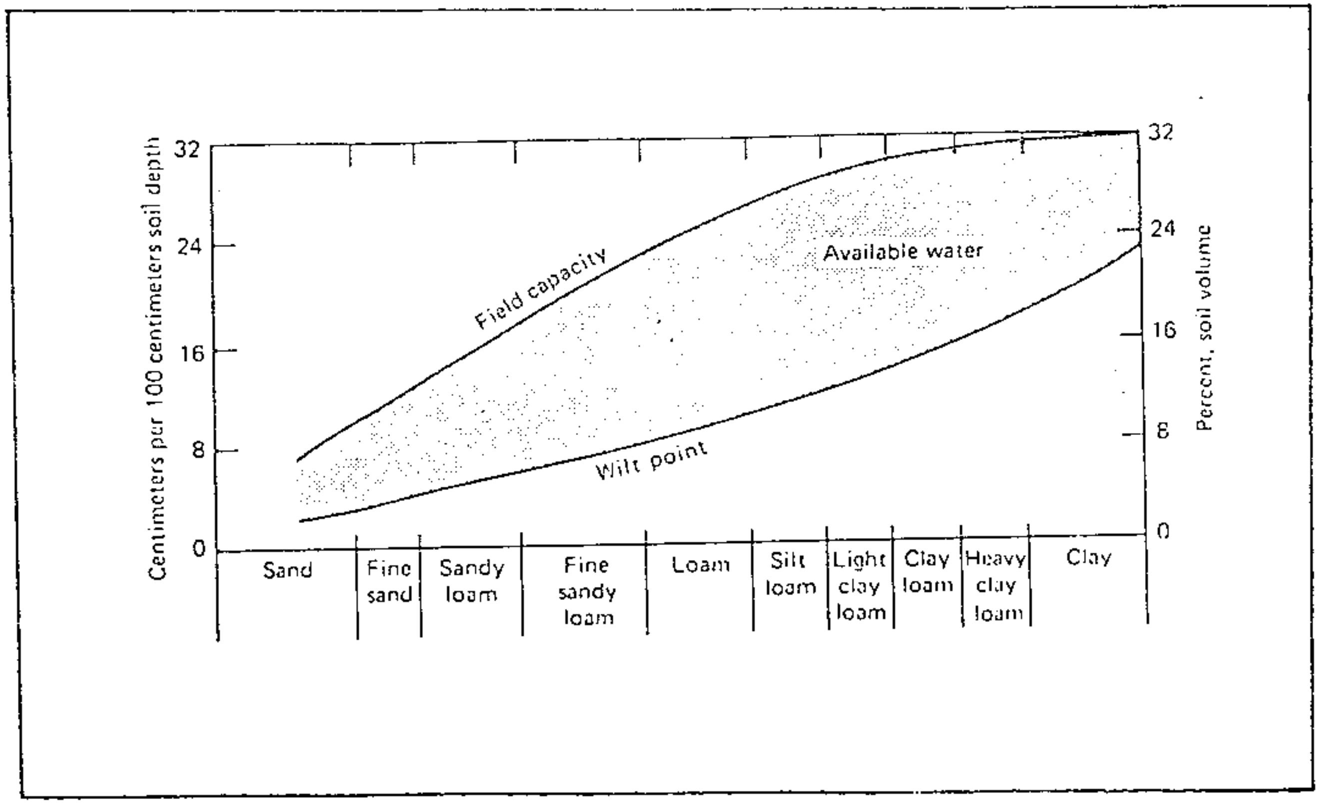


Fig. 2.10 : Relationship of soil texture to available water

The supply of water to plants is relatively more in soils of moderately fine texture than in those of coarse texture. The amount of water available to plants increases with the capacity of the soil to hold water in available form.

At very high matric potential (near zero), the lack of air may limit plant growth. The rate of plant growth is at or near a maximum at field capacity, because there is adequate oxygen accompanied by rapid water absorption. As soil water is absorbed, the water films become thinner, the matric potential decreases, and the rate of water absorption decreases. Generally, the decreasing water potential between field capacity and wilt point is associated with a reduced rate of photosynthesis and growth.

2.11 Densities of Soil

Density is the weight per unit volume of a substance. It is expressed in gram per cubic centimeter or pound per cubic foot. Two density measurements- particle density and bulk density are common for soils.

Particle Density : The weight per unit volume of the solid portion of soil is called particle density. It is also termed as true density. It is expressed in gm/cc (C.G.S. system) or lb/cft (F.P.S. system). It depends upon the accumulative densities of the individual inorganic organic constituents of the soil. Generally in the normal soils the particle density is 2.65 grams per cubic centimeter. The particle density is higher if large amounts of heavy minerals such as magnetite, limonite, hematite and zircon are present. With increase in organic matter of the soil, the particle density decreases. When particle density is divided by density of water, a relative weight number is obtained is called specific gravity.

Bulk Density : Bulk density is defined as the mass (weight) per unit volume of a dry soil (volume of solid and pore spaces). It is also expressed in gm/c.c. (G.G.S. system) or lb/cft (F.P.S. system). The bulk density of a soil is always lower than its particle density. Loose and porous soils have low weights per unit volume and compact soils have high values. Thee bulk density of sand dominated soils is about 1.7 gm/cc, whereas in organic peat soils the value of bulk density is about 0.5 gm/cc. Bulk density normally decreases as mineral soils become finer in texture. Bulk density is of greater importance than particle density in understanding the physical behaviour of soils. Generally. soils having low and high bulk densities exhibit favourable and poor physical conditions respectively. Generally in normal soils bulk density ranges from 1-1.60 gm/cc excepting in very compact sub-soils 2 gm/cc. Behaviour of soil is dependent on the bulk density of the soil profile.

Factors Affecting Bulk Density

(i) Amount of pore space : If the soil containing more pore spaces than that of solid spares per unit volume, then the value of bulk density will he very low.

(ii) Compactness of the soil : In high compacted soil or waterlogged soils the bulk density will be more.

(iii) Texture of the soil : Textural variations influence the value of bulk density in soils. As for example, clay, clay loam and silt loam surface soils show low bulk density as compared to sands and sandy loam soils which show high bulk density value.

(iv) Organic matter content : Soils containing high organic matter show lower value of bulk density.

(v) Soil structure : Soil structure affects bulk density by influencing tile porosity of the soil. As for example, crumb soil structure shows low bulk density than that of platy soil structure.

2.12 Porosity

Pore-spaces (also called voids) in a soil consists of that portion of the soil volume not occupied by solids, either mineral or organic. The pore-space under field conditions, are occupied at all times by air and water. Pore-space directly control the amount of water and air in the soil and indirectly influence the plant growth and crop production. In general there a broadly two types of pores in soils (i) Macro pores and (ii) Micro or capillary pores.

(i) Macro pores. Large-sized pores are reffered to as macro-pores which allow air and water movement readily. Sands and sandy soils have a large number of macro-pores. It is found in between the granules.

(ii) Micro or Capillary pores. Smaller sized pores are generally refferd to as a micro or capillary pores in which movement of air and water is restricts to some extent. Clays and clayey soils have a greater number of micro or capillary pores. It has got more important in the plant growth relationship. It is found within the granules.

Besides soil pores have been divided into following four categories base on the size groupings of soil separates.

Coarse pores. Greater than 0.2 mm or 200 microns (0.008 inch) average diameter. 1 micron = 1 millionth of a meter.

Size of Medium Sands

Medium pores. 0.2-0.02 mm or 200-20 microns (0.008-0.0008 inch)

average diameter. Size of Coarse slit particles.

Fine pores. 0.02-0.002mm, which is 20-2 microns (0.0008 inch) average diameter. Size of fine silt particles.

Very fine pores. Less than 2 microns (0.00008 inch) average diameter

(Large clay particles are 2 microns in average diameter). Size of large clay particles.

Porosity refers to the percentage of soil volume occupied by pore spaces. Size of individual pores, rather than total pore space in a soil, is more significant in its plant growth relationship. For optimum growth of the plant, the existence of approximately equal amount of macro and micro-pores which influence aeration, permeability, drainage and water retention favourably. Porosity of a soil can be easily changed.

Factors Affecting Porosity of Soil

Wide difference in the total pore spa-.e of various soils occurs depending upon the following several factors:

(i) Soil Structure : A soil having granular and crumb structure contains more pore spaces than that of prismatic and platy soil. structure. So well aggregated soil structure has greater pore space as compared to structureless or single grain soil.

(jj) Soil Texture : In Sandy soils the total pore space is small whereas in fine textured clay and clayey loam soils total pore space is high and there is a possibility of more granulation in clay soils.

(iii) Arrangement of Soil Particles : When the sphere like particles are arrangement in columnar form (i.e. one after another on the surface forming column like shape) it gives the most open packing system resulting very low amount of pore spaces. When such particles, are arranged in the pyramidal form it gives the most close packing system resulting high amount of pore spaces.

(iv) Organic Matter : Soil containing high organic matter possesses high, porosity because of well aggregate formation.

(v) Macro-organisms : Macro-organisms like earthworm rodents, insects etc. increase macro-pores in the soil.

(vi) Depth of Soil : With the increase in depth of soil, the porosity will decrease because of compactness in the sub-soil.

(vii) Cropping : Intensive crop cultivation tends to lower the porosity of soil as compared to fallow soils. The decrease in porosity may be due to reduction in organic matter content.

2.13 Irrigable Soil Classifications in India

The soil is not only the live media which sustains crops but also a water reservoir of micro nature

Table 2.14 - Irrigation Soil Classification in India (Constraints of Soil Efficiency)

Soil properties	Irrigable soil class				Non-irrigable soil class
	A	B	C	D	
Effective soil depth (useful to crops)	More than 90 cm	45-90 cm	22.5-45 cm	7.5-22.5 cm	Less than 7.5 cm
Texture of surface 30 cms	Sandy loam to clay loam inclusive	Loamy sand clay	Sand clay	Sand clay	Any texture
*Soil permeability of least permeable layers.	5.0-50 mm/hr	1.3-5 mm/hr. 50-130 mm/hr.	0.3-1.3 mm/hr 130-250 mm/hr	Less than 0.3 mm greater than 250 mm/hr.	Not applicable
Available water holding capacity depth of 90 cms.	12 cm or more	9-12 cm	6-9 cm	2-6 cm	Less than 2 cm
Coarse fragments (%) cobble sand stones -/75mm	Less than 5	5-15	15-35	35-65	More than 65
Gravel and kankar -/723 to 75 mm	Less than 15	15-35	35-55	55-70	More than 70
Rock out crops distance,apart in meters.	40	20	15	5	Less than 5
**Salinity E.C. x 10^3 (in saturation est. or salinity in 1:2 dilutions.	Less than 4.0mm Mhos/cm	4.0 milli mhos/cm	8-12 milli mhos/cm	12-16 milli m.hos/cm	More than 16 m.Mhos.
Salt affected (visual) (% of area effected)	Less than 20%	Less than 20%	20-50%	20-50%	More than 50%
Severity of Alkali problem	E.S.P. less than 15%	E.S.P. less than 15%	E.S.P. more than 15%	E.S.P. more than 15%	E.S.P. more than 15%
Sub-soil or sub-strata drainage characteristics	Lower sub-soilisat least permeable or a permeable layer of at least 6" thickness occurs below the soil.		No moderately permeable sub-soil or other permeable layer of at least 6" thickness.		
Soil erosion status.	Effects of sheet and rill erosion are reflected in effective soil depth available moisture holding capacity and in some other factors shown above. Moderately or severaly gullied soils may be classified based on local experiments.				

* Soil permeablity as a criteria is not applicable to deep black soils because of their unique properties deep black soils (vertisols) which are inherently slowly permeable due to expanding 2:1 lathice type clay minerals do not qualify for irrigability soil class A. They would qualify for being placed in B, C & D class.

** The criteria for salinity and alkalinity refer to equilibrium conditions under irrigation with specified irrigation waters.

Table 2.15 – Irrigation Soil Classification in India (Specification for Land Irrigability Classes)

Land Classification	Irrigable Land Class				Class Temporary non-irrigable unclassified further investigations needed	Class not suitable for irrigation includes lands which do not meet the minimum requirement for the other land classes are not suitable for irrigation or small isolated tracts (specifying size or distance from canal) not susceptible to delivery of irrigation water.
	Class 1	Class 2	Class 3	Class 4		
Sil Irrigatibilities Class	A	A to B	A to C	A to D		
	TOPOGRAPHY					
Slope	Less than 1%	1-3%	3-5%	5-10%		
Surface grading	No restriction	Moderate restrictions	Moderately severe restrictions	Service restrictions		
	Specifications to be developed locally					
	DRAINAGE					
Out-lets	Suitable outlets available	Suitable outlets available	Suitable outlets available	No drainage outlets available		
Surface	Less than Mtr. of shallow surface drains required per acre	Less than Mtrs. of shallow surface drains required per acre	Develop specification			
Sub-surface	No sub-surface drainage needed or land in with in ...mtr/ of adequate drainage (Nalla or rivers)	No sub-surface drainage needed or land in within ...Mtr/ of adequate drainage ways (Nalla or river)	Sub-surface drainage needed specification to be developed run off drainage exceeds	No natural drainage outlets available cost of pump off drainage exceed ...Rs./hr		Note: With regard to items under topography (-) and drainage (2) and (3), the criteria will have to be worked out for each project on the basis of local conditions
Depth of water table	More than 5 Mtr.	3.0-5 Mtr.	1.5-3 Mtr.	1.5 Mtr. & below		

in comparison to the main irrigation reservoir. It has a live storage (field capacity moisture level) and dead storage (wilting moisture level). Therefore soil characteristics play a major role in irrigated agriculture. Efficiency of an irrigation system is greatly influenced by various soil constraints. The classification of various soil parameters and their various ranges to be considered are given in Table 2.14 & 2.15.

2.14 Hydrologic Soil Grouping by All India Soil and Land Use Survey Organization

All India Soil and Land Use survey Organization has been carrying out soil surveys since 1958 in various parts of Andhra Pradesh, Bihar, Gujarat, Himachal Pradesh, Madhya Pradesh, Maharashtra, Orissa, West Bengal. The surveys were done in the catchments of selected River Valley Projects namely, Sutlej, Chambal, Ramganga, Mayurakshe, Damodar Valley, Kangsabati, Machkund, Mahandi, Ghod, Dantiwada, Tungbhadra and Kunda. Some of the non-river valley project areas have also been surveyed. So far more than 12 million hectors area have been surveyed by this organization and about 4500 soil series have been recognized by them. All India Soil and Land Use Survey Organization has also attempted the classification of the soil series into hydrologic soil groups. The important soil characteristics like effective depth, average clay in the profile, soil structure, infiltration rate, permeability were considered in soil classification.The important characteristics of these soil series, their hydrologic soil groups, area mapped under the soil series and their location with regard to state, district, river valley project or non-river valley project have been estimated and presented in the report published in 1984.

3.0 STUDY AREA

3.1 Dudhnai Sub-Basin

The study area is the representative basin i.e. the Dudhnai sub-basin (Fig. 3.1) on the south bank of the Brahmaputra. This sub-basin mostly lies in the district of East Garo Hills in Meghalaya and partly (towards out-fall) in the district of Goalpara, Assam. On the east lies the Deosila sub-basin and on the west is Krishnai sub-basin. On the North is the mighty Brahmaputra river where it outfalls and on the southwest Khashi hill ranges limit the basin. The catchment area is about 510 Sq.Km. Basin elevation varies from 2100 meter to 2227 meter above mean sea level (m.s.l) and basin slope from south to north. 83% of sub-basin is within district of East Garo Hills in Meghalaya and 17% in Goalpara district of Assam. The study area is geographically located between 25° 35' N and 26° N latitude and 90° 40' E and 90° 55' E longitude. Dudhnai Township at the basin mouth is situated at a distance of 60 Km. from Guwahati City. The outlet of the sub-basin is at Dudhnai with gauge discharge site at bridge site of NH-37 crossing. The basin is covered in four SOI maps of 1:50,000 scale as listed in Table 3.1 below:

Table 3.1: Details of Toposheets

Sl.No.	Sheet Reference Number	Scale	Year
1.	78K/9	1:50,000	1963-64
2.	78K/13	1:50,000	1963-64
3.	78K/14	1:50,000	1963-64
4.	78J/16	1:50,000	1963-64

Major part of the sub-basin is a hilly terrain with a few isolated V shaped valleys developed along the course of river with undulating topography. Geomorphologically the basin can be divided into three broad limits. The first one is hilly gneissic complex, the second one the foot hill zone consisting of unsorted mixture of boulders, clay and the third one i.e. flood plains is of alluvium deposits. The elevation of the basin decreases towards north.

While detailed soil investigations in the basin is in progress it has been reported that soil in the lower catchment is predominantly hard reddish clay to light yellowish & light grays felspar & Mica. The basin plains are mostly new alluvium as found in riparian areas. Soil in the upper catchment is sandy loam or silty mainly comprising of quartzite & laterite. The hydrologic classification of soils in the basin has been

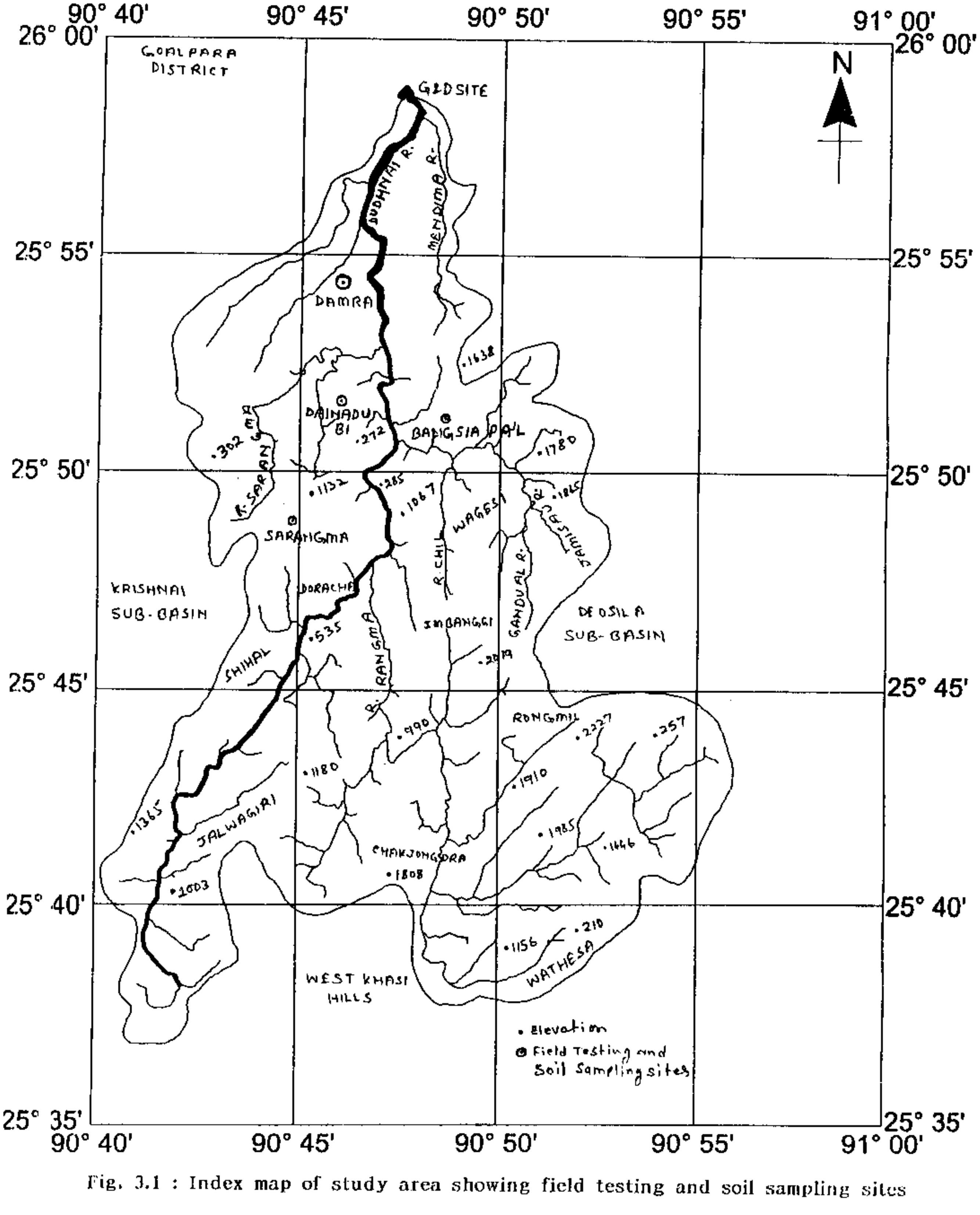


Fig. 3.1 : Index map of study area showing field testing and soil sampling sites

attempted on the basis of soil properties, NBSS & LU Maps, data of electric sounding and Remote Sensing Imageries that were available for a part of the sub-basin (lower part of about 50% up to 25 Deg. 47 Min. North).

3.1.1 Dudhnai River System

The river Dudhnai is one of the small south bank tributaries of the river Brahmaputra. It originates from the Northern slopes of the Garo Hill ranges of Meghalaya at latitude 25Deg.35Min.E at an elevation of around 400m. From here the river flows in the N.E. direction by the name Manda for a distance of about 26-km till it is joined by the river Rongma -Chichra, a right bank tributary.

Depending on the topography, river gradient and bifurcation/confluence of important tributaries, the river Dudhnai can be divided into the following four reaches:

1. From its origin to the joining point of Chil.
2. From the joining point of Chil to Dianadubi at the Assam Meghalaya border.
3. From Dainadubi to its confluence with Krishnai near Domani.
4. From Domani to outfall into Brahmaputra.

3.1.2 Land Use and Land Cover

The land utilization statistics of most of the basin areas for which information were available are as in Table 3.2 below:

Table 3.2 : Land Uses from Topo-Sheets

Sl. No.	Land Use	Area in Goalpara Dist	Area in East Garo Hills	Total
1.	Total Area	9988Ha.	37760Ha.	47748Ha.
2.	Forest	1739Ha.	13883Ha.	15622Ha.
3.	Barren (Uncultivable lands)	3296Ha.	5288Ha.	8584Ha.
4.	Cultivable Waste	455Ha.	10076Ha.	10531Ha.
5.	Fallow Land	210Ha.	5079Ha.	5289Ha.
6.	Net area sown	4238Ha.	3434Ha.	7672Ha.

3.1.3 Hydrometeorology

The Dudhnai sub-basin falls within the climate zone-1, which comprises North and North-East India, and adjoining parts of Nepal, Bhutan, Bangladesh and North Burma. The sub-basin enjoys an average annual rainfall of 1817.20 mm. In this zone the bulk of the rainfall occurs during the month of May to September. Significant rainfall occurs in May and October too. The months from November to March are generally dry. Tropical storms and depressions affect the weather in this zone during the months from June and September.

Tropical storms and depressions affect the weather in this zone during the months from June and September. Climatological situation prevailing in Dudhnai sub-basin in different parts of the year is briefly outlined below. It is predominantly characterized by four distinct seasons in a year which are: (i) Winter, (ii) Pre-Monsoon, (iii) Monsoon and (iv) Post Monsoon seasons.

The Winter Season (Dec-Feb) is the driest season and the rainfall is generally light. The precipitation is in association with the passage of low pressure, originating in the Bay of Bengal and moving in a Westerly and North-Westerly direction. The sub-basin receives significant rain under the influence of Eastern bound tropical disturbances which may appear as low pressure area. However, this season is devoid of flood in the valley due to low rainfall.

The Pre-Monsoon Season (March-May) is the season of thunder storms. The rainfall is in association with thunder storms. The precipitation due to tropical storms developed over the Bay of Bengal sometimes cause extensive rain and floods in the month of May.

The Monsoon Season (June-Sept) is the principal rainy season for the entire region and accounts for 65% of the rainfall. The orographic influence is dominant in the distribution of rainfall during this season as the prevailing winds blow almost at right angles against Khasi-Jayantia hills. The south-west monsoon sets in the first week of June and starts withdrawing by the end of September or beginning of October.

The Post Monsoon Season (Oct.-Nov.) is the season when the catchment receives generally light to moderate rainfall. The rainfall during this season is due to the cyclonic storms which form in the Bay of Bengal. Sometimes, western disturbances appear in the sub-basin mainly in second half of the October and cause light precipitation. However, floods are rare during this season.

The area is in the highest rainfall zone of the country. The rains are of long duration and occur mostly between March and October. During March and April the rainfall is sporadic, but it is steady and heavy or very heavy during May and October. The average annual rainfall over the whole catchment is around 1817 mm based on simple arithmetic average of three existing ordinary raingauge stations in the basin. It is seen that maximum rainfall occurs at Damra where the annual average accounts for being 2881 mm followed by 1326 mm and 1244 mm at Domoni and Dudhnoi respectively. Of the mean annual rainfall of 1817 mm the seasonal distribution is: monsoon (June to Sept.)-1173mm (64.55%), pre-monsoon (March to May)-474.60mm (26.12%), post monsoon (Oct to Nov.)-140.86mm (07.75%) and winter season (Dec. to Feb.)-28.93mm (01.59%).

3.1.4 Agriculture

Agriculture and forests are the mainstay of the people in the sub-basin. Rice is the principal crop. Other important crops grown are jute, wheat, sugarcane, mustard, pulses, millet, maize, sweet potato etc. Shifting cultivation known as Jhum cultivation is the age-old practice in the hilly region. Shifting cultivation degraded the vegetal cover of the area and washes down the rich top fertile soil cover rendering the surface area progressively infertile.

3.2 Soils of N.E. Region

Soils of North Eastern Region have developed in situ on many types of rocks. The rocks comprise mainly of biotite-gneiss, tourmaline schist etc. The soils around Garo and Khasi hills have originated from quartzite and granites. Barail series, simsan formation (Garo Hills), Jaintia series, Disang series (ultrabasic in deep shades) occupy almost entire area of Manipur and Nagaland Western Jaintia Hills. Barail series and Simsang formation are predominantly shale and silt-stone with hands of weathered rather soft and micaceous medium grained yellowish gray rocks. Jaintia series and Disang series are represented by a monotonous sequence of gray shale with minor mud-stone, silt-stone and siliceous limestone. Manipur valley soils have developed from the transported material formed from shale and this is the reason why these soils are heavier in texture.

The soils of Assam have been derived from two major types of parent materials - residual and transported. The Assam plateau is mostly occupied by ferroginous red soils. The soils of the Northern part of the Brahmaputra valley are formed on the alluvium transport from the Assam Himalayas by the tributaries on the northern side of the Brahmaputra. But the alluvium brought down by the tributaries on the southern part of the river Brahmaputra forms the soils of the southern part of the Brahmaputra valley. The soils of the Barak valley are not very much different from those of the southern part of the Brahmaputra valley. Being formed from sandstone, shale and sandy shale of the surrounding hilly areas, the flat lands of this valley are deep and heavy.

Soils of the north eastern hilly regions have been classified into red loamy soils, red and yellow soils, lateritic soils, brown hill soils and old and new alluvial soils. The soils of this hilly region have not been surveyed thoroughly due to hilly terrain, poor communication and inaccessibility and dense forest. Based on the available meager information, soils of the region can be broadly classified as shown in Table 3.3.

Table 3.3: Classification of soils of N.E. Region

Soil classification (Tradition or popular/ nomenclature)	Equivalent name according to the approximation classification.
Red loamy soils	Paleustafs Rhodustalfs Haplustalfs
Red & yellow soils	Haplustalfs Ochraqualfs Rhodustulfs
Laterite soils	Plinthaqualfs
Brownhill soils (On Plinthustults Sandstone and Shales)	Plinthaqualfs

The hill soils are classified on the basis of topography and natural vegetation or major crops grown. These include non-laterite red loam soils like ferroginous red soil, ferroginous gravelly soils, mixed red and black soils, forest soils and laterized red soils. According to the new classification these soils are included under Alfisol and Ultsol. The major groups in the Alluvium derived soils are Entisol, Inceptisol and Alfisol. Delineation of different soil groups for Assam where the study area partly lies is shown in Fig. 3.2.

3.2.1 Soils of Goalpara and East Garo Hills

The soils of the Goalpara district have been grouped into old and new alluvium. The average nitrogen of few alluvial soil is 0.109%, P_2O_5 is 0.020 %, K_2O is 0.014%, pH is 6.6. Old soils are more acidic, the average pH is 4.9 in water extracts and 4.5 in KNO_3 extract. Goalpara soils vary from sands to loams. The content of P_2O_5 is fairly high in the majority of the soils but that of K_2O is just sufficient. Nitrogen content is quite high, particularly in the surface soil.

The soil in the East Garo Hills is quite heavy clay and contains about 10 per cent organic matter. The nitrogen content is also high. The soils may be grouped in to hill soils and new alluvium is shown in Fig.

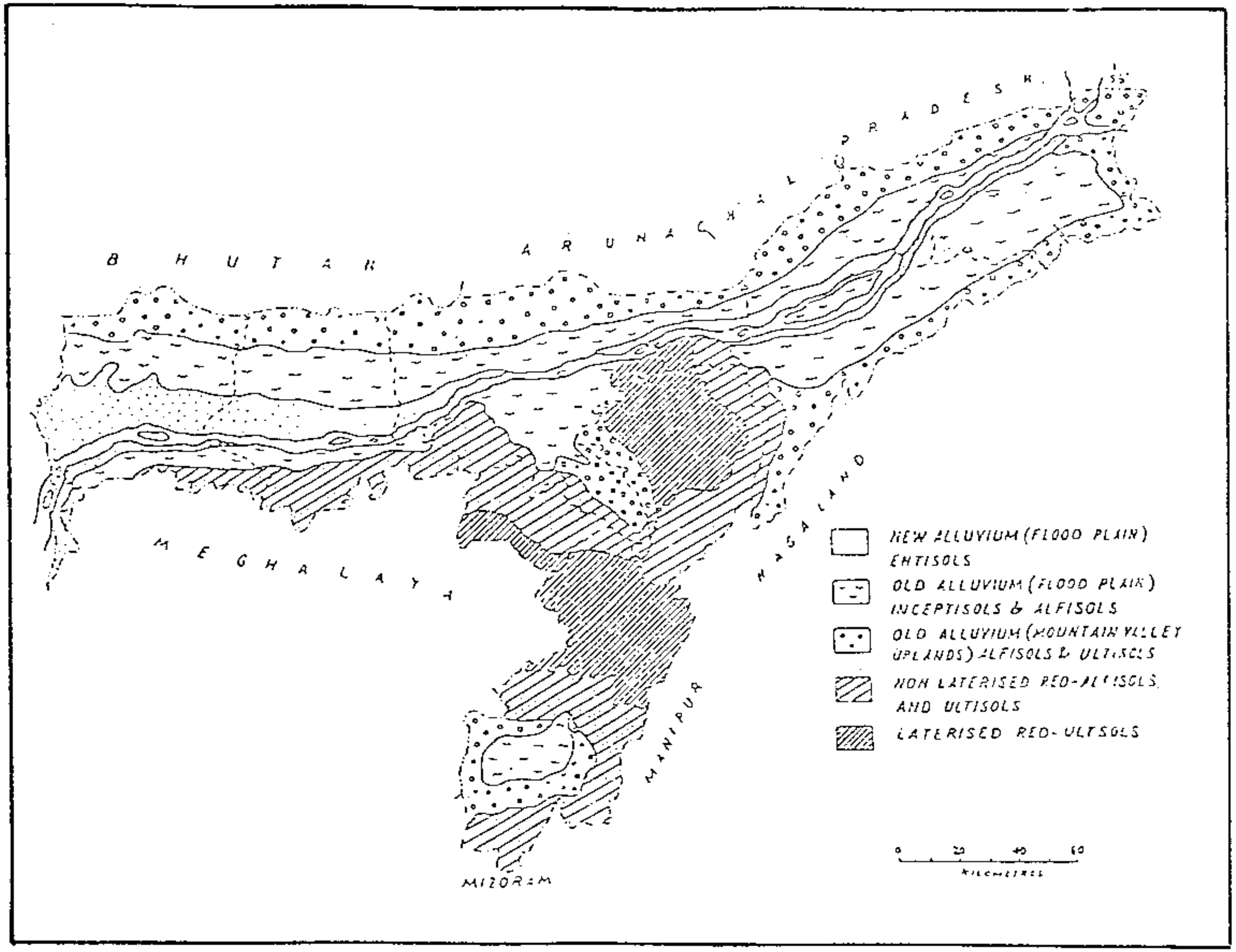
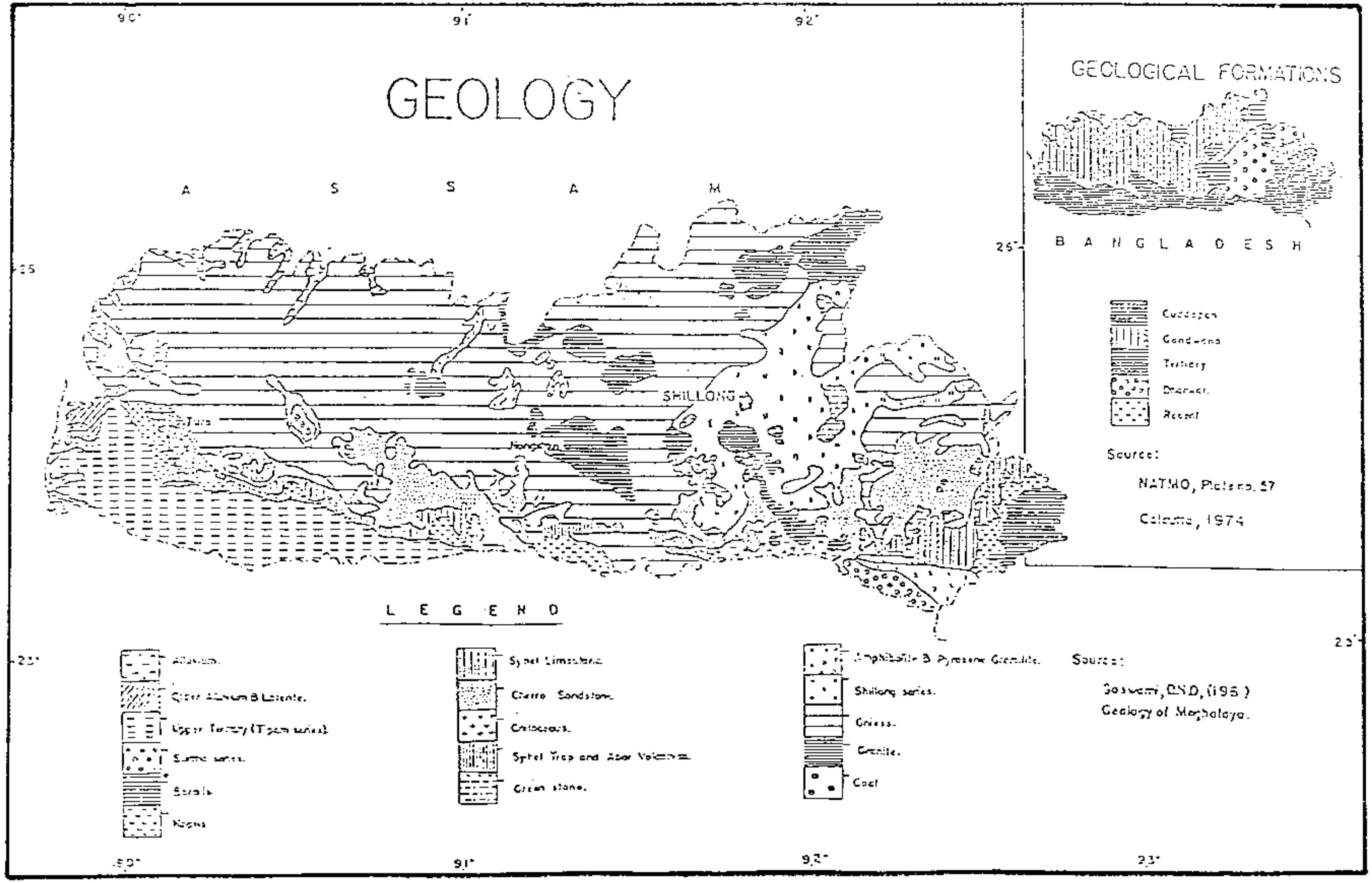


Fig. 3.2 : Soil map of Assam



Source:

NATMO, Plate no. 57

Calcutta, 1974

Source:

Goswami, D.N.D, (195)
Geology of Meghalaya.

Fig. 3.3 : Geological map of East Garo Hills

3.3. Average nutrients status of the former (in per cent) is : N= 0.146, P2O5= 0.005, NO= 0.022. The value of pH is 4.9 in water extract and 4.5 in KNO_3 extract. The average value of nutrient status of new alluvial soil (in per cent) is : N= 0.08, P_2O_5= 0.055, K_2O= 0.10. The value of pH is 4.8 in water extract, and 4.8 in KNO_3 extract.

3.2.3 Soil Classification of the Sub-Basin

Of interest to hydrology, the properties of soil which influence the runoff are effective depth, clay in the surface layer, average clay content in the profile, infiltration, permeability, soil texture etc. Detailed soil investigation results are not available for the sub-basin. However, there are some available regional information with other agencies such as the preliminary reports of deep tube well testing conducted by Department of Geology and Mining, Govt. of Assam, report of electric sounding in E.Garo Hills by CGWB, soil maps of National Bureau of Soil Survey And Land Use Planning, Jorhat and so on. These information alone are not at all sufficient to classify its soils into different groups. Therefore, besides making use of the above extra-departmental reports, field investigations/experiments were also carried out from time to time, soils samples were collected and tested in the laboratory. On the basis of these information soil has been classified under different systems of classifications and the results are presented in Chapter 5.

4.0 MATERIALS AND METHODS

To determine various soil parameters for hydrological soil classification, field survey and laboratory analyses were carried out. In the field different required parameters like infiltration rate, water table, temperature of soil, temperature of water , hydraulic conductivity, soil suction etc. were measured. After the fieldwork, the laboratory experiments were done for determining various soil parameters.

4.1 Field Methods

4.1.1 Soil sampling

The objective of this to determine the physical properties of soil. At each site of infiltration test, both disturbed and undisturbed soil samples were collected. From each site, nearly 5.0 Kg. of soil sample were collected. The samples were collected in polythene bags and sealed tightly to preserved naturality. The undisturbed soil samples were collected below 15 cm. of ground level using Kopecky rings of 50 mm dia., 51 mm length with thickness 1.5 mm.

4.1.2 Temperature

The viscosity of water changes with Temperature. Since the flow in the interstitial spaces of soil is nearly always laminar, the rate of infiltration will change with viscosity. Hence infiltration will also change with temperature. This factor causes the value of infiltration to be somewhat lower in winter and somewhat higher in summer. In the field soil temperature and water temperature had been measured with the help of digital thermometer. Soil temperature regulates germination and root growth. Early soil warming can be encouraged by the use of clear plastic mulches and drying of wet soil. Wet soil and organic mulch covers keep the soil cool longer in late spring than do dry soils and no mulch cover. Many methods are used to alter the soil and the above-soil temperature to aid plant growth.

4.1.3 Depth of Water Table

Water table is a guiding factor, which controls the movement of water through soils, though by physical character, a soil may have better drainability. Depth to water table was recorded at each side from its nearby open well spread with the help of measuring tape during field testing and soil sampling.

4.1.4 Infiltration

Infiltration rates are required in many hydrologic problems such as run-off estimation, soil moisture, budgeting and in irrigation. Commonly used methods for determining infiltration capacity are hydrograph analysis and infiltrometer tests. There are many direct & indirect methods available for

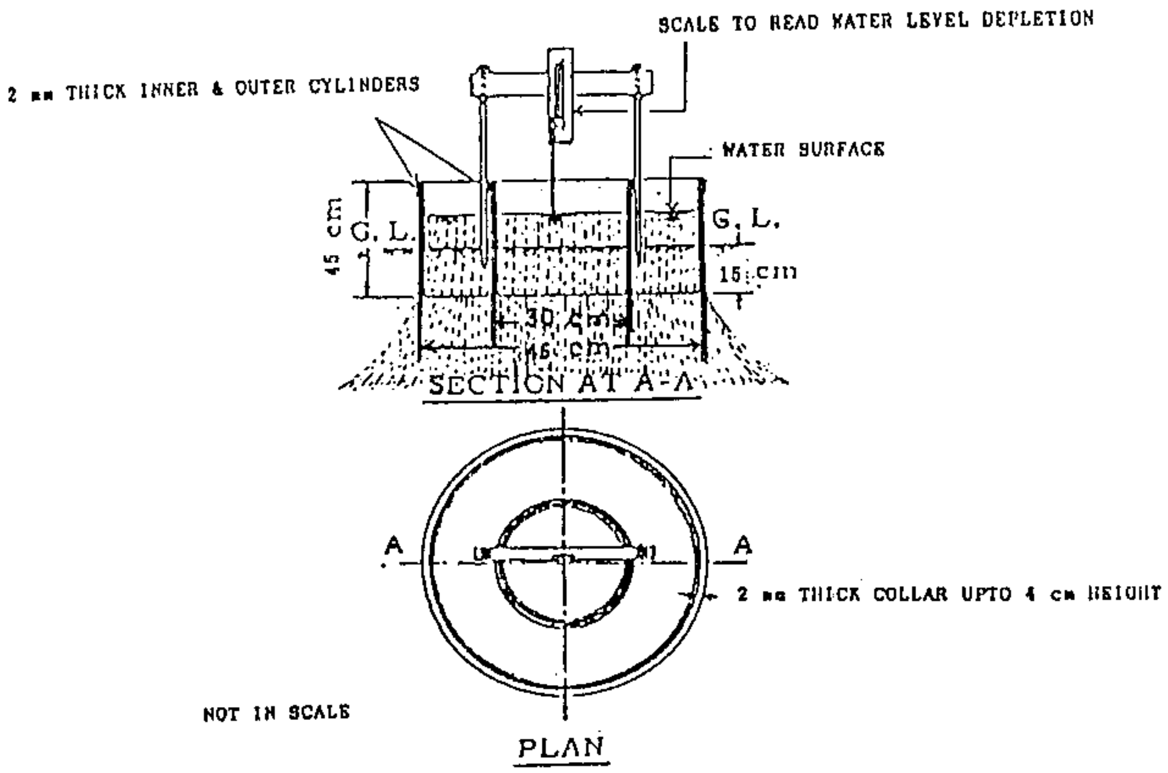


Fig. 4.1 : Schematic diagram of double ring cylinder infiltrometer

determining infiltration rate. For determination of infiltration rate, double ring infiltrometers (Fig. 4.1) are widely used due to its simplicity and cost-effectiveness besides being quick and giving results reasonable well. Infiltration rate observe by cylinder infiltrometer are influenced by the cylinder diameter, thickness of cylinder, leveling of the cylinder bottom, the method of driving the cylinder into the soil and the installation depth. The variability of data caused by ring placement could be overcome greatly by leaving the cylinders in place over a long period of time during a series of measurement. In the earlier studies only a single cylinder was used and many of the data indicated a high degree of variability. The variability was mainly due to the uncontrolled lateral movement of water from the cylinder after the wetting front reached the bottom of the cylinder. After the initiation of infiltration while the wetting front is in the cylinder, the water subsidence rate corresponds to the infiltration rate. When the wetting front passes below the cylinder, a more or less divergence of flow will occur the lateral movement of water from cylinder is minimized by ponding water in an outer guard cylinder to provide a buffer area around the inner cylinder. Detail experimental procedures are given in Kumar et al. (1995).

The infiltration test has been conducted on 44 locations in Dudhnai sub-basin with double ring infiltrometer. The infiltration capacity curves with different landuse and soil types have been elaborately described in result and analysis chapter.

4.1.5 Moisture Tension

The tension or suction with which water is held in soils is an expression of soil water potential (ψ), except it is expressed in positive rather than negative terms. Field tensiometers, such as the one-shown in Figure 4.2, measure this tension. The tensiometer is filled with water and then placed in the soil. Its effectiveness is based on the principle that water in the tensiometer is drawn through a fine porous cup into the adjacent soil until equilibrium is reached, at which time the potential in the soil is the same as that in the tensiometer. Tensiometers are used successfully in determining the need for irrigation when the soil is to be kept well-supplied with water. Their range of usefulness is between 0 and -0.8 bar potential.

4.1.6 Method to Determine Hydraulic Conductivity

Hydraulic conductivity is the measure of the ability of a soil to transmit water under a unit hydraulic gradient. For a particular soil, It represents its average water transmitting properties, which depends mainly on the number and the diameter of the pores present. In Darcy's law, hydraulic conductivity is the proportionality constants K. This K usually stands for the hydraulic conductivity of a saturated soil. Under unsaturated conditions, the hydraulic conductivity varies with the soil moisture

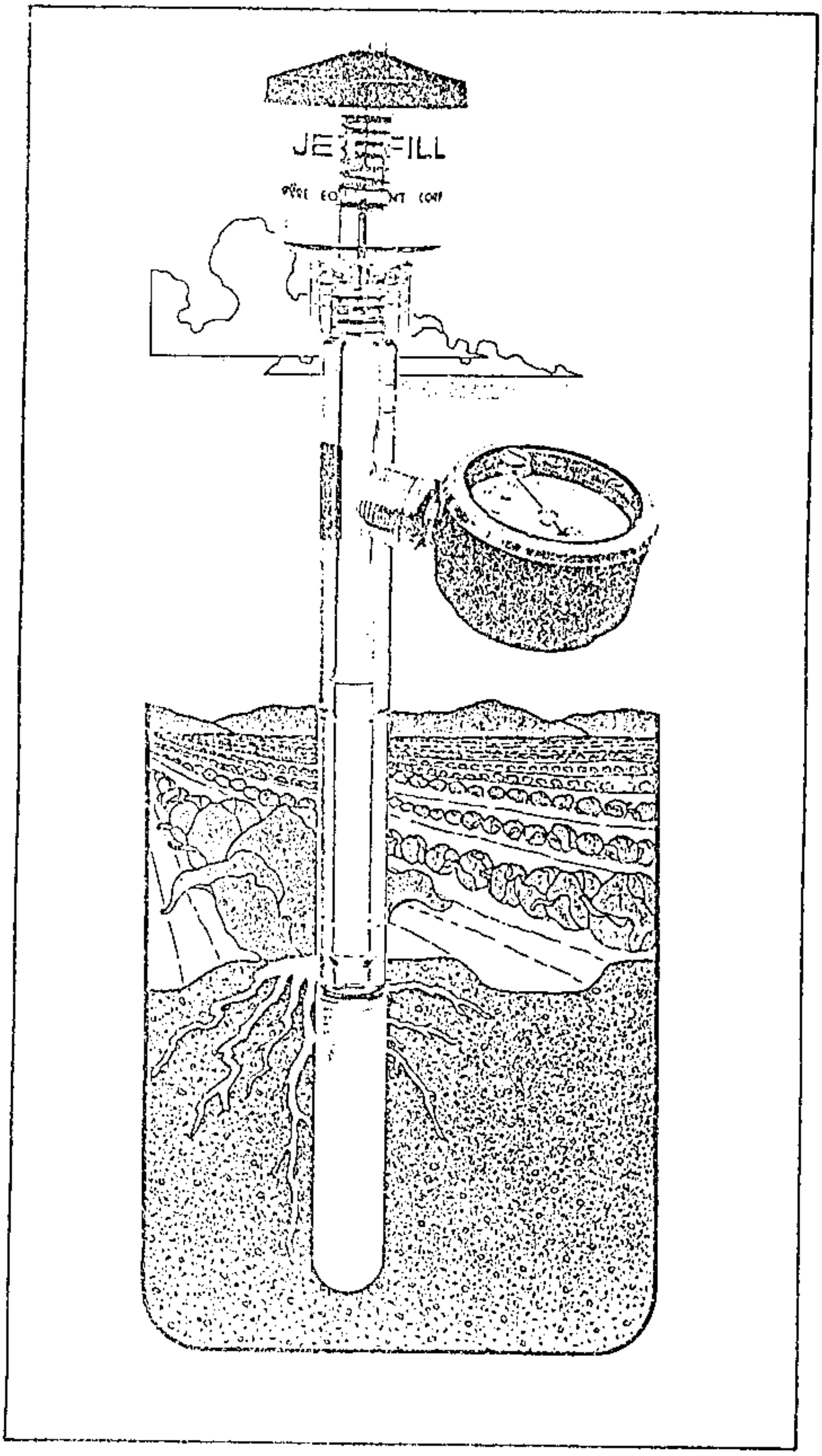


Fig. 4.2 : Field tensiometer

suction. Hydraulic conductivity decreases as the soil water suction increases. This relationship is called the conductivity pressure head relationship.

Hydraulic conductivity can be determined either in the field or from soil samples in the laboratory. Both methods impose certain flow conditions on a soil body, after which discharge is measured and hydraulic conductivity is calculated with a formula describing the relation between hydraulic conductivity, the flow conditions and the discharge.

Field measurement of hydraulic conductivity can be done either in non-saturated soils (above the water table) or in saturated soils (below water table). In the presence of the water table, the auger hole method is a simple and reliable technique for measuring saturated hydraulic conductivity in relatively uniform soils. The methods for measuring hydraulic conductivity in the absence of the water table are double tube method, the infiltrometer method and the inverse auger hole method.

The Guelph permeameter can be used to determine in-situ K_{fs} (where subscript 'fs' stands for field saturated) for a particular soil. The Guelph permeameter method (Reynold et al., 1985) measures the steady state liquid recharge necessary to maintain a constant depth of liquid in an uncased cylindrical well finished above the water table. Guelph Permeameter is a latest development for direct in-situ determination of field saturated hydraulic conductivity. This is a constant head well permeameter that creates a saturated bulb at a desired depth to measure steady rate of water entry into the soil. The rate of water entry, so obtained, is used to determine the saturated hydraulic conductivity. In the present study Guelph Permeameter (Fig. 4.3) has been used for determination of hydraulic conductivity.

Detail experimental procedures are given in Chakraborty (1999), Vivekanand Singh (1997), C.P. Kumar (1999) and Shukla & Soni (1993).

Field Saturated Hydraulic Conductivity (K_{fs})

$$K_{fs} = G_2Q_2 - G_1Q_1$$

Where,

$$G_2 = H_1C_2/\{\pi[2H_1H_2(H_2-H_1)+a^2(H_1C_2-H_2C_1)]\}$$

$$Q_2 = (X)(R_2) \text{ or } (Y)(R_2)$$

$$G_1 = G_2(H_2C_1)/(H_1C_2)$$

$$Q_1 = (X)(R_1) \text{ or } (Y)(R_1)$$

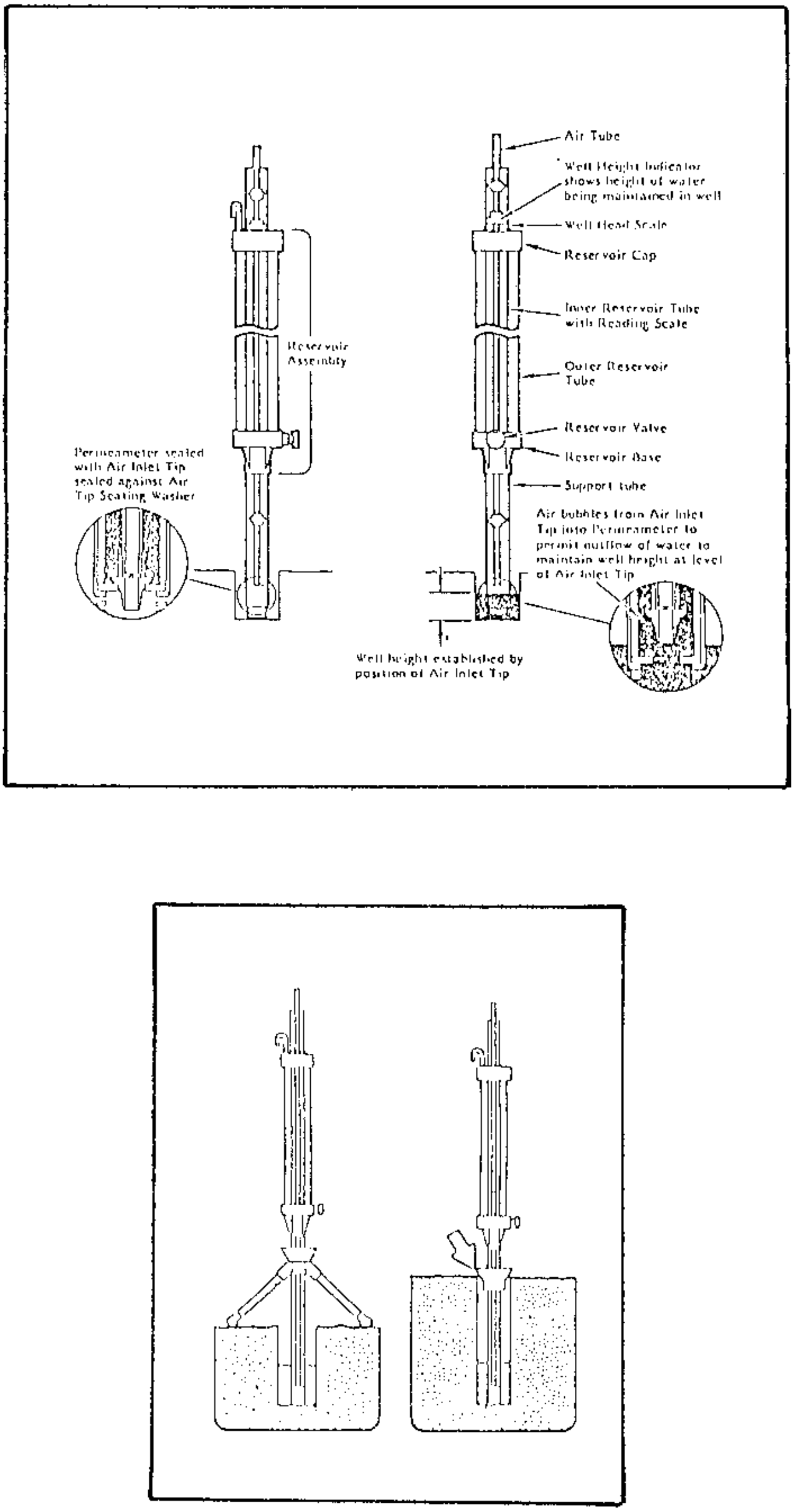


Fig. 4.3 : Guelph permeameter (a) different parts (b) permeameter placement

K_{fs} : field saturated hydraulic conductivity, in cm/sec.

H_1, H_2 : well height for first and second measurements respectively in cms.

C_1C_2 : C factors corresponding to H_1/a and H_2/a respectively.

a : well radius in cms.

R_1,R_2 : steady state rate of fall corresponding to H_1 and H_2 respectively and converted to cm/sec.

X : reservoir constant when both inner and outer reservoirs are used.

Y : reservoir constant when only inner reservoir is used.

Matrix Flux Potential (Φ_m)

$$\Phi_m = J_1Q_1 - J_2Q_2$$

where,

$$J_1 = \{(2H_2^2+a^2C_2)C_1\}/\{2\pi[2H_1H_2(H_2-H_1)+a^2(H_1C_2-H_2C_1)]\}$$

$$J_2 = J_1[(2H_1^2+a^2C_1)C_2]/[(2H_2^2+a^2C_2)C_1]$$

Sorptivity (S)

Soil sorptivity is calculated from the following equation.

$$S = \sqrt{[2(\Delta\theta)\Phi_m]}$$

Where,

$\Delta\theta$ = $(\theta_{fs}-\theta_i)$ i.e. the change in the water content in the soil adjacent to the well from the initial value θ_i to the field saturated value θ_{fs}.

Alpha Constant (α)

Alpha parameter (α) is expressed by the following relationship

$$\alpha = K_{fs}/\Phi_m$$

Alfa is a measure of the soil's ability to absorb water. It is a constant which is dependent on the porous properties of soil. The larger the ratio, the smaller the absorptive ability or capillarity.

4.2 Lab Methods

4.2.1 pH of Soil

The pH of soil is one of its most important properties. There are many relationships between soil pH and nutrient availability, overall genesis and properties of soils etc. Soil pH is commonly determined by (1) mixing one part of soil with two parts of distilled water (or other suitable material such as a neutral salt solution), (2) occasionally mixing it to allow the soil and water to approach equilibrium, and then (3) measuring the pH of the soil-water suspension using appropriate pH meter.

4.2.2 Consistency Limit

By consistency meant the relative ease with which soil can be deformed. This term is mostly used for fine grained soil for which the consistency is related to water content. Consistency denotes degree of firmness of the soil, which may be termed as soft, firm, stiff or hard. In the college laboratory, the following tests for consistency have been done:

Liquid Limit : It is the water content corresponding to the arbitrary limit between liquid and plastic state of the consistency of soil. It is defined as minimum water content at which the soil is still in the liquid state, but has a small shearing strength against flowing which can be measured by standard available means. The test had been done by static cone penetration method. In this method liquid limit is calculated by the given formula –

$$W_L = W_x + 0.01\ (25 - X)(W_x + 15)$$

Where W_L = liquid limit of the soil

W_x = water content of the soil paste corresponding to a penetration of x

x = depth of penetration, in mm. of the cone

Plastic Limit : it is defined as the minimum water content at which a soil will just begin to crumble when rolled into a thread approximately 3mm in diameter. Atterberg's method was applied for finding out this limit from different soil samples.

Other derived parameters related to consistency limit like Relative Consistency, Activity Number were also determined as per the methods described in Review section.

4.2.3 Moisture Content

It is defined as the ratio of weight of water to the weight of solids in a given soil mass. It is the generally expressed in a percentage. Wet soils do not have a high infiltration rate as do moist or dry soil. In winter or spring, the moisture of soil is generally high and the value of infiltration is low; while the case is reverse in summer season.

4.2.4 Specific Gravity

The specific gravity is determined by 50ml density bottle. This method is most accurate for most of the soil types.

4.2.5 Grain size distribution and Textural Analysis

The object of this experiment is to determine coarse grain size distribution of soil by sieving and then distribution of particle size, finer than 75 micron sieve by sedimentation analysis using a sampling pipette method. The I.S sieve size used in the test were 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 425 micron, 300 micron, 425 micron, 300 micron, 212 micron, 150 micron, 75 micron, 45 micron. Texture indicates proportions of sands (2-0.05 mm average particle diameters), silts (0.05-0.002 mm), and clays (<0.002 mm). To group the unlimited soil textures possible, all soils are placed into one of 12 textural classes such as loam, clay loam. or loamy sand. If mineral particles are larger than 2 mm (0.08 in.) in diameter, they are no longer sand particles but are called gravel, cobble, or stone as size increases. Particle size distribution is an attempt to determine the relative proportions of the different grain sizes that makes a given soil mass. The relative proportion of sand, silt and clay determines the soil texture. The diameter of the particles present in the soil sample makes the soil to be coarse, medium and fine. The soil texture is determined by separating sand, silt and clay fractions and measuring their proportion, which is called the mechanical analysis and it's practical implication is enumerated as follows :

(i) The mechanical analysis are not of much significance unless stone and gravel are present in large quantities exceeding 10 per cent. If they are present beyond 10 per cent but not exceeding too large then facilitate drainage and tillage.

(ii) It helps in deciding the textural class names like sand, sandy loam, clay loam etc. by determining the percentages of different size groups of particles.

(iii) By mechanical analysis one can easily understand the physical properties as well as colloidal behaviour of soils.

(iv) It can help cultivation of soil by giving an idea of 'light' and 'heavy' properties of soil. The use of the terms 'light' and 'heavy' refer to ease of tillage and not to soil weight.

The soil texture triangle is used to convert quantitative data from detailed gradation analysis of separates less than 2mm in diameter to textural class names of soils. In present case the textural triangle of US Public Road Administration is used to determine the soil textural name after the percentages of sand, silt, and clay are determined from laboratory analysis.

To carry out the particle size distribution, first of all the oven dried soil sample weighing 500 gm is washed through the sieve of number 200. The portion of the soil particles retained on sieve is subjected to sieve analysis and the particles passing through the sieve is subjected to sedimentation analysis. In sieve analysis, the portion retained on each sieve is collected and weighted. The percentage of soil sample retained on each sieve on the basis of total weight of soil sample and the percentage of weight passing through each sieve is calculated (Bowles, 1986).

In the Indian Standard (IS: 460-1962), the sieves are designated by the size of aperture in mm, whereas in BS (410-1962) and ASTM (El I- 196 1) standards, the sieve sizes are given in term of the number of openings per inch. These are described in Report TR-82 by Dr. Seth, 1990. The detail procedure of sieve and sedimentation analysis is given in Bowles, (1986).

The sieving process does not provide information on the shape of the soil grains. It only yields information on grains that can pass through rectangular sieve opening of a certain size. Information obtained from the grain size analysis is presented in the form of a curve as specified by BIS. In such a curve, the y-axis or the ordinate in the graph indicates the percentage of soil particles having diameter finer than indicated on X-axis.

4.3 Index Properties of Soil

The various soil parameters such as void ratio, porosity, degree of saturation, percentage air voids, air content, uniformaty coefficient, coefficient of curvature, plasticity index, consistency index and liquidity index are computed from the field and laboratory results as described below-

- **Void Ratio (e)** : It is the ratio of volume of voids to the total volume of soil solids in a given soil mass. It is expressed in percentage and calculated by the given relation-

  $$e = G\rho_{\omega} / \rho_d - 1$$

  Where G is the specific gravity , ρ_{ω} is the density of Water, ρ_d is the dry density.

- **Bulk Density** : A measurement of the physical looseness or compaction of a sod is the soil's bulk density, weight (mass) per unit volume (which includes both the individual particles and the pore space). Particle density measures density of only the particles. Soil compaction and/or large proportions of sand cause higher bulk densities (1.6-1.9 g/cm2). The bulk density or moist density is the total mass of the soil per unit of its total volume. It is expressed in terms of gm/cc. Loose and porous soils have low bulk density while compacted soils have high values. Generally, behaviour of soil is dependent on the bulk density of the soil profile.

- **Porosity (n)** : Porosity is the ratio of volume of voids to the total volume of a given soil mass. It is expressed in percentage and computed by the given relation-

$n = e / (1+e)$

- **Degree of Saturation (Sr) :** It is defined as the ratio of volume of Water present in a given soil mass to the total volume of voids in it. It is expressed in percentage and computed by the given relation-

  $Sr = \omega G/e$ Where ω is the natural moisture content.

  For a fully saturated sample Sr =1 and for perfectly dry sample Sr =0.

- **Air Content (a_c) :** The air content is defined as the ratio of volume of air voids to the volume of voids. It is computed by the given relation-

  $a_c = 1 - Sr$

- **Percentage Air Voids (n_a) :** Percentage air voids is defined as the ratio of the volume of air voids to the total volume of the soil mass and is expressed in percentage. It is computed by the given relation-

  $n_a = n \cdot a_c$

- **Uniformaty Coefficient (Cu) :** It is measure of particle size range and is calculated by the given relation-

  $Cu = D_{60} / D_{10}$

  Where, D_{10} = Particle diameter at which 10% of the soil mass is finer.

  D_{60} = Particle diameter at which 60%of the soil mass is finer.

- **Coefficient Of Curvature (Cc) :** The shape of the particle size represented by the coefficient of curvature by the given relation-

  $Cc = (D_{30})^2 / (D_{10} \cdot D_{60})$

  Where, D_{30} = Particle diameter at which 30% of the soil mass is finer

- **Plasticity Index (Ip) :** The range of consistency within which a soil exhibits plastic properties is called plastic range and is indicated by plasticity index. The plasticity index is defined as the numerical difference between liquid limit (W_L) and plastic (W_P) limit of a soil.

  $Ip = W_L - W_P$

- **Consistency Index (Ic) :** The consistency index or the relative consistency is defined as the ratio of the liquid limit minus the natural water content (W) to the plasticity index of a soil and calculated as follows:

$$I_c = (W_L - W) / I_P$$

- **Liquidity Index (I_L)** : The liquidity index or water plasticity ratio is the ratio, expressed as a percentage of the natural Water content of a soil minus its plastic limit, to its plasticity index.

  $$I_L = (W - W_p) / I_p$$

For determination of index/engineering/hydrological/textural/structural properties of soil, detail experimental procedures are available in Punmia (1991), Lambe (1951), Chakraborty (1999), Vivekanand Singh (1997), C.P. Kumar (1999), Shukla & Soni (1993) and Alam Singh (1981).

5.0 RESULTS AND ANALYSIS

Soil classifications using different criteria at Dudhnai sub-basin for an area around 510 sq km have been made based on the field and laboratory experiments on soil samples collected from time to time. In requirement of various soil classification systems, soil properties together with other information have been studied and grouped into different classes as a reference base for future hydrological studies of the basin.

Point infiltration tests, tensiometer tests, Guelph Permeameter tests for hydraulic conductivity & flux potential etc. were conducted at various locations in respect of different land uses and soil type conditions. Soil samples in disturbed and undisturbed mode were also collected from each field testing sites and tested in laboratory to find out the required information for soil classification.

Soil classifications based on hydrologic soil properties and soil indices are analyzed here in this section. Forty four locations are selected for collection of field samples over the whole of basin are shown in Fig. 3.1. On the basis of data ascertained from field & laboratory experiments, the interpretation has been made to classify soils of Dudhnai sub-basin into different soil groups.

The soil parameters used for classification and hydrologic grouping of soils are effective soil depth, soil structure, texture, infiltration and permeability, engineering and index properties, consistency limits, chemical composition etc. which are determined from field & laboratory tests and the results are discussed below.

5.1 Classification Based on Effective Soil Depth of Dudhnai :

The effective depth are determined for the representative sites of the basin based on the data of vertical electric sounding conducted by C.G.W.B , Basic Data Report on Dudhnoi deep tube well (Directorate of Geology and Mining, Govt of Assam) and field observation using Sample Ring Kit Auger are given in Table-5.1.

5.2 Grain Size Distribution Curves :

The grain size distribution curve gives an idea regarding the gradation of the soil i.e. it is possible to identify whether a soil is well graded or poorly graded. In mechanical soil stabilization, the main principle is to mix a few selected soils in such a proportion that a desired grain size distribution is

Table – 5.1 : Soil Classification Based on Effective Soil Depth

S. No.	Testing Location	Test No.	Land Use	Effective Depth of Soil in M	Soil Depth Class	Runoff Potential
1	Bangsiapal	B1	Banana garden (on urban land)	0.50	d3	Moderately High
2		B2	Banana garden (on urban land)	0.50	d3	Moderately High
3		B3	Banana garden (on urban land)	0.50	d3	Moderately High
4	Bangsiapal	B4	Banana + Betel Nut garden	0.50	d3	Moderately High
5		B5	Banana + Betel Nut garden	0.50	d3	Moderately High
6		B6	Banana + Betel Nut garden	0.50	d3	Moderately High
7	Bangsiapal	B7	Footway of grassy land	0.50	d3	Moderately High
8		B8	Footway of grassy land	0.50	d3	Moderately High
9		B9	Footway of grassy land	0.50	d3	Moderately High
10	Bangsiapal	B10	Grassy (100%) land	0.50	d3	Moderately High
11		B11	Grassy (100%) land	0.50	d3	Moderately High
12		B12	Grassy (100%) land	0.50	d3	Moderately High
13	Damra	D1	Betel Nut garden	>1.0	d5	Low
14		D2	Betel Nut garden	>1.0	d5	Low
15		D3	Betel Nut garden	>1.0	d5	Low
16	Damra	D4	Rubber garden	>1.0	d5	Low
17		D4	Rubber garden	>1.0	d5	Low
18		D6	Rubber garden	>1.0	d5	Low
19	Dainadubi	DB1	Rose garden	0.60	d4	Moderately Low
20		DB2	Rose garden	0.60	d4	Moderately Low
21	Dainadubi	DB3	Grassy with humus	0.60	d4	Moderately Low
22		DB4	Grassy with humus	0.60	d4	Moderately Low
23		DB5	Grassy with humus	0.60	d4	Moderately Low
24	Dainadubi	DB6	Grassy (80%) land	0.60	d4	Moderately Low
25		DB7	Grassy (80%) land	0.60	d4	Moderately Low
26		DB8	Grassy (80%) land	0.60	d4	Moderately Low
27	Dainadubi	DB9	Barren land	0.60	d4	Moderately Low
28		DB10	Barren land	0.60	d4	Moderately Low
29		DB11	Barren land	0.60	d4	Moderately Low
30	Sarangma	S1	Agri.(harvested paddy field)	>1.0	d5	Low
31		S2	Agri.(harvested paddy field)	>1.0	d5	Low
32		S3	Agri.(harvested paddy field)	>1.0	d5	Low
33	Sarangma	S4	Deforested land with stumps	>1.0	d5	Low
34		S5	Deforested land with stumps	>1.0	d5	Low
35		S6	Deforested land with stumps	>1.0	d5	Low
36	Sarangma	S7	Teak forest	>1.0	d5	Low
37		S8	Teak forest	>1.0	d5	Low
38		S9	Teak forest	>1.0	d5	Low
39	Sarangma	S10	Banana garden on deforested land	>1.0	d5	Low
40		S11	Banana garden on deforested land	>1.0	d5	Low
41		S12	Banana garden on deforested land	>1.0	d5	Low
42	Sarangma	S13	Shrub land	>1.0	d5	Low
43		S14	Shrub land	>1.0	d5	Low
44		S15	Shrub land	>1.0	d5	Low

obtained for the design mix. Grain size distribution of soils is important to many of their properties. Whether soils consist of sand, clay, or some mixture of those and silt, the size distribution affects the movement and retention of water, consistency, and capacity to shrink and swell etc. Most soil classification systems use particle size distribution as one criterion. Grain size distribution is an, attempt to determine the relative proportions of the different grain sizes that makes a given soil mass. The relative proportion of sand, silt and clay determines the soil texture. The diameter of the particles present in the soil sample makes the soil to be coarse, medium and fine. Fig. 5.1(a) to 5.1(i) show the grain size distribution curves of the soil samples collected from different sites under Dudhnai sub-basin and used for textural class names of soils as per USDA system. The soil texture is determined by separating sand, silt and clay fractions and measuring their proportion. Grain size distribution envelopes for each soil type is also prepared by considering all the grain size analysis values of the particular soil type and placed at Fig. 5.2(a) to 5.2(f). The grain size distribution envelopes indicate upper and lower bound curves. Differences of upper and lower bounds provide distribution range (max. and min.) of gravel, sand, silt and clays.

5.3 Classification Based on Soil Texture of Dudhnai :

From the grain size distribution curves of the soil samples percentage of sand, silt and clays were found out as per USDA system. Using USDA soil triangle classification of textural system (Fig. 5.3), the textural classification of the soil samples of the study area were found and are given in Table-5.2.

5.4 Classification Based on Soil Structure of Dudhnai :

Soil structure is the combination of primary particles (sand, silt, clay) into larger units, caged pads if formed naturally or clods if formed artificially, as by plowing. Organic and other materials "cement" sands, silts, and clays into stable "clumps" called aggregates. These allow faster air and water movement into and through soils. The shapes of aggregates or groups of aggregates are structural units called granular, platy, blocky, or prismatic. The arrangement of soil particles in the soil is referred to as structure of a particular soil and this governs the moisture and air regimes in the soil. The structure is classified to various nomenclature as discussed in Review chapter of the report on the basis of visual inspection and are grouped as given in Table-5.3.

5.5 Classification Based on Infiltration Data of Dudhnai :

Infiltration tests at Dudhnai sub-basin were conducted with Double Ring Infiltrometer at 44 selected locations as per the method discussed earlier in the report. Steady state infiltration rate at the representative sites are considered for grouping the soils into various hydrological classes. The results are

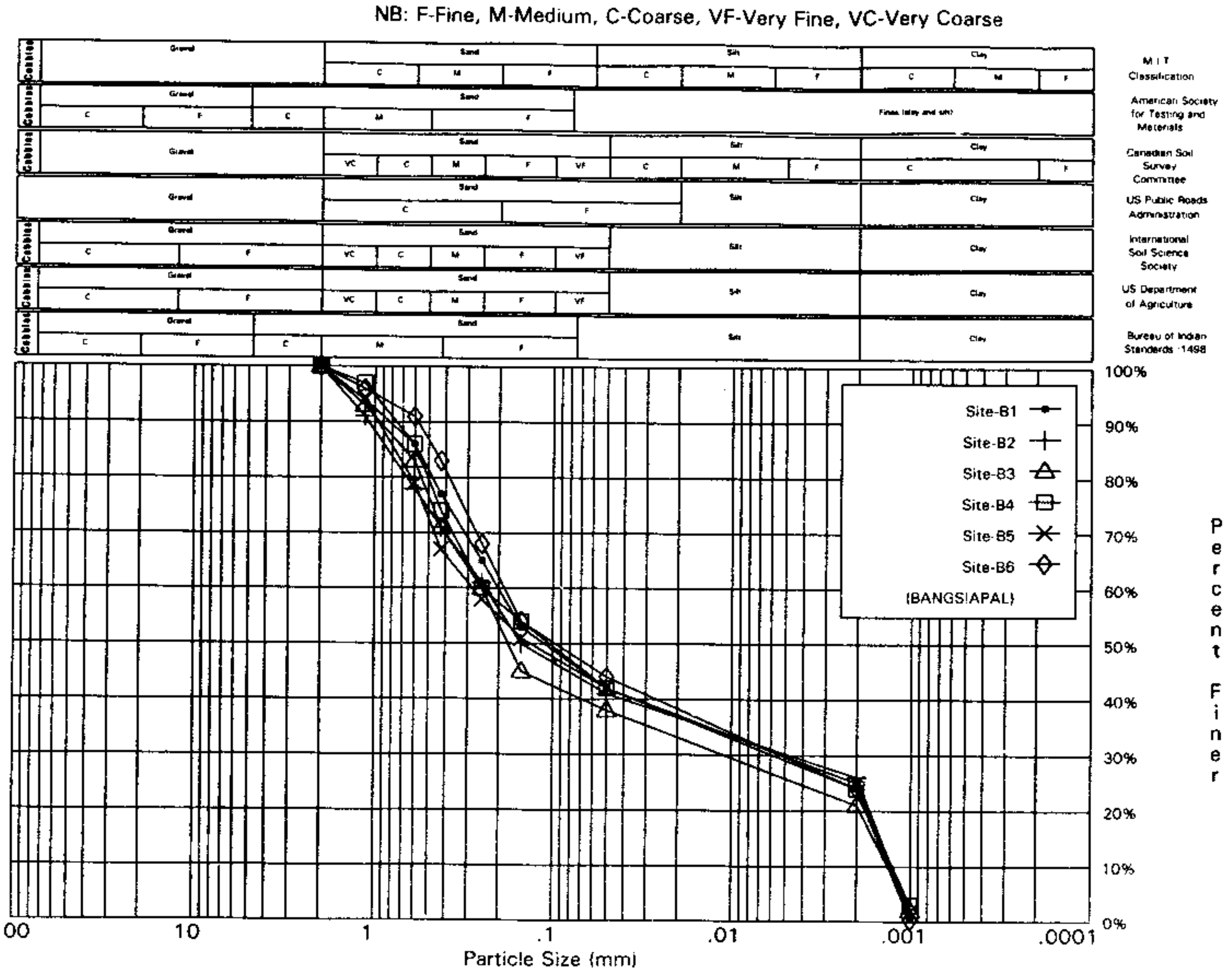


Fig. 5.1 (a): Grain Size Distribution Curves of Soils at Bangsiapal (Site B1 to B6)

NB: F-Fine, M-Medium, C-Coarse, VF-Very Fine, VC-Very Coarse

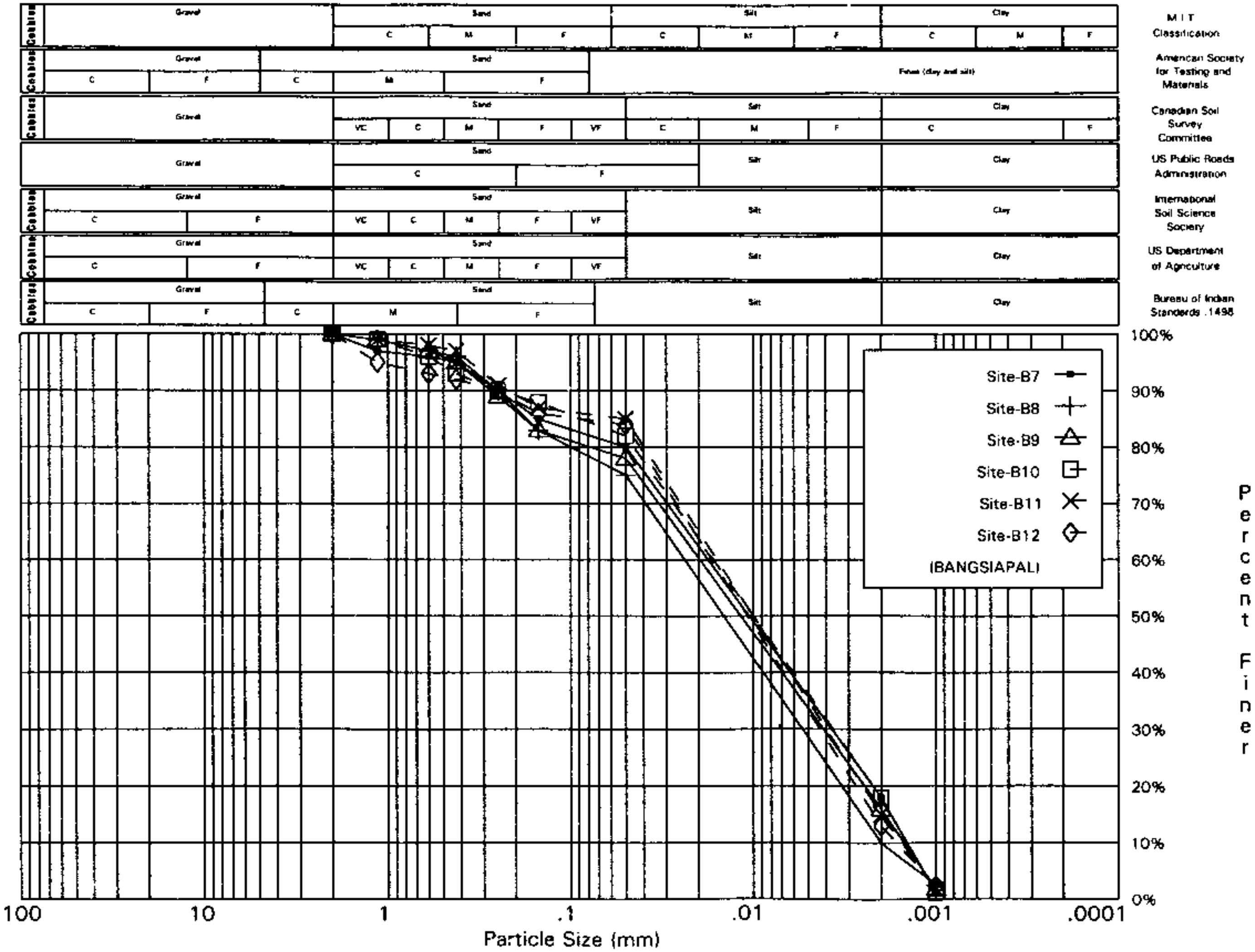


Fig. 5.1 (b): Grain Size Distribution Curves of Soils at Bangsiapal (Site B7 to B12)

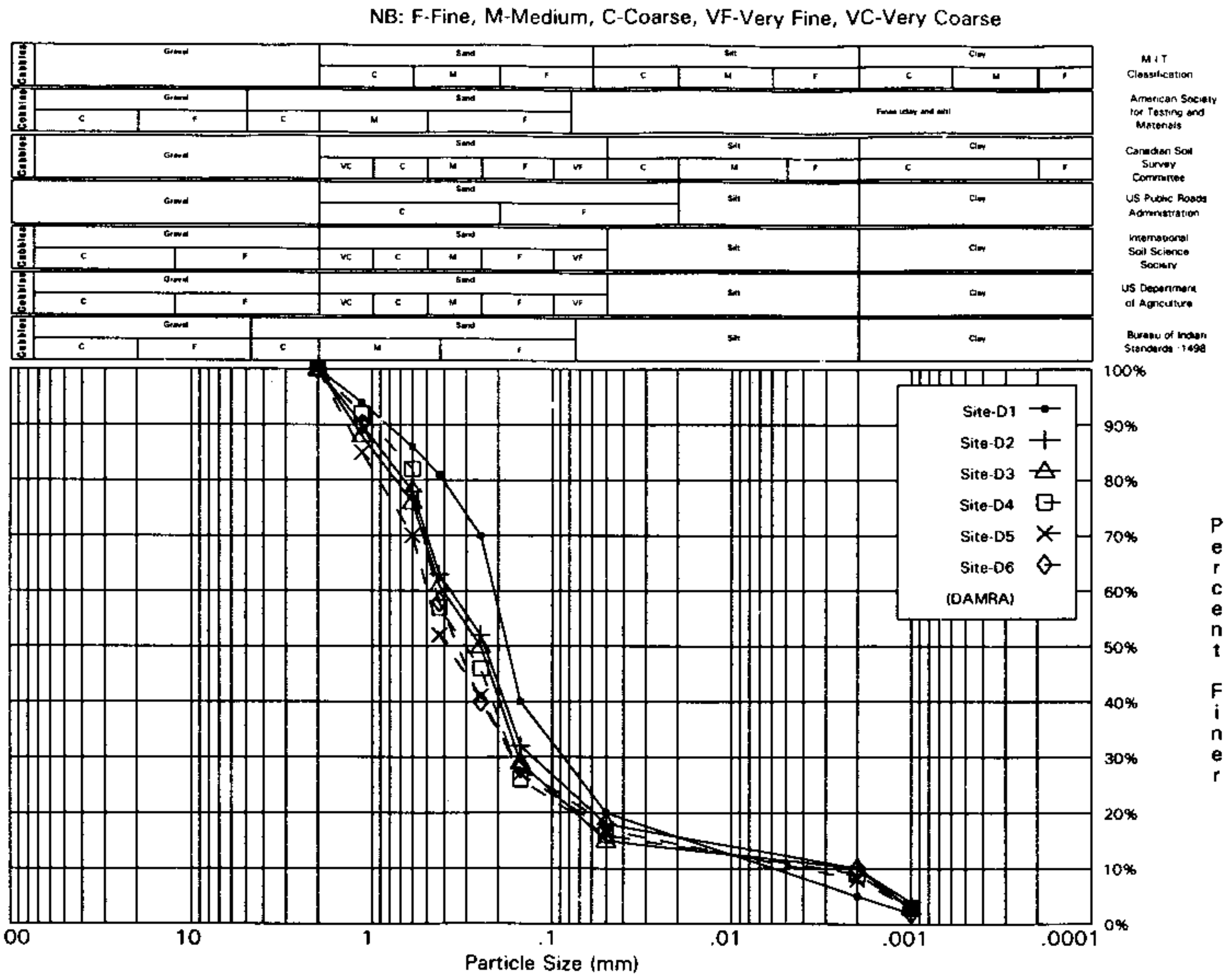


Fig. 5.1 (c): Grain Size Distribution Curves of Soils at Damra (Site D1 to D6)

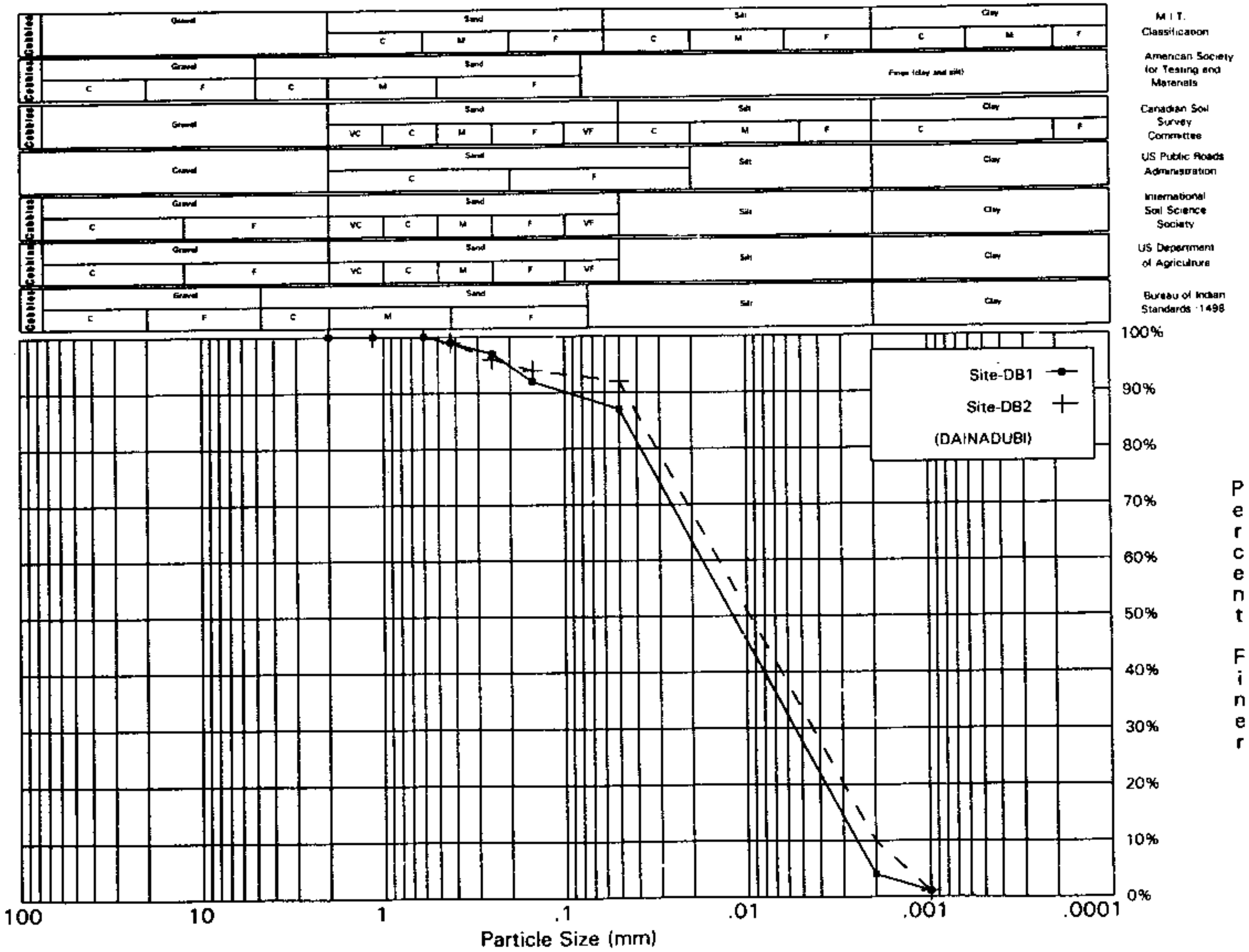

NB: F-Fine, M-Medium, C-Coarse, VF-Very Fine, VC-Very Coarse

Fig. 5.1 (d): Grain Size Distribution Curves of Soils at Dainadubi (Site DB1 to DB2)

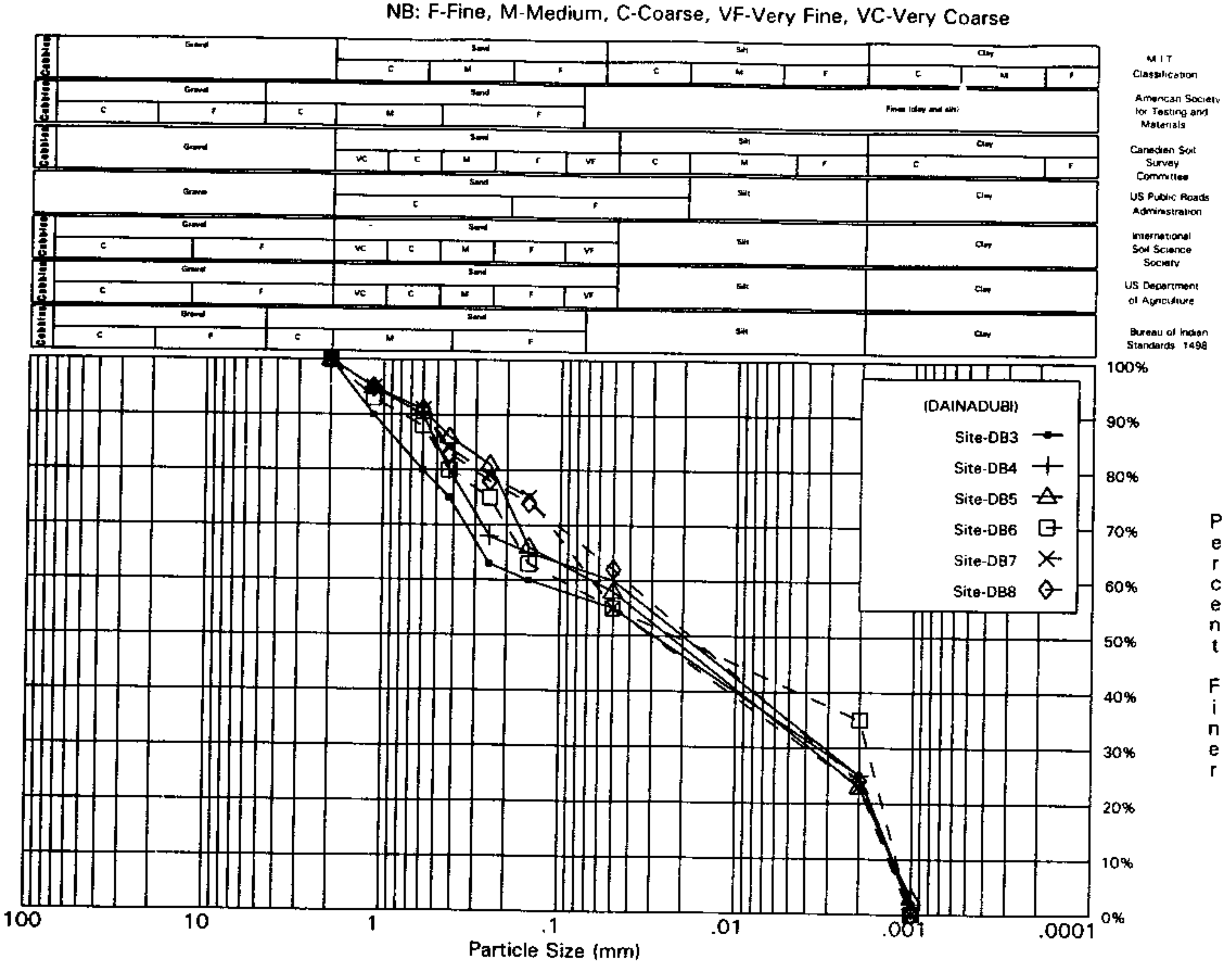


Fig. 5.1 (e): Grain Size Distribution Curves of Soils at Dainadubi (Site DB3 to DB8)

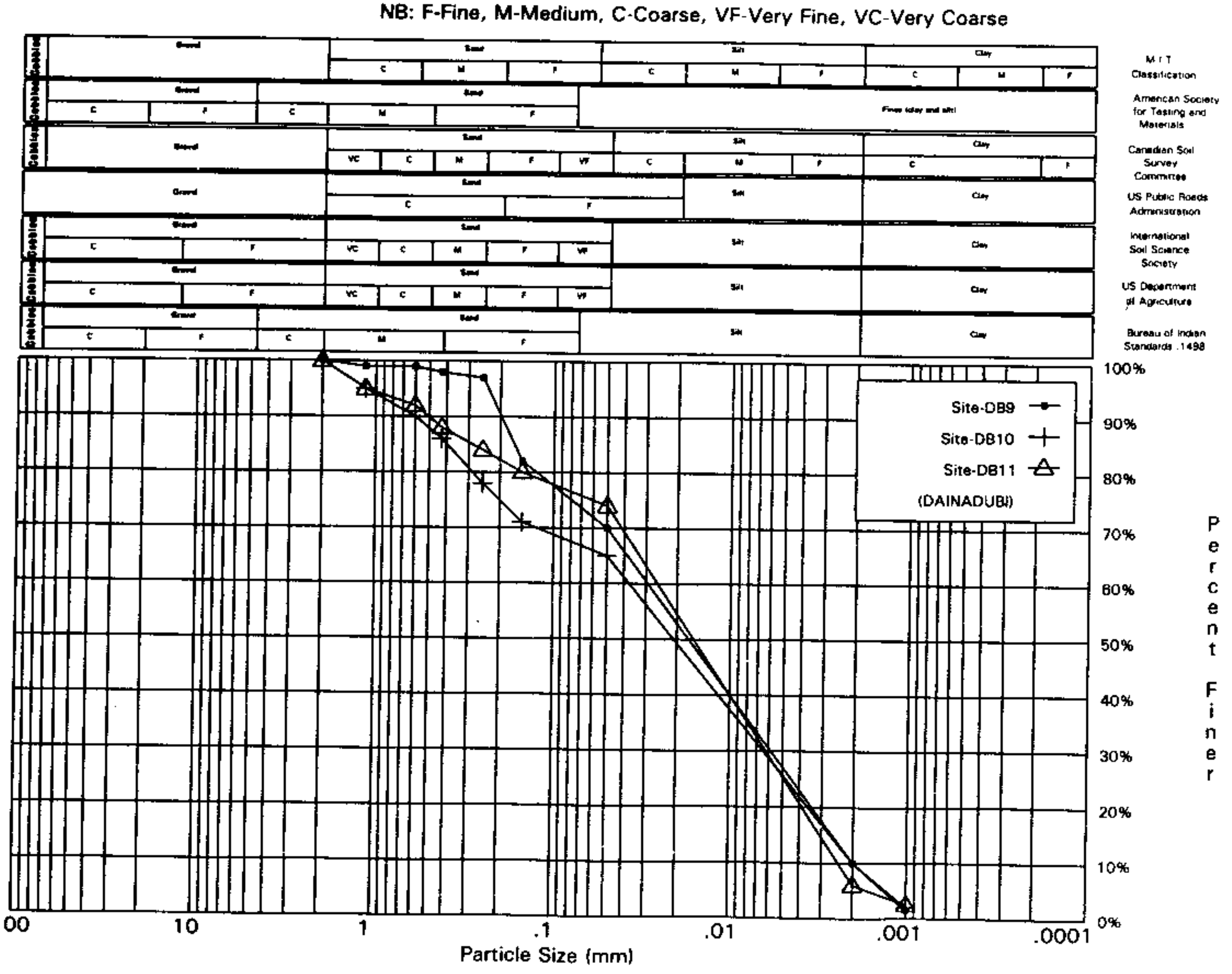


Fig. 5.1 (f): Grain Size Distribution Curves of Soils at Dainadubi (Site DB9 to DB11)

NB: F-Fine, M-Medium, C-Coarse, VF-Very Fine, VC-Very Coarse

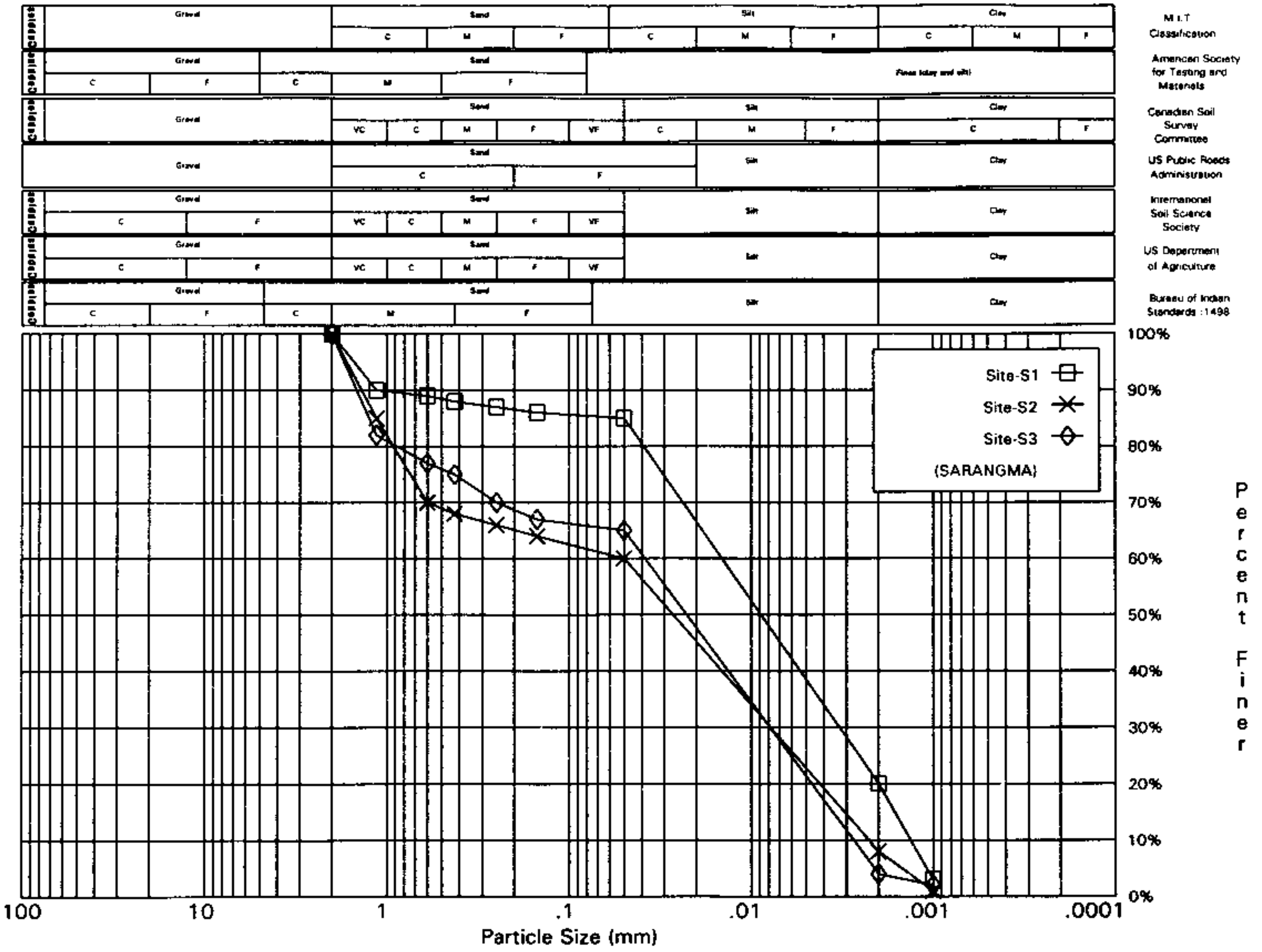


Fig. 5.1 (g): Grain Size Distribution Curves of Soils at Sarangam (Site S1 to S3)

NB: F-Fine, M-Medium, C-Coarse, VF-Very Fine, VC-Very Coarse

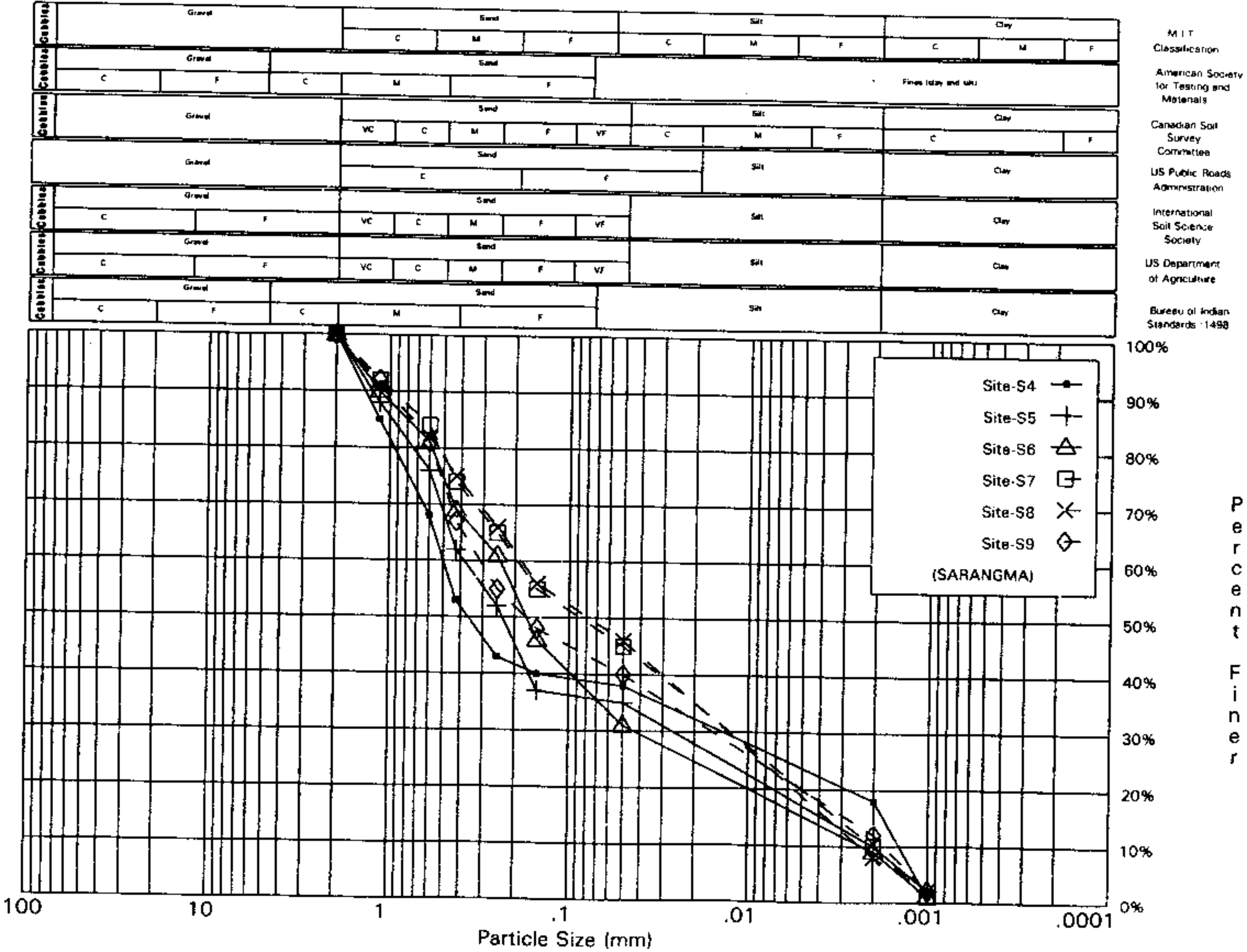


Fig. 5.1 (h): Grain Size Distribution Curves of Soils at Sarangma (Site S4 to S9)

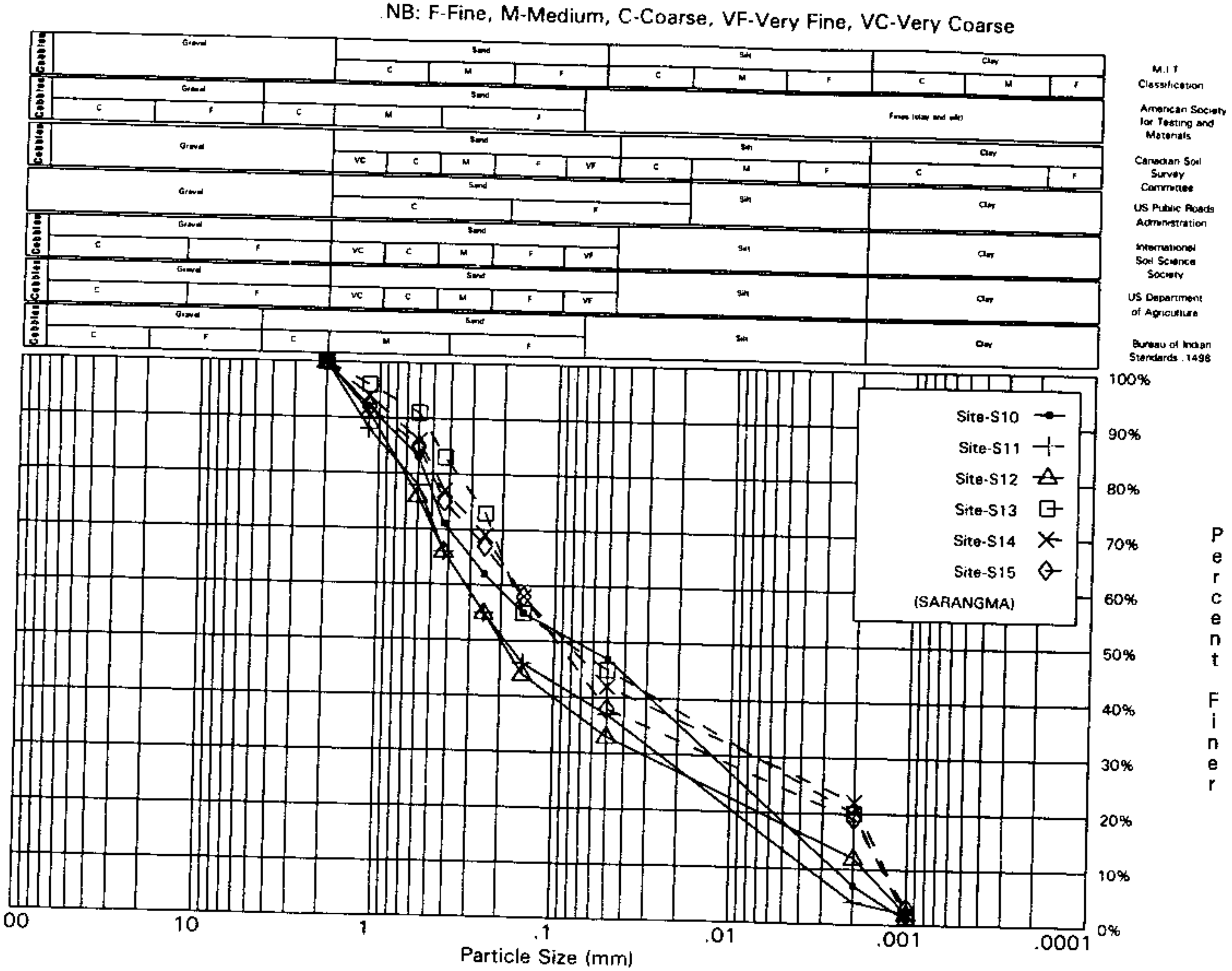


Fig. 5.1 (i): Grain Size Distribution Curves of Soils at Sarangma (Site S10 to S15)

NB: F-Fine, M-Medium, C-Coarse, VF-Very Fine, VC-Very Coarse

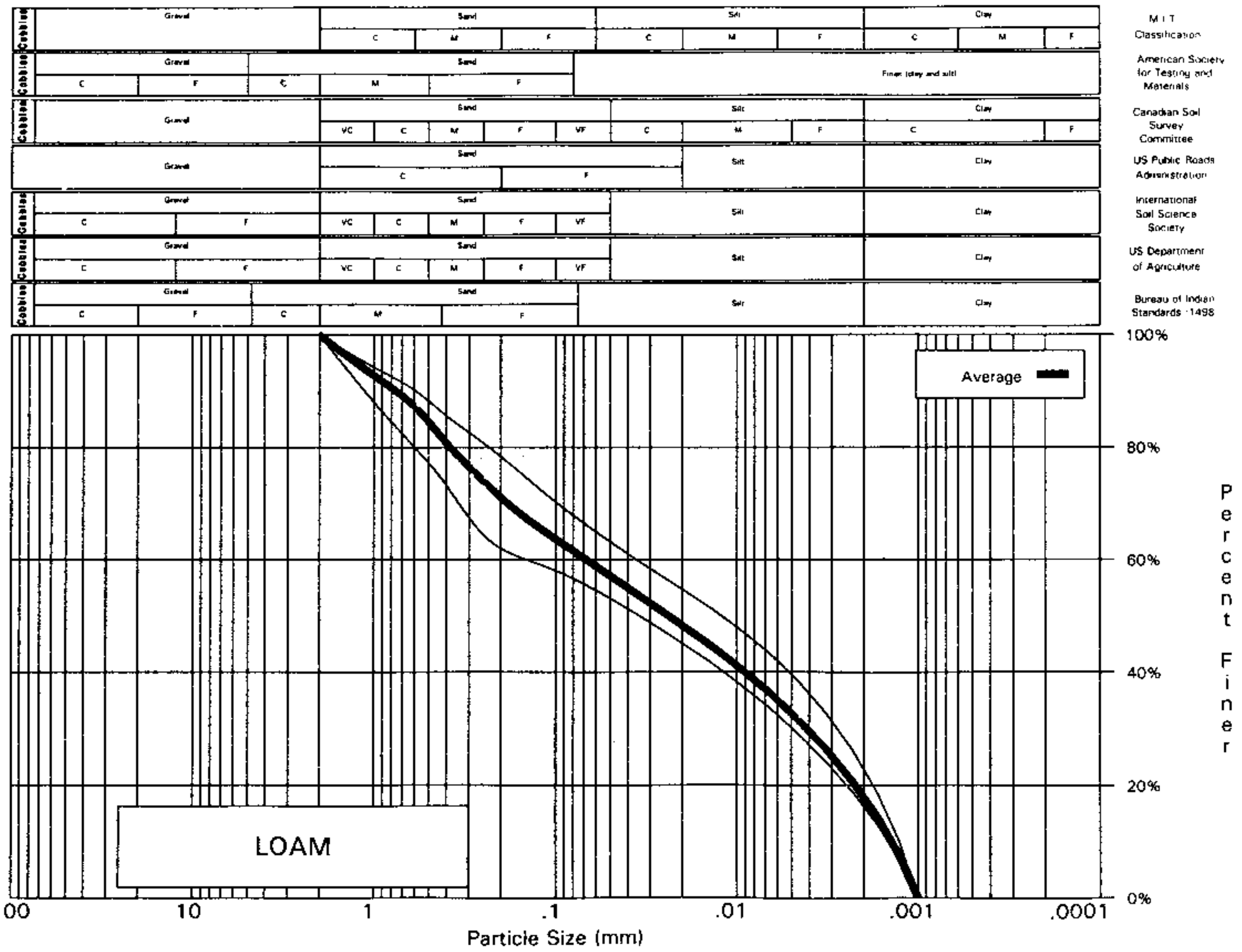


Fig. 5.2 (a): Grain Size Distribution Envelop for Loamy Soil at Dudhnai

NB: F-Fine, M-Medium, C-Coarse, VF-Very Fine, VC-Very Coarse

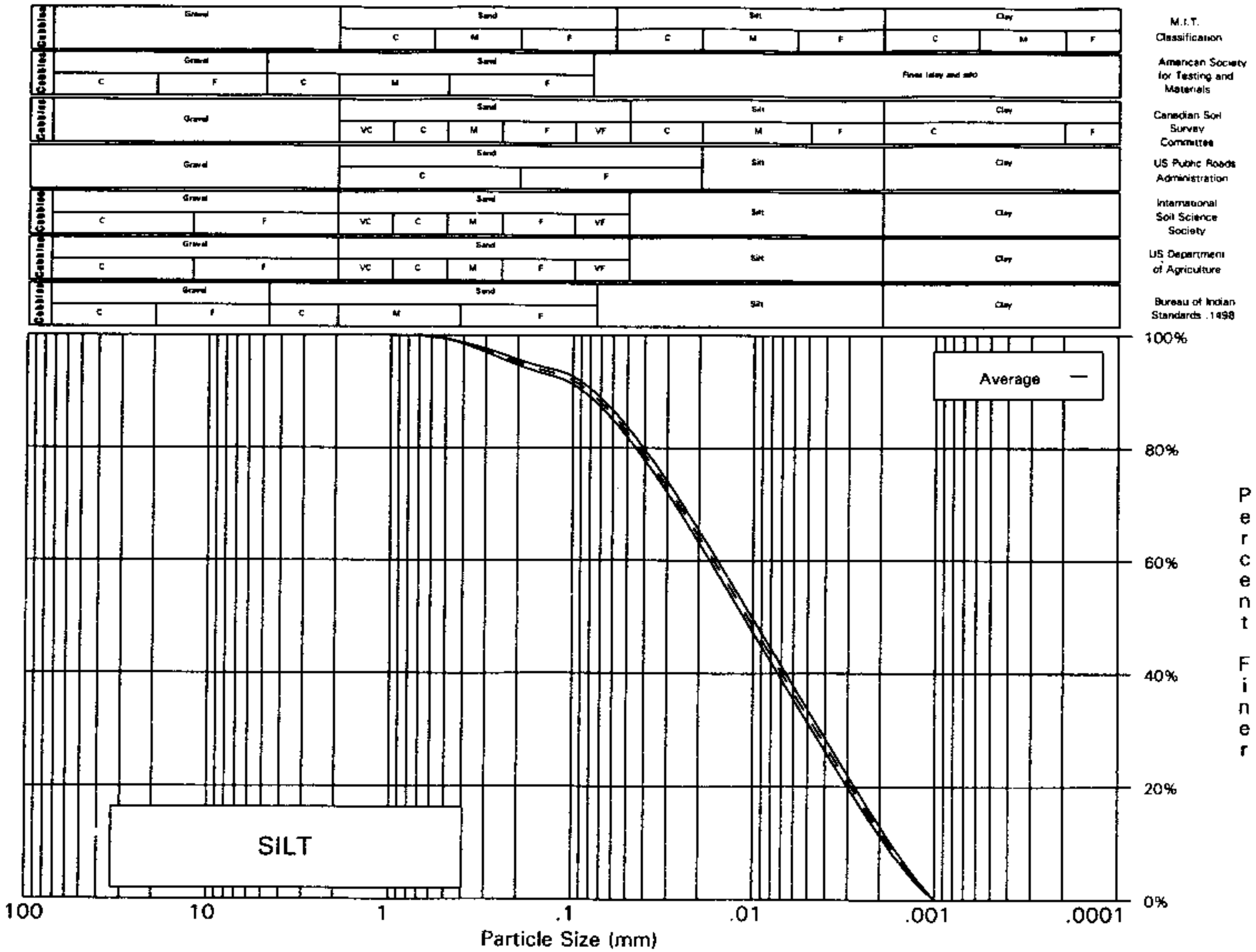


Fig. 5.2 (b): Grain Size Distribution Envelop for Silty Soil at Dudhnai

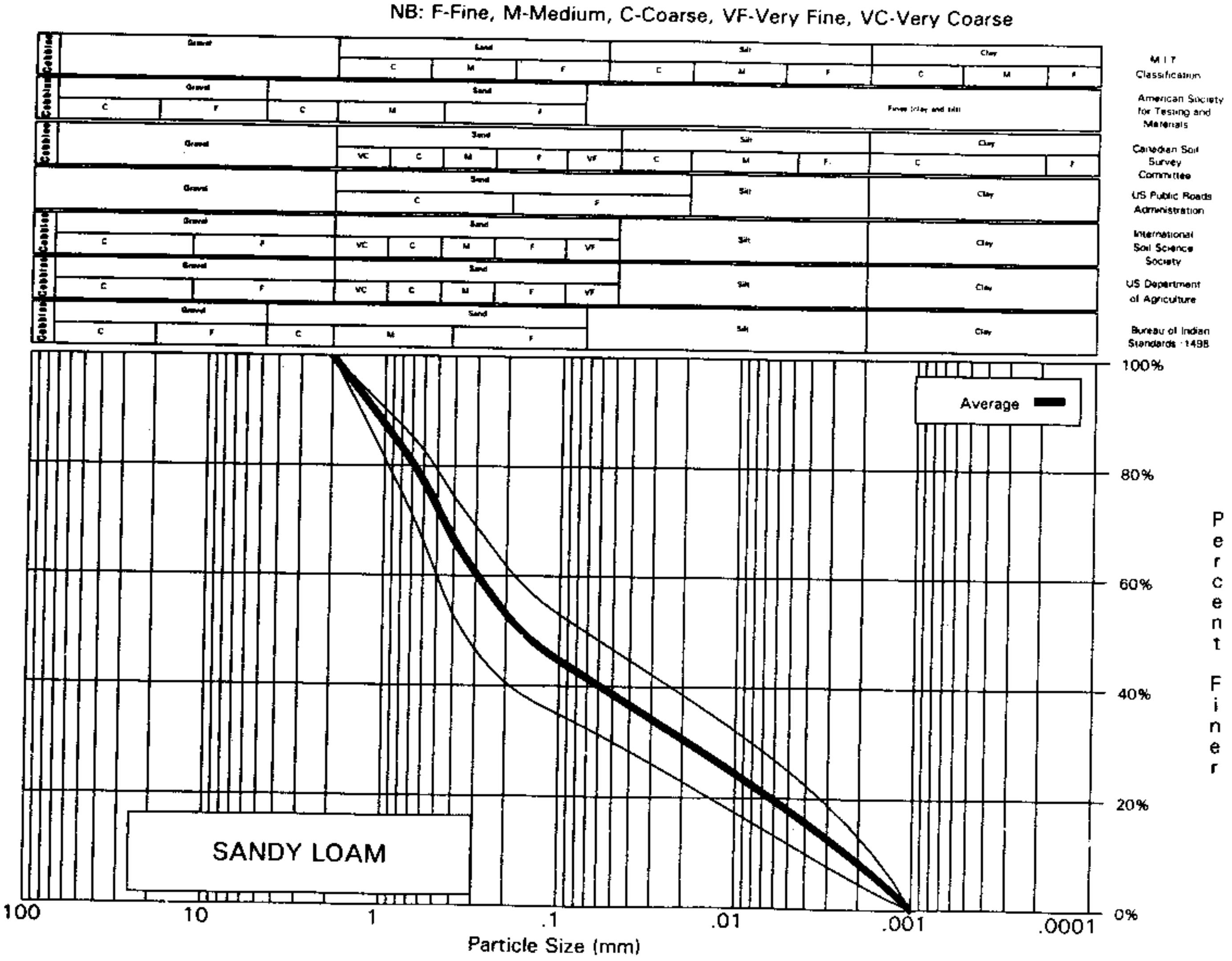


Fig. 5.2 (c): Grain Size Distribution Envelop for Sandy Loam Soil at Dudhnai

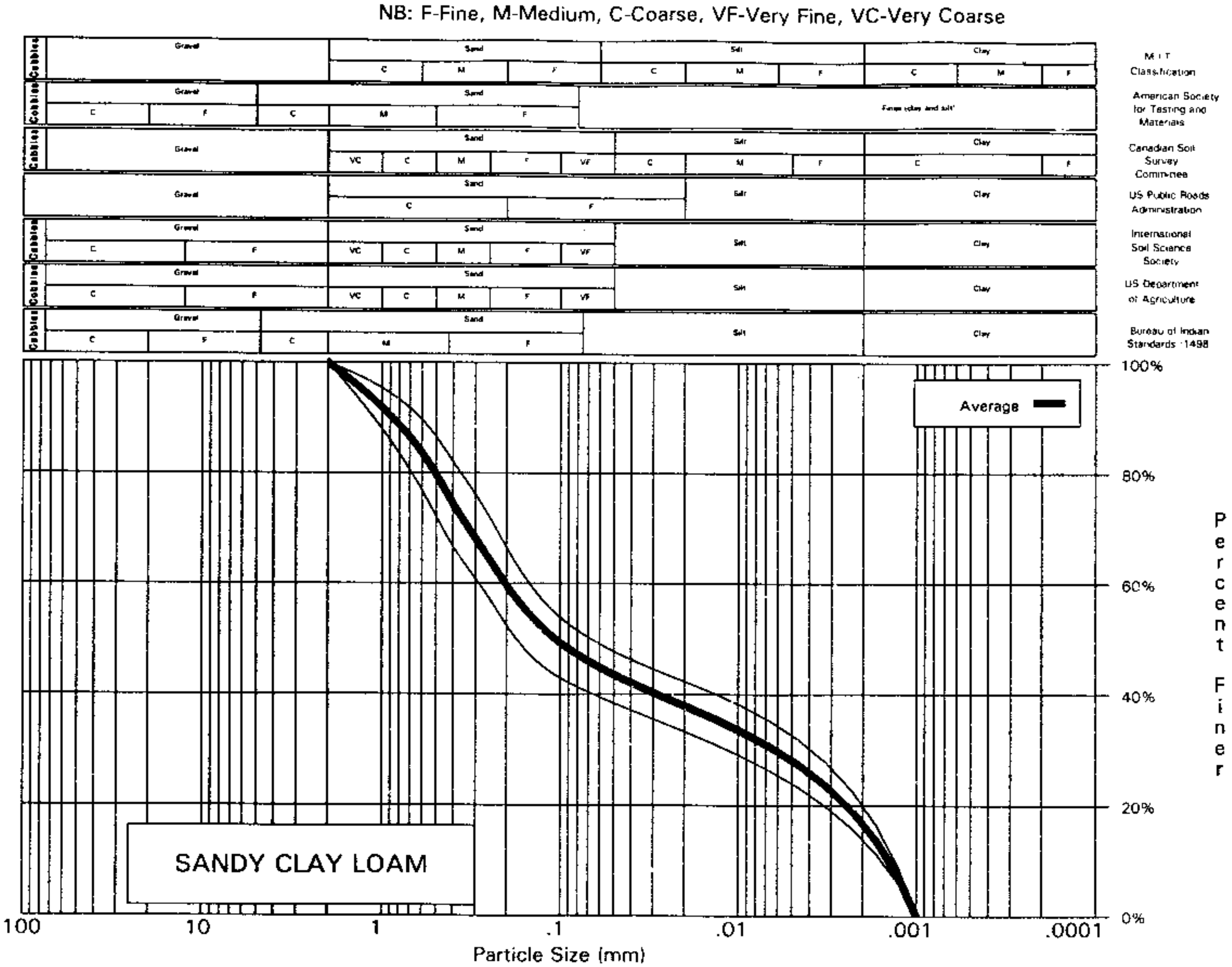


Fig. 5.2 (d): Grain Size Distribution Envelop for Sandy Clay Loam Soil at Dudhnai

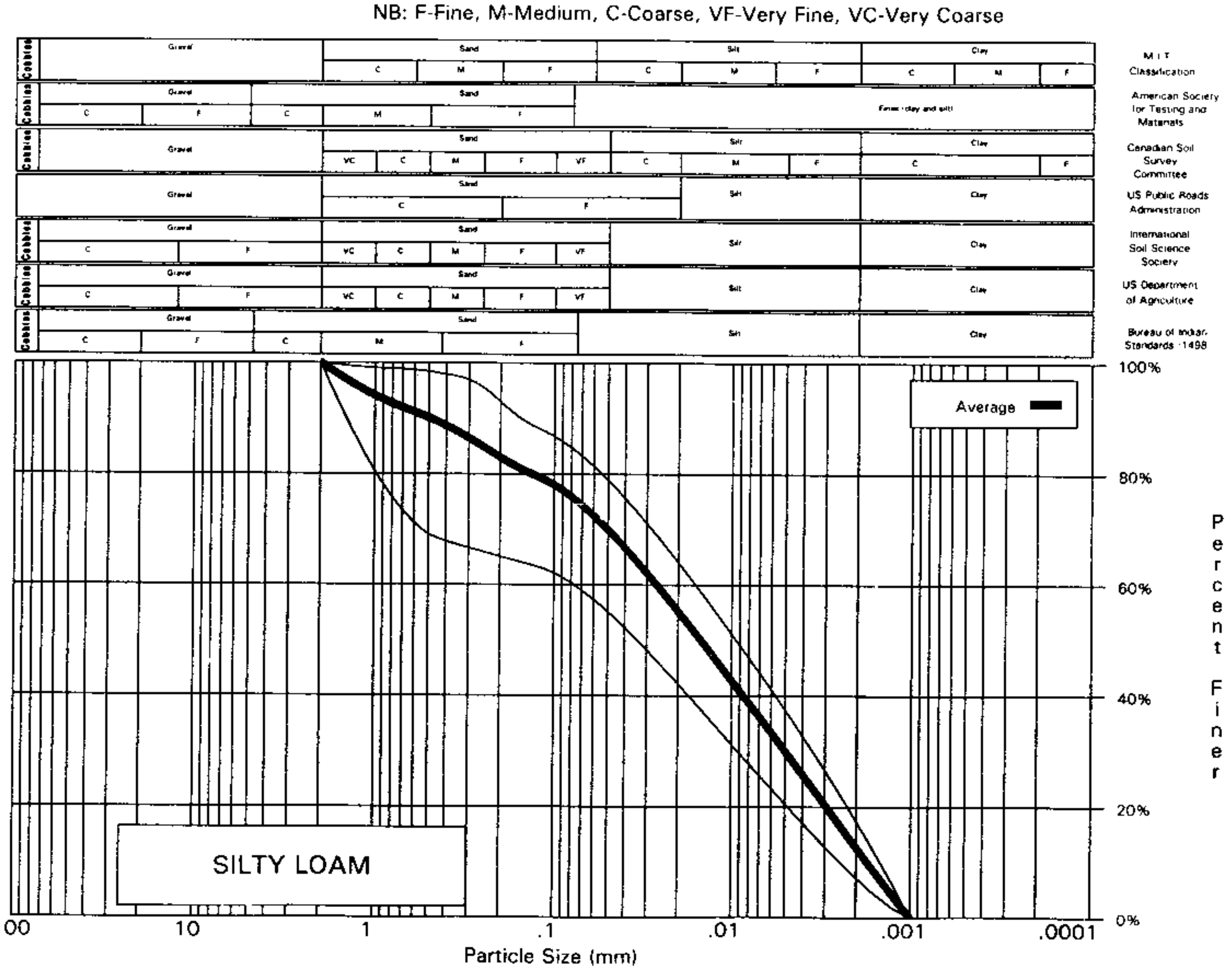
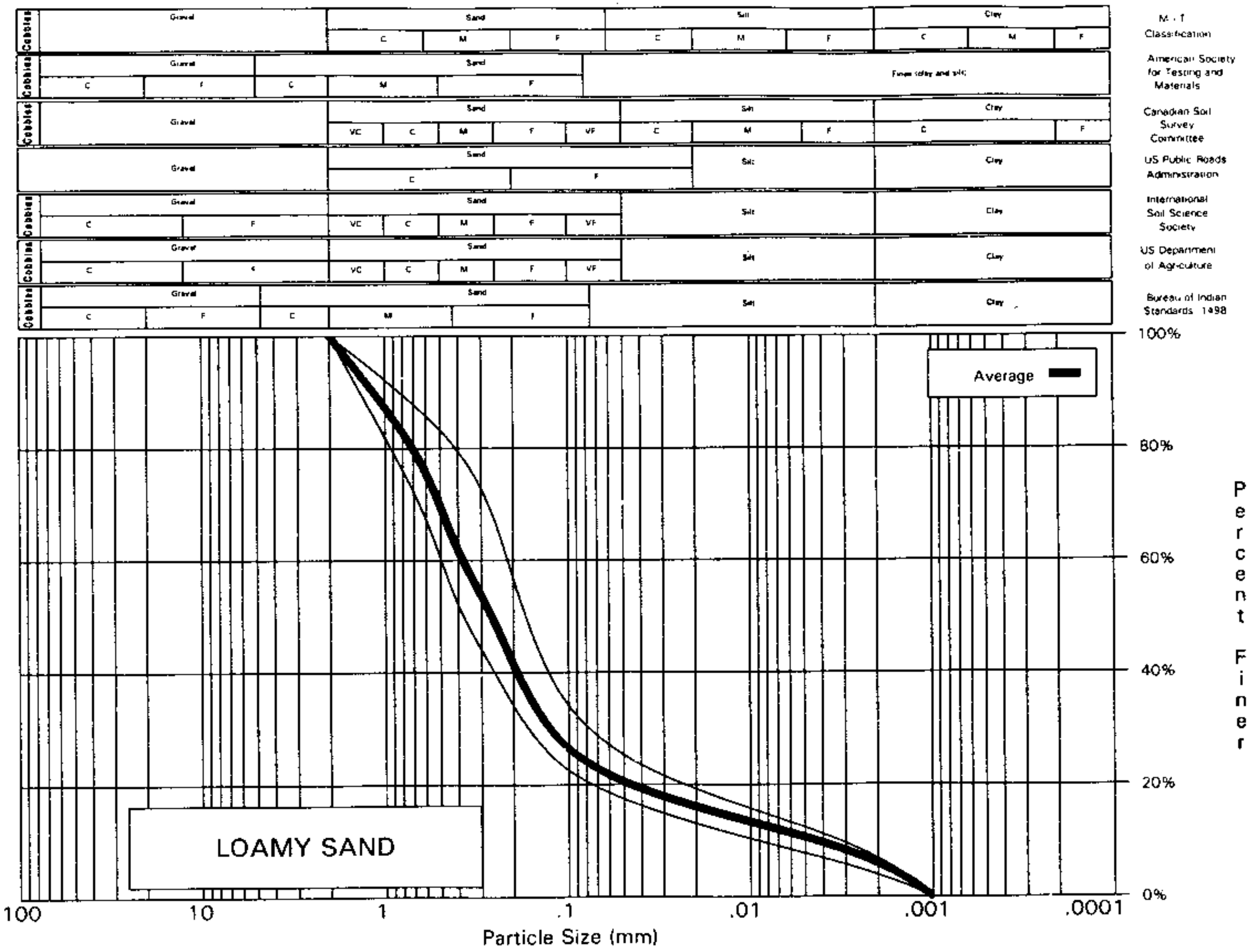


Fig. 5.2 (e): Grain Size Distribution Envelop for Silty Loam Soil at Dudhnai



NB: F-Fine, M-Medium, C-Coarse, VF-Very Fine, VC-Very Coarse

Fig. 5.2 (f): Grain Size Distribution Envelop for Loamy Sand Soil at Dudhnai

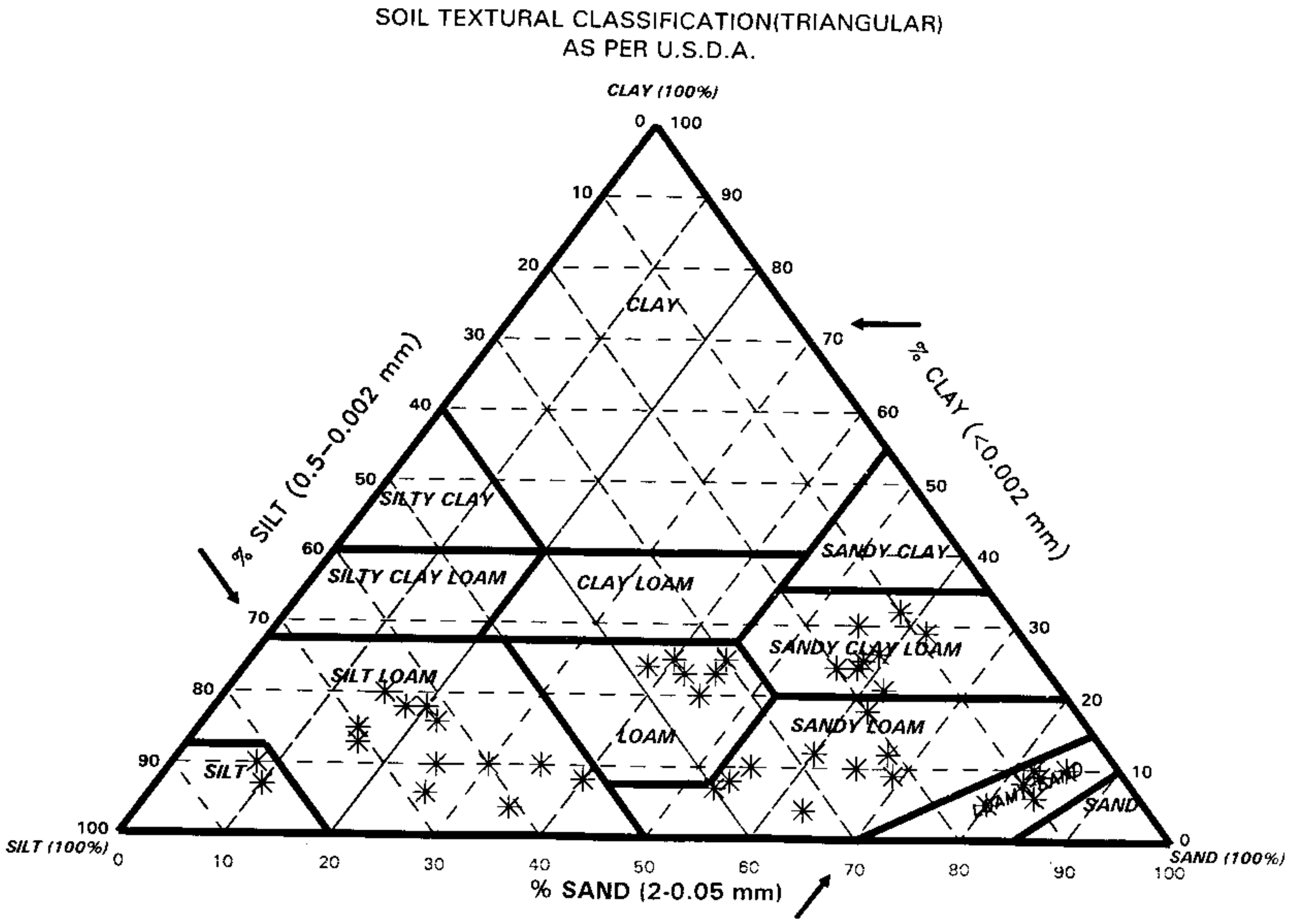


Fig. 5.3: USDA Textural Classification of Soils at Dudhnai

Table - 5.2 : Soil Classification Based on USDA Textural System of Soils of Dudhnai

S. No.	Testing Location	Test No.	Land Use	Soil Type Based on USDA System	Runoff Potential
1	Bangsiapal	B1	Banana garden (on urban land)	Sandy clay loam	Moderately High to High
2		B2	Banana garden (on urban land)	Sandy clay loam	Moderately High to High
3		B3	Banana garden (on urban land)	Sandy clay loam	Moderately High to High
4	Bangsiapal	B4	Banana + Betel Nut garden	Sandy clay loam	Moderately High to High
5		B5	Banana + Betel Nut garden	Sandy clay loam	Moderately High to High
6		B6	Banana + Betel Nut garden	Sandy clay loam	Moderately High to High
7	Bangsiapal	B7	Footway of grassy land	Silty loam	Moderately Low
8		B8	Footway of grassy land	Silty loam	Moderately Low
9		B9	Footway of grassy land	Silty loam	Moderately Low
10	Bangsiapal	B10	Grassy (100%) land	Silty loam	Moderately Low
11		B11	Grassy (100%) land	Silty loam	Moderately Low
12		B12	Grassy (100%) land	Silty loam	Moderately Low
13	Damra	D1	Betel Nut garden	Loamy sand	Low
14		D2	Betel Nut garden	Loamy sand	Low
15		D3	Betel Nut garden	Loamy sand	Low
16	Damra	D4	Rubber garden	Loamy sand	Low
17		D4	Rubber garden	Loamy sand	Low
18		D6	Rubber garden	Loamy sand	Low
19	Dainadubi	DB1	Rose garden	Silt	Moderately High
20		DB2	Rose garden	Silt	Moderately High
21	Dainadubi	DB3	Grassy with humus	Loam	Moderately Low
22		DB4	Grassy with humus	Loam	Moderately Low
23		DB5	Grassy with humus	Loam	Moderately Low
24	Dainadubi	DB6	Grassy (80%) land	Loam	Moderately Low
25		DB7	Grassy (80%) land	Loam	Moderately Low
26		DB8	Grassy (80%) land	Loam	Moderately Low
27	Dainadubi	DB9	Barren land	Silty loam	Low
28		DB10	Barren land	Silty loam	Low
29		DB11	Barren land	Silty loam	Low
30	Sarangma	S1	Agri.(harvested paddy field)	Silty loam	Low
31		S2	Agri.(harvested paddy field)	Silty loam	Low
32		S3	Agri.(harvested paddy field)	Silty loam	Low
33	Sarangma	S4	Deforested land with stumps	Sandy loam	Low to Moderately Low
34		S5	Deforested land with stumps	Sandy loam	Low to Moderately Low
35		S6	Deforested land with stumps	Sandy loam	Low to Moderately Low
36	Sarangma	S7	Teak forest	Sandy loam	Low to Moderately Low
37		S8	Teak forest	Sandy loam	Low to Moderately Low
38		S9	Teak forest	Sandy loam	Low to Moderately Low
39	Sarangma	S10	Banana garden on deforested land	Sandy loam	Low to Moderately Low
40		S11	Banana garden on deforested land	Sandy loam	Low to Moderately Low
41		S12	Banana garden on deforested land	Sandy loam	Low to Moderately Low
42	Sarangma	S13	Shrub land	Sandy clay loam	High
43		S14	Shrub land	Sandy clay loam	High
44		S15	Shrub land	Sandy clay loam	High

Table - 5.3 : Soil Classification Based on Soil Structure of Soils of Dudhnai

S. No.	Testing Location	Test No.	Soil Structure	Runoff Potential
1	Bangsiapal	B1	Sub angular blocky, columnar prismatic	Moderately Low-Modeerately High
2		B2	Sub angular blocky, columnar prismatic	Moderately Low-Modeerately High
3		B3	Sub angular blocky, columnar prismatic	Moderately Low-Modeerately High
4	Bangsiapal	B4	Sub angular blocky, columnar prismatic	Moderately Low-Modeerately High
5		B5	Sub angular blocky, columnar prismatic	Moderately Low-Modeerately High
6		B6	Sub angular blocky, columnar prismatic	Moderately Low-Modeerately High
7	Bangsiapal	B7	Granular crumb, sub angular blocky	Moderately High
8		B8	Granular crumb, sub angular blocky	Moderately High
9		B9	Granular crumb, sub angular blocky	Moderately High
10	Bangsiapal	B10	Granular crumb, sub angular blocky	Moderately High
11		B11	Granular crumb, sub angular blocky	Moderately High
12		B12	Granular crumb, sub angular blocky	Moderately High
13	Damra	D1	Strong platy, Compact massive	High
14		D2	Strong platy, Compact massive	High
15		D3	Strong platy, Compact massive	High
16	Damra	D4	Strong platy, Compact massive	High
17		D4	Strong platy, Compact massive	High
18		D6	Strong platy, Compact massive	High
19	Dainadubi	DB1	Strong platy, Compact massive	High
20		DB2	Strong platy, Compact massive	High
21	Dainadubi	DB3	Strong platy, Compact massive	High
22		DB4	Strong platy, Compact massive	High
23		DB5	Strong platy, Compact massive	High
24	Dainadubi	DB6	Strong platy, Compact massive	High
25		DB7	Strong platy, Compact massive	High
26		DB8	Strong platy, Compact massive	High
27	Dainadubi	DB9	Strong platy, Compact massive	High
28		DB10	Strong platy, Compact massive	High
29		DB11	Strong platy, Compact massive	High
30	Sarangma	S1	Simple grained granular crumb	High
31		S2	Simple grained granular crumb	High
32		S3	Simple grained granular crumb	High
33	Sarangma	S4	Strong angular, blocky prismatic	Moderately High to High
34		S5	Strong angular, blocky prismatic	Moderately High to High
35		S6	Strong angular, blocky prismatic	Moderately High to High
36	Sarangma	S7	Single grained	Low
37		S8	Single grained	Low
38		S9	Single grained	Low
39	Sarangma	S10	Strong angular, blocky prismatic	Moderately High to High
40		S11	Strong angular, blocky prismatic	Moderately High to High
41		S12	Strong angular, blocky prismatic	Moderately High to High
42	Sarangma	S13	Strong angular, blocky prismatic	Moderately High to High
43		S14	Strong angular, blocky prismatic	Moderately High to High
44		S15	Strong angular, blocky prismatic	Moderately High to High

illustrated for all represented sites in the Table-5.4 and graphs of test results are shown in Fig.5.4(a) to 5.4(d).

5.6 Classification Based on Consistency of Soil :

Soil consistency describes how well a soil sticks together or resists fragmentation. It is of value to predict cultivation problems and adaptation to engineering qualifications, such as the ability to bear building weight. Consistency results of soil samples i.e. liquid and plastic limits, plasticity index, consistency index and liquidity index are presented in Table-5.5. Soil can be classified according to following criteria :

If Plasticity Index > Plasticity Index of 'A' line in Fig. 2.4, the soil is clay
If Plasticity Index < Plasticity Index of 'A' line in Fig. 2.4, the soil is silt
If Liquid Limit = 0-35, soil is low compressible
If Liquid Limit = 35-50, soil is medium compressible
If Liquid Limit >50, soil is high compressible

The value of liquid and plastic limit are directly used for classifying the fine grained cohesive soils according to Indian Standard on soil classification. Ones the soil is classified, it helps a lot in understanding the behavior of soils and selecting the suitable methods of design, construction and maintenance of the structures made up or/and resting on soils.

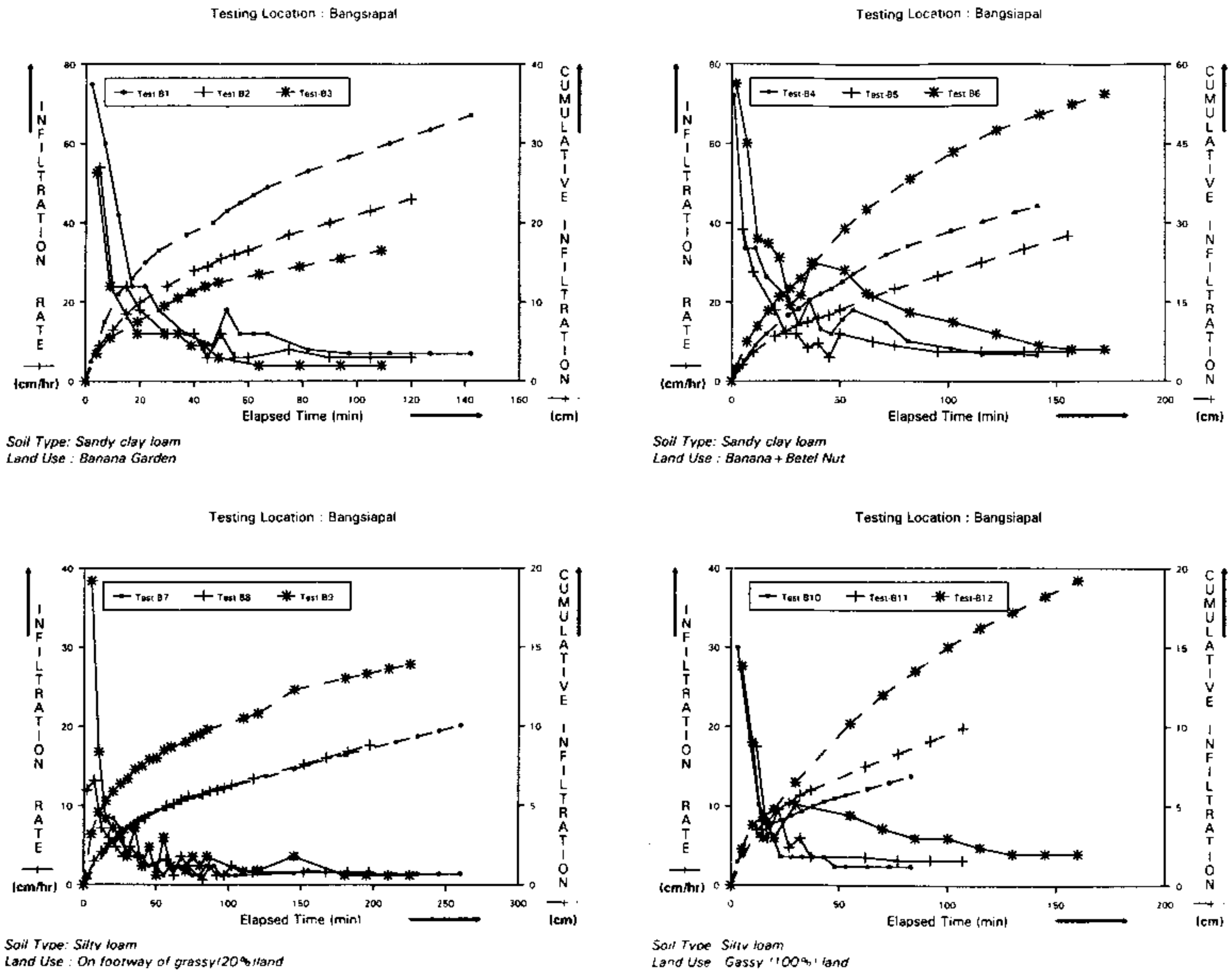
The values of these limits are also used in calculating the flow index, toughness index, and relative plasticity index which are useful in giving an idea about the plasticity, cohesiveness, compressibility, shear strength, permeability, consistency and state of cohesive soils. Atterberg (1911) shows the following correlation between the plasticity index, soil type, degree of plasticity and degree of cohesiveness.

Plasticity Index	Soil Type	Degree of Plasticity	Degree of Cohesiveness
0	Sand	Non-plastic	Non cohesive
<7	Silt	Low-plastic	Partly cohesive
7-17	Silt clay	Medium plastic	Cohesive
>17	Clay	High plastic	Cohesive

The suggested state of consistency in terms of consistency index are also given below :

Table - 5.4 : Soil Classification Based on Infiltration of Soils of Dudhnai

S. No.	Testing Location	Test No.	Land Use	Soil Type	Steady infiltration rate (cm/hr)	Time taken (min)	Cumulative infiltration (cm)	Runoff Potential
1	Bangsiapal	B1	Banana garden (on urban land)	Sandy clay loam	7.00	97	28.25	Low to Moderately Low
2		B2	Banana garden (on urban land)	Sandy clay loam	6.00	90	20.00	Low to Moderately Low
3		B3	Banana garden (on urban land)	Sandy clay loam	4.00	64	13.50	Moderately Low-Moderately High
4	Bangsiapal	B4	Banana + Betel Nut garden	Sandy clay loam	6.60	141	33.10	Low to Moderately Low
5		B5	Banana + Betel Nut garden	Sandy clay loam	7.50	95	20.00	Low to Moderately Low
6		B6	Banana + Betel Nut garden	Sandy clay loam	8.00	172	54.40	Low
7	Bangsiapal	B7	Footway of grassy land	Silty loam	1.40	230	9.35	High
8		B8	Footway of grassy land	Silty loam	1.60	167	8.00	Moderately High to High
9		B9	Footway of grassy land	Silty loam	1.20	180	13.00	High
10	Bangsiapal	B10	Grassy (100%) land	Silty loam	2.40	53	5.70	Moderately High to High
11		B11	Grassy (100%) land	Silty loam	3.20	92	9.10	Moderately Low-Moderately High
12		B12	Grassy (100%) land	Silty loam	4.00	130	17.20	Moderately Low-Moderately High
13	Damra	D1	Betel Nut garden	Loamy sand	4.20	47	4.90	Moderately Low-Moderately High
14		D2	Betel Nut garden	Loamy sand	6.00	65	7.00	Low to Moderately Low
15		D3	Betel Nut garden	Loamy sand	5.40	72	6.30	Low to Moderately Low
16	Damra	D4	Rubber garden	Loamy sand	6.00	71	11.70	Low to Moderately Low
17		D4	Rubber garden	Loamy sand	6.00	61	11.00	Low to Moderately Low
18		D6	Rubber garden	Loamy sand	6.00	35	7.50	Low to Moderately Low
19	Dainadubi	DB1	Rose garden	Silt	1.20	51	2.10	High
20		DB2	Rose garden	Silt	1.10	60	4.98	High
21	Dainadubi	DB3	Grassy with humus	Loam	3.20	130	18.60	Moderately Low-Moderately High
22		DB4	Grassy with humus	Loam	1.80	108	16.10	Moderately High to High
23		DB5	Grassy with humus	Loam	2.40	80	6.20	Moderately High to High
24	Dainadubi	DB6	Grassy (80%) land	Loam	2.40	110	7.80	Moderately High to High
25		DB7	Grassy (80%) land	Loam	2.00	96	4.50	Moderately High to High
26		DB8	Grassy (80%) land	Loam	1.80	93	5.70	Moderately High to High
27	Dainadubi	DB9	Barren land	Silty loam	0.60	70	5.30	High
28		DB10	Barren land	Silty loam	0.40	97	1.30	High
29		DB11	Barren land	Silty loam	0.60	130	6.70	High
30	Sarangma	S1	Agri.(harvested paddy field)	Silty loam	0.40	80	2.40	High
31		S2	Agri.(harvested paddy field)	Silty loam	0.60	65	5.30	High
32		S3	Agri.(harvested paddy field)	Silty loam	0.80	102	1.80	High
33	Sarangma	S4	Deforested land with stumps	Sandy loam	1.20	107	8.30	High
34		S5	Deforested land with stumps	Sandy loam	1.60	102	27.40	Moderately High to High
35		S6	Deforested land with stumps	Sandy loam	2.40	42	2.60	Moderately High to High
36	Sarangma	S7	Teak forest	Sandy loam	10.00	84	22.50	Low
37		S8	Teak forest	Sandy loam	8.00	138	65.50	Low
38		S9	Teak forest	Sandy loam	6.00	51	12.50	Low to Moderately Low
39	Sarangma	S10	Banana garden on deforested land	Sandy loam	6.00	45	8.50	Low to Moderately Low
40		S11	Banana garden on deforested land	Sandy loam	1.20	97	4.00	High
41		S12	Banana garden on deforested land	Sandy loam	4.80	68	22.60	Moderately Low-Moderately High
42	Sarangma	S13	Shrub land	Sandy clay loam	1.60	105	9.20	Moderately High to High
43		S14	Shrub land	Sandy clay loam	1.20	60	2.80	High
44		S15	Shrub land	Sandy clay loam	1.20	115	8.40	High



Testing Location : Bangsiapal

Soil Type: Sandy clay loam
Land Use : Banana Garden

Testing Location : Bangsiapal

Soil Type: Sandy clay loam
Land Use : Banana + Betel Nut

Testing Location : Bangsiapal

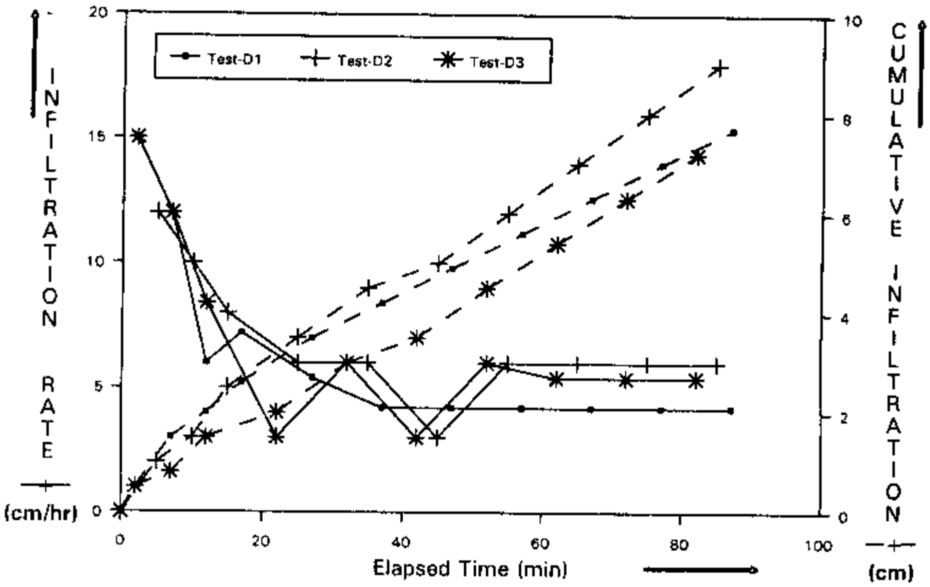
Soil Type: Silty loam
Land Use : On footway of grassy(20%)land

Testing Location : Bangsiapal

Soil Type Silty loam
Land Use Gassy (100%) land

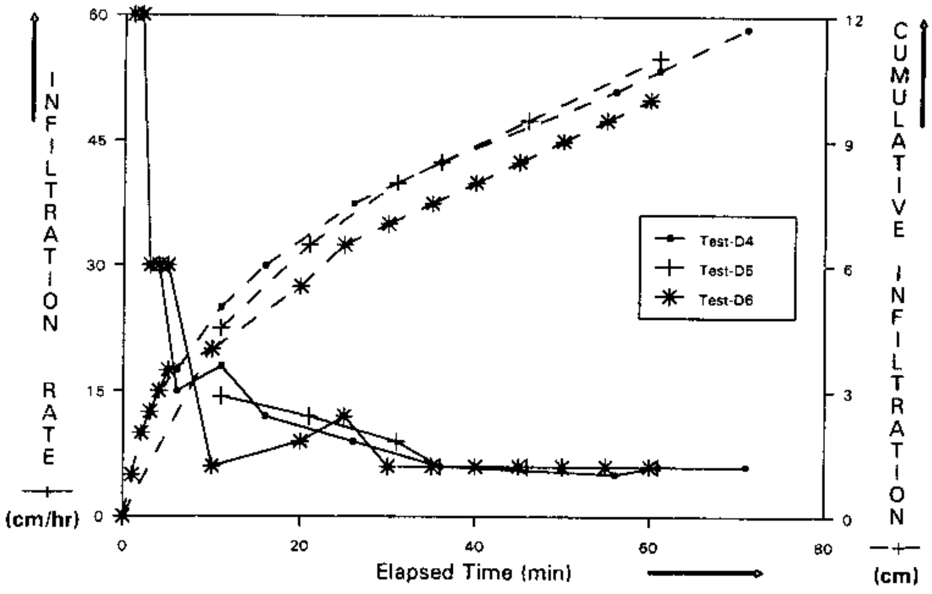
Fig. 5.4 (a): Infiltration Curves at Bangsiapal (Site B1 to B12)

Testing Location : Damra



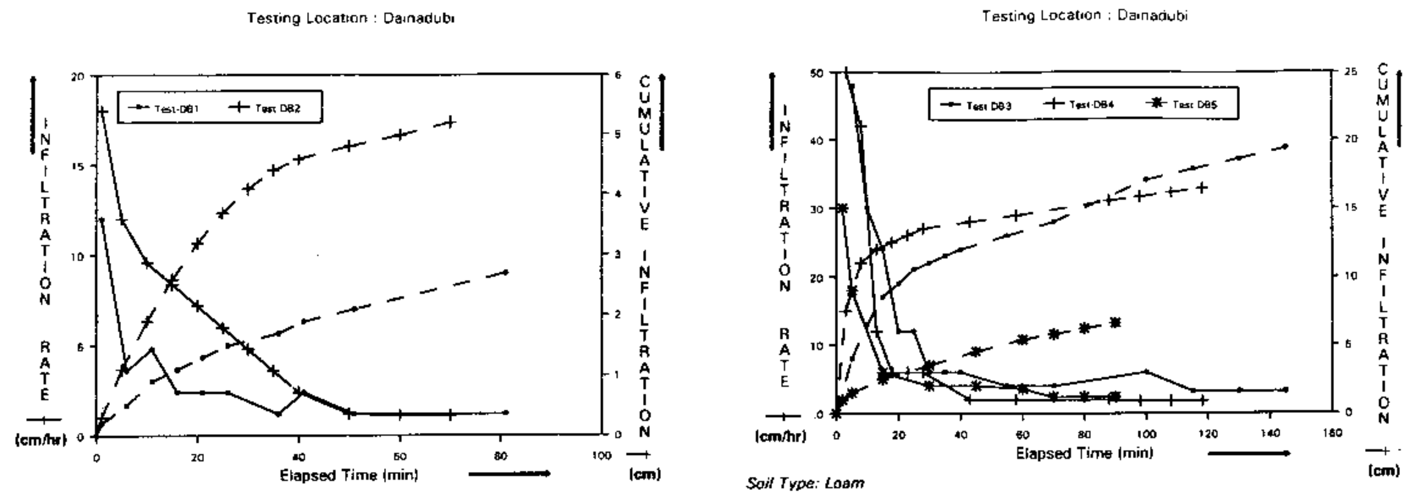
Soil Type: Loamy sand
Land Use : Betel Nut Garden (matured)

Testing Location : Damra



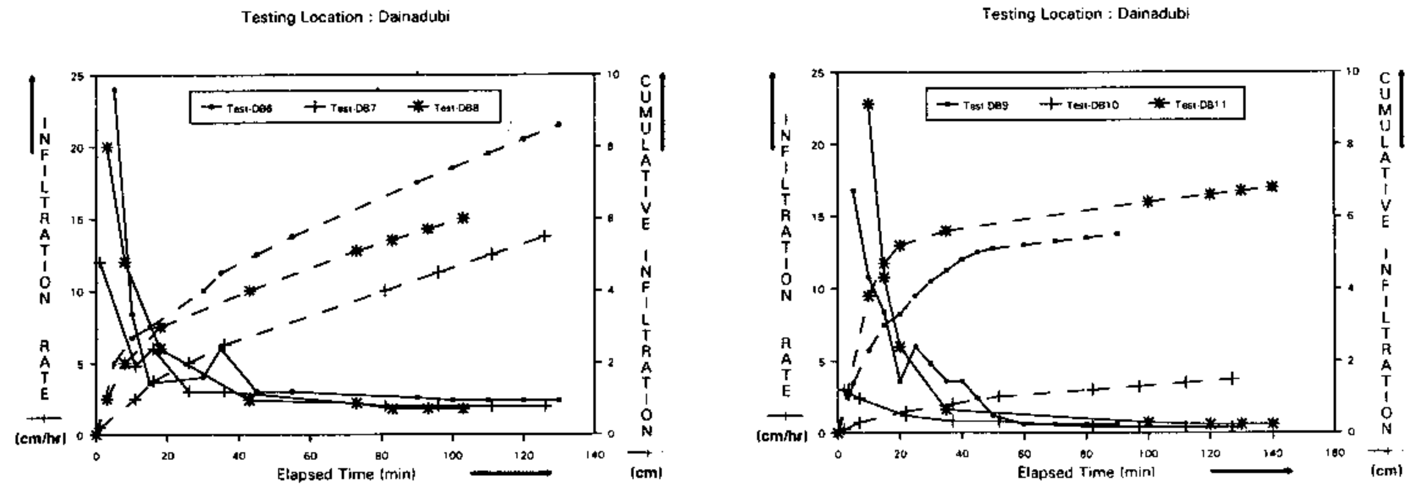
Soil Type: Loamy sand
Land Use : Rubber Garden (matured)

Fig. 5.4 (b): Infiltration Curves at Damra (Site D1 to D6)



Soil Type: Silt
Land Use : Rose Garden

Soil Type: Loam
Land Use : Grassy with Humus surrounding
Saal Forest

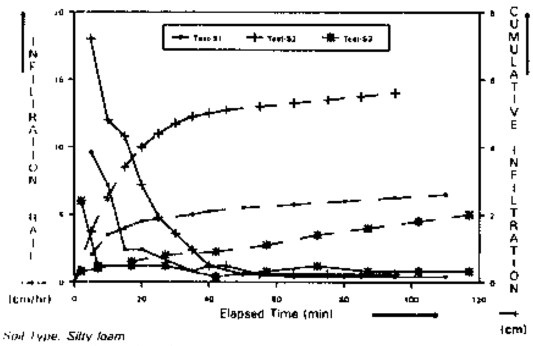


Soil Type: Loam
Land Use · Grassy (80%) Land

Soil Type: Silty loam
Land Use · Barren Land

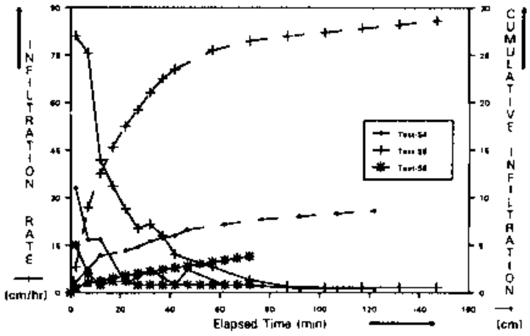
Fig. 5.4 (c): Infiltration Curves at Dainadubi (Site DB1 to DB12)

Testing Location : Sarangma



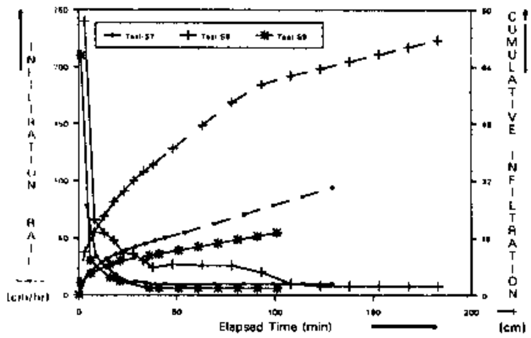
Soil Type: Silty loam
Land Use : Agricultural Land
(harvested paddy field)

Testing Location : Sarangma



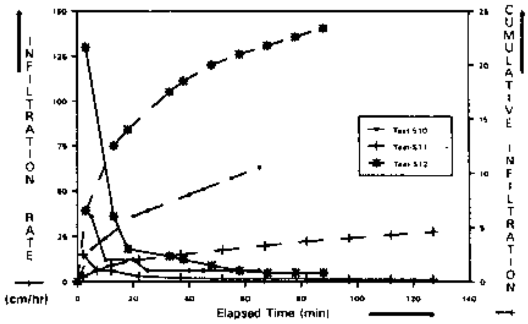
Soil Type: Sandy loam
Land Use : Deforested land with stumps

Testing Location : Sarangma



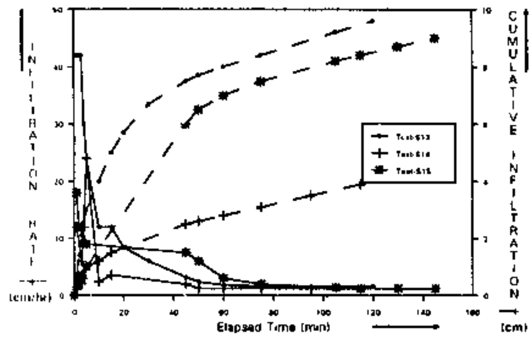
Soil Type: Sandy loam
Land Use : Teak Forest

Testing Location : Sarangma



Soil Type: Sandy clay loam
Land Use : Banana Garden
on deforested land

Testing Location : Sarangma



Soil Type: Sandy loam
Land Use : Shrub Land (green bushes)

Fig. 5.4 (d): Infiltration Curves at Sarangma (Site S1 to S15)

Table - 5.5 : Soil Classification Based on Consistency of Soils of Dudhnai

S. No.	Location	Test No.	Liquid Limit %	Compressibility	Plastic Limit %	Plasticity Index(PI)	Atterberg's Classification			Consistency		Liquidity Index(LI)	PI of 'A' line(IS: 1498-1970)	Dominant Particle
							Soil Type	Degree of Plasticity	Degree of Cohesiveness	Index(CI)	State			
1	Bangsiapal	B1	31.50	Low	11.30	20.20	Clay	High Plastic	Cohesive	0.59	Firm	0.41	8.40	Clay
2		B2	32.23	Low	14.54	17.69	Clay	High Plastic	Cohesive	0.93	Stiff	0.07	8.93	Clay
3		B3	22.10	Low	7.50	14.60	Silt Clay	Medium Plastic	Cohesive	0.29	Soft	0.71	1.53	Clay
4	Bangsiapal	B4	25.15	Low	6.00	19.15	Clay	High Plastic	Cohesive	0.62	Firm	0.38	3.76	Clay
5		B5	29.78	Low	12.56	17.22	Clay	High Plastic	Cohesive	0.50	Firm	0.50	7.14	Clay
6		B6	30.60	Low	12.10	18.50	Clay	High Plastic	Cohesive	0.71	Firm	0.29	7.74	Clay
7	Bangsiapal	B7	19.00	Low	9.65	9.35	Silt Clay	Medium Plastic	Cohesive	0.85	Stiff	0.15	-Ve	Silt
8		B8	19.15	Low	11.23	7.92	Silt Clay	Medium Plastic	Cohesive	0.79	Stiff	0.21	-Ve	Silt
9		B9	18.23	Low	9.34	8.89	Silt Clay	Medium Plastic	Cohesive	0.88	Stiff	0.12	-Ve	Silt
10	Bangsiapal	B10	19.85	Low	8.60	11.25	Silt Clay	Medium Plastic	Cohesive	0.02	Very Soft	0.98	-Ve	Silt
11		B11	19.00	Low	9.20	9.80	Silt Clay	Medium Plastic	Cohesive	0.08	Very Soft	0.92	-Ve	Silt
12		B12	18.56	Low	12.23	6.33	Silt	Low Plastic	Partly Cohesive	0.60	Firm	0.40	-Ve	Silt
13	Damra	D1	22.15	Low	13.50	8.65	Silt Clay	Medium Plastic	Cohesive	0.46	Soft	0.54	1.57	Clay
14		D2	21.00	Low	12.30	8.70	Silt Clay	Medium Plastic	Cohesive	0.53	Firm	0.47	0.73	Clay
15		D3	22.20	Low	12.60	9.60	Silt Clay	Medium Plastic	Cohesive	0.69	Firm	0.31	1.61	Clay
16	Damra	D4	21.21	Low	12.80	8.41	Silt Clay	Medium Plastic	Cohesive	0.75	Stiff	0.25	0.88	Clay
17		D5	23.12	Low	13.20	9.92	Silt Clay	Medium Plastic	Cohesive	0.41	Soft	0.59	2.28	Clay
18		D6	19.46	Low	10.78	8.68	Silt Clay	Medium Plastic	Cohesive	0.01	Very Soft	0.99	-Ve	Silt
19	Dainadubi	DB1	19.00	Low	12.80	6.20	Silt	Low Plastic	Partly Cohesive	0.98	Stiff	0.02	-Ve	Silt
20		DB2	18.12	Low	11.50	6.62	Silt	Low Plastic	Partly Cohesive	0.92	Stiff	0.08	-Ve	Silt
21	Dainadubi	DB3	31.58	Low	14.56	17.02	Clay	High Plastic	Cohesive	0.70	Firm	0.30	8.45	Clay
22		DB4	29.23	Low	10.23	19.00	Clay	High Plastic	Cohesive	0.86	Stiff	0.14	6.74	Clay
23		DB5	24.13	Low	15.56	8.57	Silt Clay	Medium Plastic	Cohesive	0.36	Soft	0.64	3.01	Clay
24	Dainadubi	DB6	30.14	Low	12.23	17.91	Clay	High Plastic	Cohesive	0.58	Firm	0.42	7.40	Clay
25		DB7	25.30	Low	14.54	10.76	Silt Clay	Medium Plastic	Cohesive	0.96	Stiff	0.04	3.87	Clay
26		DB8	27.23	Low	9.56	17.67	Clay	High Plastic	Cohesive	0.86	Stiff	0.14	5.28	Clay
27	Dainadubi	DB9	19.50	Low	5.65	13.85	Silt Clay	Medium Plastic	Cohesive	0.10	Very Soft	0.90	-Ve	Silt
28		DB10	19.98	Low	5.12	14.86	Silt Clay	Medium Plastic	Cohesive	0.04	Very Soft	0.96	-Ve	Silt
29		DB11	19.00	Low	8.54	10.46	Silt Clay	Medium Plastic	Cohesive	0.04	Very Soft	0.96	-Ve	Silt
30	Sarangma	S1	19.56	Low	11.32	8.24	Silt Clay	High Plastic	Cohesive	0.57	Firm	0.43	-Ve	Silt
31		S2	18.57	Low	15.46	3.11	Silt	Low Plastic	Partly Cohesive	0.23	Very Soft	0.77	-Ve	Silt
32		S3	17.53	Low	12.23	5.30	Silt	Low Plastic	Partly Cohesive	0.24	Very Soft	0.76	-Ve	Silt
33	Sarangma	S4	24.60	Low	11.89	12.71	Silt Clay	Medium Plastic	Cohesive	0.48	Soft	0.52	3.36	Clay
34		S5	24.32	Low	15.50	8.82	Silt Clay	Medium Plastic	Cohesive	0.36	Soft	0.64	3.15	Clay
35		S6	21.89	Low	13.45	8.44	Silt Clay	Medium Plastic	Cohesive	0.60	Firm	0.40	1.38	Clay
36	Sarangma	S7	21.46	Low	10.69	10.77	Silt Clay	Medium Plastic	Cohesive	0.90	Stiff	0.10	1.07	Clay
37		S8	21.22	Low	12.54	8.68	Silt Clay	Medium Plastic	Cohesive	0.77	Stiff	0.23	0.89	Clay
38		S9	21.44	Low	12.68	8.76	Silt Clay	Medium Plastic	Cohesive	0.83	Stiff	0.17	1.05	Clay
39	Sarangma	S10	30.15	Low	22.56	7.59	Silt Clay	Medium Plastic	Cohesive	0.10	Very Soft	0.90	7.41	Clay
40		S11	21.54	Low	13.69	7.85	Silt Clay	Medium Plastic	Cohesive	0.81	Stiff	0.19	1.12	Clay
41		S12	26.98	Low	17.56	9.42	Silt Clay	Medium Plastic	Cohesive	0.07	Very Soft	0.93	5.10	Clay
42	Sarangma	S13	30.78	Low	12.23	18.55	Clay	High Plastic	Cohesive	0.57	Firm	0.43	7.87	Clay
43		S14	32.63	Low	11.21	21.42	Clay	High Plastic	Cohesive	0.58	Firm	0.42	9.22	Clay
44		S15	33.56	Low	15.32	18.24	Clay	High Plastic	Cohesive	0.59	Firm	0.41	9.90	Clay

State of Consistency	Consistency Index (Ic)
Liquid or fluid	<0
Very soft, or fluid-plastic	<0.25-0
Soft, or soft-plastic	<0.50-0.25
Firm, or hard-plastic	<0.75-0.50
Stiff, or semi-hard	1-0.75
Hard	>1

Accordingly soil samples have been classified and presented in Table-5.5 alongwith consistency results.

5.7 Classification Based on Clay Content of Soil :

Amount and nature of clay colloids greatly influence the plasticity. An increase in the percentage of clay causes plastic limits to be higher with the moisture content and increases the plasticity number or index. With the decrease in clay content in the soil, the upper plastic limit decreases and thereby decreases the plasticity number or the index of plasticity. Atterberg limits are raised as the surface is increased due to higher amount of clay present in soil. The clay content therefore, determines the amount of surface that is available for water adsorption. For a particular clay mineral, the amount of absorbed water required at the plastic limit will increase with the amount and size of the particles present. The type of clay mineral has a tremendous influence upon the adsorption of water by the colloidal system. The plasticity of the montmorillonite group is high because of greater surface hydration, which results from more orientation of water and the interlattice swelling as the thickness of the water films increases. Clay content also reflects the runoff intensity of any soil strata. On the basis of clay content, runoff potential of soils were classified and presented in Table-5.6 as discussed in section 2.4.2 of Review section.

5.8 Classification Based on Activity of Clay :

Activity of clay may be estimated if clay fraction is known by the following formula :

Activity = Plasticity Index (%) / Clay Fraction (%)

Activity helps in classifying the soils as follows :

If activity	< 0.75,	soil is Inactive
If activity	0.75-1.25,	soil is Normal
If activity	>1.25,	soil is Active

Table - 5.6 : Soil Classification Based on Clay Content of Soils of Dudhnai

S. No.	Location	Test No.	Clay Content %	Runoff Potential
1	Bangsiapal	B1	24	Low to Moderate
2		B2	26	Moderately High to High
3		B3	21	Low to Moderate
4	Bangsiapal	B4	24	Low to Moderate
5		B5	25	Low to Moderate
6		B6	24	Low to Moderate
7	Bangsiapal	B7	18	Low to Moderate
8		B8	10	Low to Moderate
9		B9	16	Low to Moderate
10	Bangsiapal	B10	18	Low to Moderate
11		B11	15	Low to Moderate
12		B12	13	Low to Moderate
13	Damra	D1	5	Low
14		D2	10	Low to Moderate
15		D3	10	Low to Moderate
16	Damra	D4	6	Low
17		D5	9	Low to Moderate
18		D6	8	Low
19	Dainadubi	DB1	7	Low
20		DB2	10	Low to Moderate
21	Dainadubi	DB3	25	Low to Moderate
22		DB4	25	Low to Moderate
23		DB5	23	Low to Moderate
24	Dainadubi	DB6	20	Low to Moderate
25		DB7	23	Low to Moderate
26		DB8	24	Low to Moderate
27	Dainadubi	DB9	10	Low to Moderate
28		DB10	10	Low to Moderate
29		DB11	6	Low
30	Sarangma	S1	20	Low to Moderate
31		S2	8	Low
32		S3	4	Low
33	Sarangma	S4	18	Low to Moderate
34		S5	10	Low to Moderate
35		S6	9	Low to Moderate
36	Sarangma	S7	10	Low to Moderate
37		S8	8	Low to Moderate
38		S9	12	Low to Moderate
39	Sarangma	S10	7	Low
40		S11	4	Low
41		S12	12	Low to Moderate
42	Sarangma	S13	30	Moderately High to High
43		S14	32	Moderately High to High
44		S15	29	Moderately High to High

Accordingly activities of soil samples have been classified and results are presented in Table 5.7 alongwith plasticity index.

Expansivity or expansiveness represents the property of a soil to swell when its environment is changed in a certain way. Expansivity may be defined in terms of parameters such as swell pressure, swell potential and potential expansivity. Williams (1958), classified the soil into four degree of 'potential expansivity' PE, low, medium, high and very high (Fig. 5.5). Soil samples collected from the study area have also been classified according to Williams (1958) and presented in Fig.5.5 and Table-5.7. From the figure it is found that 'potential expansivity' of soil samples fall in low to medium zone.

5.9 Classification Based on IS : 1498-1970 :

Knowing the liquid limit and plasticity index, soil may be classified with the help of plasticity chart according to Indian Standard on soil classification (IS 1498-1970) , Fig. 5.6. In the plasticity chart following symbols are used :

CL = Clay of low compressibility
CI = Clay of medium compressibility
CH = Clay of high compressibility
ML = Silt of low compressibility
MI = Silt of medium compressibility
MH = Silt of high compressibility
OL = Organic soil of low compressibility
OI = Organic soil of medium compressibility
OH = Organic soil of high compressibility

In the present case, all soil samples of the study area captured CL group of classification as shown in Fig. 5.6.

5.10 Classification Based on Temperature of Soil :

Temperature classes are based on mean annual soil temperature and the difference between mean summer and mean winter temperatures. Mean annual soil temperature is determined by measurement mostly in the deep root zone. The soil temperature classes for temperate region soils are defined in terms of mean annual soil temperature as

Table - 5.7 : Soil Classification Based on Activity and Expansivity of Clay of Soils of Dudhnai

S. No.	Location	Test No.	Clay Content %	Plasti-City Index(PI)	Activity of Clay	Soil Classification	Williams' Potential Expansivity
1	Bangsiapal	B1	24	20.20	0.84	Normal	Medium
2		B2	26	17.69	0.68	Inactive	Medium
3		B3	21	14.60	0.70	Inactive	Medium
4	Bangsiapal	B4	24	19.15	0.80	Normal	Medium
5		B5	25	17.22	0.69	Inactive	Medium
6		B6	24	18.50	0.77	Normal	Medium
7	Bangsiapal	B7	18	9.35	0.52	Inactive	Low
8		B8	10	7.92	0.79	Normal	Low
9		B9	16	8.89	0.56	Inactive	Low
10	Bangsiapal	B10	18	11.25	0.63	Inactive	Low
11		B11	15	9.80	0.65	Inactive	Low
12		B12	13	6.33	0.49	Inactive	Low
13	Damra	D1	5	8.65	1.73	Active	Low
14		D2	10	8.70	0.87	Normal	Low
15		D3	10	9.60	0.96	Normal	Low
16	Damra	D4	6	8.41	1.40	Active	Low
17		D5	9	9.92	1.10	Normal	Low
18		D6	8	8.68	1.09	Normal	Low
19	Dainadubi	DB1	7	6.20	0.89	Normal	Low
20		DB2	10	6.62	0.66	Inactive	Low
21	Dainadubi	DB3	25	17.02	0.68	Inactive	Medium
22		DB4	25	19.00	0.76	Normal	Medium
23		DB5	23	8.57	0.37	Inactive	Low
24	Dainadubi	DB6	20	17.91	0.90	Normal	Medium
25		DB7	23	10.76	0.47	Inactive	Low
26		DB8	24	17.67	0.74	Inactive	Medium
27	Dainadubi	DB9	10	13.85	1.39	Active	Low
28		DB10	10	14.86	1.49	Active	Low
29		DB11	6	10.46	1.74	Active	Low
30	Sarangma	S1	20	8.24	0.41	Inactive	Low
31		S2	8	3.11	0.39	Inactive	Low
32		S3	4	5.30	1.33	Active	Low
33	Sarangma	S4	18	12.71	0.71	Inactive	Low
34		S5	10	8.82	0.88	Normal	Low
35		S6	9	8.44	0.94	Normal	Low
36	Sarangma	S7	10	10.77	1.08	Normal	Low
37		S8	8	8.68	1.09	Normal	Low
38		S9	12	8.76	0.73	Inactive	Low
39	Sarangma	S10	7	7.59	1.08	Normal	Low
40		S11	4	7.85	1.96	Active	Low
41		S12	12	9.42	0.79	Normal	Low
42	Sarangma	S13	30	18.55	0.62	Inactive	Medium
43		S14	32	21.42	0.67	Inactive	Medium
44		S15	29	18.24	0.63	Inactive	Medium

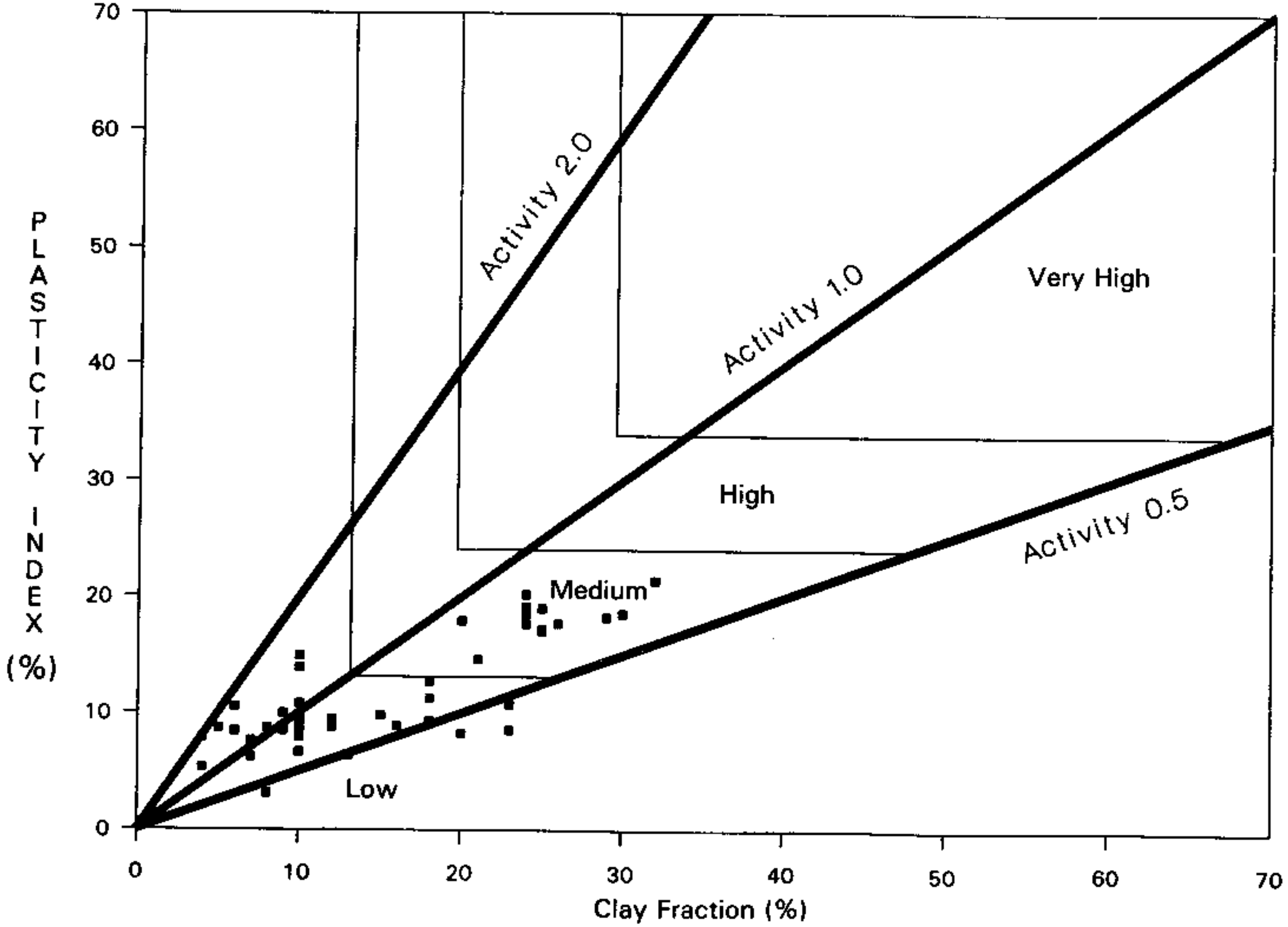


Fig. 5.5: Williams Classification for Potential Expansivity of Soils at Dudhani

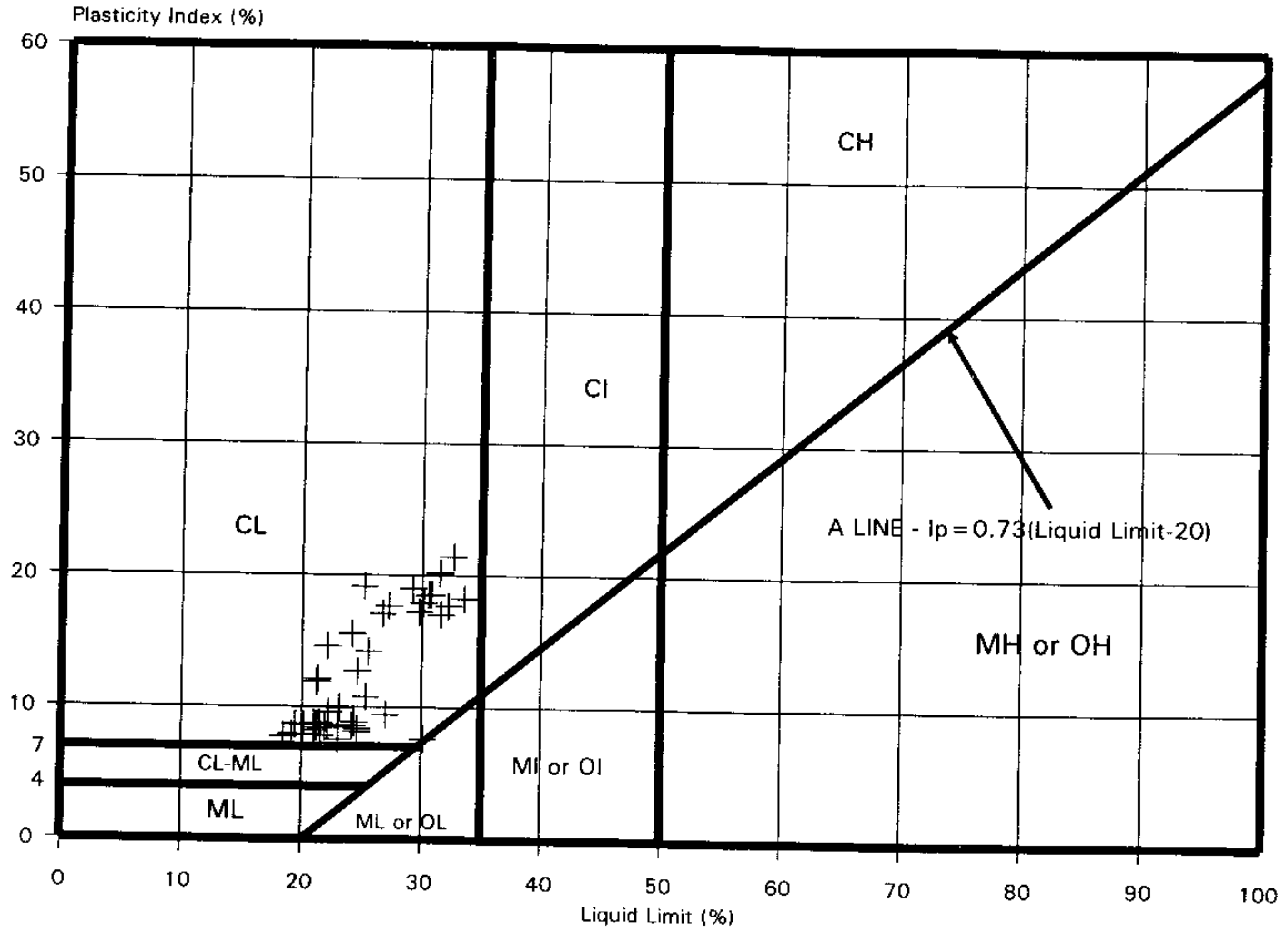


Fig. 5.6: BIS Classification (IS:1498-1970) of Soil at Dudhnai

Pergelle	< 0°C(32°F); permafrost present (unless dry)
Cryic	0-8°C(32-47°F); summer soil temperature below about 15°C
Frigid	0-8°C(32-47°F); summer soil temperature above about 15°C
Mesic	8-15°C(47-59°F)
Thermic	15-22°C(59-72°F)
Hyperthermic	>22°C(72°F)

As per the above classification system, soils of the study area fall under 'Thermic' and 'Hyperthermic' range of the temperature classification system and presented in Table-5.8.

5.11 pH of Soils :

The soil pH is easily determined and provides various clues about other soil properties. The soil pH greatly affects the solubility of minerals. Most minerals are more soluble in acid soils than in neutral or slightly basic solutions. The soil pH can also influence plant growth by the pH effect on activity of beneficial microorganisms. The greatest general influence of pH on plant growth is its effect on the availability of nutrients. Besides nutritional aspects, some soil borne diseases are influenced by pH of soil. The pH requirements of some disease organisms can be used by soil management practices as a means to control diseases. Potato scab, root of tobacco etc. are favored by neutral to alkaline soil conditions and these diseases can be controlled by lowering the soil pH (acidic soil reaction).

Different plants have specific soil pH requirements (as shown in Table-5.9) give rise to the need to alter soil pH for successful growth of many plants. There are two approaches to assure that plants will grow without serious inhibition from unfavorable soil pH : (1) plants can be selected that will grow well with the existing soil pH, or (2) the pH of the soil can be altered to suit the preference of the plants.

To see the importance of soil pH, a field investigation was conducted in Dudhnai sub-basin and pH of soils were determined under different representative land use conditions. Variation in pH of soils were found from 3.3 to 8.9 and findings are presented in Table-5.10. Results can be utilized in different fields of watershed management activities like soil water conservation, on-farm water management, land development, nutrient management, soil improvement, irrigation management, plant growth etc.

Table - 5.8 : Soil Classification Based on Mean Annual Temperature of Soils of Dudhnai

S. No.	Location	Test No.	Mean Annual Temperature of Soil (degree C)	Temperature Class
1	Bangsiapal	B1	22.2	Hyperthermic
2		B2	22.1	Hyperthermic
3		B3	22.6	Hyperthermic
4	Bangsiapal	B4	22.5	Hyperthermic
5		B5	22.8	Hyperthermic
6		B6	22.0	Hyperthermic
7	Bangsiapal	B7	23.5	Hyperthermic
8		B8	23.4	Hyperthermic
9		B9	23.2	Hyperthermic
10	Bangsiapal	B10	23.5	Hyperthermic
11		B11	23.9	Hyperthermic
12		B12	24.0	Hyperthermic
13	Damra	D1	25.1	Hyperthermic
14		D2	25.4	Hyperthermic
15		D3	25.2	Hyperthermic
16	Damra	D4	25.6	Hyperthermic
17		D5	26.0	Hyperthermic
18		D6	24.9	Hyperthermic
19	Dainadubi	DB1	22.5	Hyperthermic
20		DB2	21.5	Thermic
21	Dainadubi	DB3	24.1	Hyperthermic
22		DB4	23.5	Hyperthermic
23		DB5	23.7	Hyperthermic
24	Dainadubi	DB6	21.6	Thermic
25		DB7	21.4	Thermic
26		DB8	21.7	Thermic
27	Dainadubi	DB9	21.6	Thermic
28		DB10	21.3	Thermic
29		DB11	21.0	Thermic
30	Sarangma	S1	27.8	Hyperthermic
31		S2	23.1	Hyperthermic
32		S3	23.2	Hyperthermic
33	Sarangma	S4	25.8	Hyperthermic
34		S5	25.9	Hyperthermic
35		S6	26.3	Hyperthermic
36	Sarangma	S7	27.4	Hyperthermic
37		S8	24.6	Hyperthermic
38		S9	25.9	Hyperthermic
39	Sarangma	S10	24.3	Hyperthermic
40		S11	24.5	Hyperthermic
41		S12	24.9	Hyperthermic
42	Sarangma	S13	23.2	Hyperthermic
43		S14	23.1	Hyperthermic
44		S15	23.7	Hyperthermic

Table 5.9 - Optimum pH ranges of selected plants growing on high base-status soils

Field Crops		Alyssum	6.0-7.5	Oak, Pine	5.0-6.5
Alfalfa	6.2-7.8	Azalea	4.5-5.0	Oak, White	5.0-6.5
Barley	6.5-7.8	Barberry, Japanese	6.0-7.5	Pine, Jack	4.5-5.0
Bean, field	6.0-7.5	Begonia	5.5-7.0	Pine, Loblolly	5.0-6.0
Beets, sugar	6.5-8.0	Burning Bush	5.5-7.5	Pine, Red	5.0-6.0
Bluegrass, Ky.	5.5-7.5	Calendula	5.5-7.0	Pine, White	4.5-6.0
Clover, red	6.0-7.5	Carnation	6.0-7.5	Spruce, Black	4.0-5.0
Clover, sweet	6.5-7.5	Chrysanthemum	6.0-7.5	Spruce, Colorado	6.0-7.0
Clover, white	5.6-7.0	Gardenia	5.0-6.0	Spruce, White	5.0-6.0
Corn	5.5-7.5	Geranium	6.0-8.0	Sycamore	6.0-7.5
Flax	5.0-7.0	Holly, American	5.0-6.0	Tamarack	6.0-7.5
Oats	5.0-7.5	Ivy, Boston	6.0-8.0	Walnut, Black	6.0-8.0
Pea, field	6.0-7.5	Lilac	6.0-7.5	Yew, Japanese	6.0-7.0
Peanut	5.3-6.6	Lily, Easter	6.0-7.0	**Weeds**	
Rice	5.0-6.5	Magnolia	5.0-6.0	Dandelion	5.5-7.0
Rye	5.0-7.0	Orchid	4.0-5.0	Dodder	5.5-7.0
Sorghum	5.5-7.5	Phlox	5.0-6.0	Foxtail	6.0-7.5
Soybean	6.0-7.0	Poinsettia	6.0-7.0	Goldenrod	5.0-7.5
Sugar Cane	6.0-8.0	Quince, flowering	6.0-7.0	Grass, Crab	6.0-7.0
Tobacco	5.5-7.5	Rhododendron	4.5-6.0	Grass, Quack	5.5-6.5
Wheat	5.5-7.5	Rose, hybrid tea	5.5-7.0	Horse Tail	4.5-6.0
Vegetable Crops		Snapdragon	6.0-7.5	Milkweed	4.0-5.0
Asparagus	6.0-8.0	Snowball	6.5-7.5	Mustard, wild	6.0-8.0
Beets, table	6.0-7.5	Sweet William	6.0-7.5	Thistle, canada	5.0-7.5
Broccoli	6.0-7.0	Zinnia	5.5-7.5	**Fruits**	
Cabbage	6.0-7.5	**Forest Plants**		Apple	5.0-6.5
Carrot	5.5-7.0	Ash, white	6.0-7.5	Apricot	6.0-7.0
Cauliflower	5.5-7.5	Aspen, American	3.8-5.5	Arbor Vitae	6.0-7.5
Celery	5.8-7.0	Beech	5.0-6.7	Blueberry, High Bush	4.0-5.0
Cucumber	5.5-7.0	Birch, European (white)	4.5-6.0	Cherry, sour	6.0-7.0
Lettuce	6.0-7.0	Cedar, white	4.5-5.0	Cherry, sweet	6.0-7.5
Muskmelon	6.0-7.0	Club Moss	4.5-5.0	Crab apple	6.0-7.5
Onion	5.8-7.0	Fir, Balsam	5.0-6.0	Cranberry, large	4.2-5.0
Potato	4.8-6.5	Fir, Douglas	6.0-7.0	Peach	6.0-7.5
Rhubarb	5.5-7.0	Heather	4.5-6.0	Pineapple	5.0-6.0
Spinach	6.0-7.5	Hemlock	5.0-6.0	Raspberry, Red	5.5-7.0
Tomato	5.5-7.5	Larch, European	5.0-6.5	Strawberry	5.0-6.5
Flowers and Shrubs		Maple, Sugar	6.0-7.5		
African Violet	6.0-7.0	Moss, Sphagnum	3.5-5.0		
Almond, flowering	6.0-7.0	Oak, Black	6.0-7.0		

(Source : Spurway, 1941)

Table - 5.10 : Status of pH in Soils of Dudhnai

S. No.	Testing Location	Test No.	Land Use	Soil Type (USDA)	pH of Soil
1	Bangsiapal	B1	Banana garden (on urban land)	Sandy clay loam	5.40
2		B2	Banana garden (on urban land)	Sandy clay loam	6.15
3		B3	Banana garden (on urban land)	Sandy clay loam	6.42
4	Bangsiapal	B4	Banana + Betel Nut garden	Sandy clay loam	5.70
5		B5	Banana + Betel Nut garden	Sandy clay loam	8.40
6		B6	Banana + Betel Nut garden	Sandy clay loam	7.60
7	Bangsiapal	B7	Footway of grassy land	Silty loam	6.40
8		B8	Footway of grassy land	Silty loam	4.52
9		B9	Footway of grassy land	Silty loam	5.59
10	Bangsiapal	B10	Grassy (100%) land	Silty loam	6.80
11		B11	Grassy (100%) land	Silty loam	5.91
12		B12	Grassy (100%) land	Silty loam	6.20
13	Damra	D1	Betel Nut garden	Loamy sand	8.90
14		D2	Betel Nut garden	Loamy sand	7.10
15		D3	Betel Nut garden	Loamy sand	4.12
16	Damra	D4	Rubber garden	Loamy sand	4.90
17		D4	Rubber garden	Loamy sand	4.70
18		D6	Rubber garden	Loamy sand	4.85
19	Dainadubi	DB1	Rose garden	Silt	4.60
20		DB2	Rose garden	Silt	4.58
21	Dainadubi	DB3	Grassy with humus	Loam	4.00
22		DB4	Grassy with humus	Loam	4.85
23		DB5	Grassy with humus	Loam	4.40
24	Dainadubi	DB6	Grassy (80%) land	Loam	3.55
25		DB7	Grassy (80%) land	Loam	3.70
26		DB8	Grassy (80%) land	Loam	3.30
27	Dainadubi	DB9	Barren land	Silty loam	4.10
28		DB10	Barren land	Silty loam	4.60
29		DB11	Barren land	Silty loam	3.97
30	Sarangma	S1	Agri.(harvested paddy field)	Silty loam	4.78
31		S2	Agri.(harvested paddy field)	Silty loam	4.92
32		S3	Agri.(harvested paddy field)	Silty loam	5.10
33	Sarangma	S4	Deforested land with stumps	Sandy loam	5.10
34		S5	Deforested land with stumps	Sandy loam	5.13
35		S6	Deforested land with stumps	Sandy loam	4.75
36	Sarangma	S7	Teak forest	Sandy loam	5.59
37		S8	Teak forest	Sandy loam	4.90
38		S9	Teak forest	Sandy loam	4.75
39	Sarangma	S10	Banana garden on deforested land	Sandy loam	7.20
40		S11	Banana garden on deforested land	Sandy loam	4.40
41		S12	Banana garden on deforested land	Sandy loam	4.10
42	Sarangma	S13	Shrub land	Sandy clay loam	4.40
43		S14	Shrub land	Sandy clay loam	4.80
44		S15	Shrub land	Sandy clay loam	3.40

5.12 Hydrologic Soil Classification based on SCS Criteria :

SCS governed guidelines as discussed in clause 2.6 of Review chapter are used to identify the soil groupings of different locations. The results are presented in Table-5.11and soils are classified using infiltration as a main criteria.

5.13 Classification Based on Hydraulic Conductivity Data of Dudhnai :

In persuance of the field tests measurement of Hydraulic Conductivity and Flux Potential were carried out at 50 cm layer at 44 sites using Guelph Permeameter. The results are used for classification as shown in Table-5.12.

5.14 In Situ Soil Suction by Tensiometer :

A tensiometer is a practical instrument capable of providing reliable data on the in-situ state of soil moisture profiles and their changes with time. It has been found useful in guiding the time of irrigation. Tensiometer reading gives instantly current status of the vital soil moisture. It provides visual picture of the rate at which plants are withdrawing moisture from the soil. In the vadose zone, the unsaturated zone between soil surface and the ground water, the soil suction in different areas determines the direction in which unsaturated flow of water will take place. Water held at low suction values in the soil will move to adjacent areas which have a higher soil suction value. This movement can be in any direction depending upon the relative soil suction values. Tensiometer provides a simple tool to reveal underground flow pattern. We can reveal the presence of perched water tables, aquifers, and unusual moisture conditions near changing strata in the soil profile. It can also reveal the presence of subsurface seepage below water or waste storage areas. Tensiometer can also be used to indicate when soil suction values are suitable for extraction of soil water samples with suction lysimeter for chemical analysis. Tensiometer located in typical areas of the field provide the critical information to rigidly control the water table height. (If the water table is too high, plant growth will be retarded or stopped completely). Tensiometer data is also an important input in Conductivity-Pressure Head relationship for field condition to describe the changes in unsaturated hydraulic conductivity with soil suction. Table-5.13 provides the soil suction data under different land use, soil type and moisture content conditions during field testing. Data is valuable for infiltration and ground water modelling.

5.15 Index Properties of Soil :

Index properties of soils include texture, structure, density, porosity, consistency, temperature, color, water content and specific gravity. The physical properties are dominant factors affecting the use of a soil. These properties determine the availability of oxygen in soils, the mobility of water into or through

Table – 5.11 : Hydrologic Soil Classification Based on SCS Criteria of Soils of Dudhnai

S. No.	Testing Location	Test No.	Land Use	Soil Type	Steady infiltration rate (cm/hr)	Depth of Gr.Water Table(bgl)	Hydrological Soil Group
1	Bangsiapal	B1	Banana garden (on urban land)	Sandy clay loam	7.00	4.00	B
2		B2	Banana garden (on urban land)	Sandy clay loam	6.00	4.00	B
3		B3	Banana garden (on urban land)	Sandy clay loam	4.00	4.00	C
4	Bangsiapal	B4	Banana + Betel Nut garden	Sandy clay loam	6.60	4.00	B
5		B5	Banana + Betel Nut garden	Sandy clay loam	7.50	4.00	B
6		B6	Banana + Betel Nut garden	Sandy clay loam	8.00	4.00	B
7	Bangsiapal	B7	Footway of grassy land	Silty loam	1.40	5.00	D
8		B8	Footway of grassy land	Silty loam	1.60	5.00	C
9		B9	Footway of grassy land	Silty loam	1.20	5.00	D
10	Bangsiapal	B10	Grassy (100%) land	Silty loam	2.40	5.00	C
11		B11	Grassy (100%) land	Silty loam	3.20	5.00	C
12		B12	Grassy (100%) land	Silty loam	4.00	5.00	C
13	Damra	D1	Betel Nut garden	Loamy sand	4.20	4.80	C
14		D2	Betel Nut garden	Loamy sand	6.00	4.80	B
15		D3	Betel Nut garden	Loamy sand	5.40	4.80	B
16	Damra	D4	Rubber garden	Loamy sand	6.00	5.50	B
17		D4	Rubber garden	Loamy sand	6.00	5.50	B
18		D6	Rubber garden	Loamy sand	6.00	5.50	B
19	Dainadubi	DB1	Rose garden	Silt	1.20	3.70	D
20		DB2	Rose garden	Silt	1.10	3.70	D
21	Dainadubi	DB3	Grassy with humus	Loam	3.20	3.70	C
22		DB4	Grassy with humus	Loam	1.80	3.70	C
23		DB5	Grassy with humus	Loam	2.40	3.70	C
24	Dainadubi	DB6	Grassy (80%) land	Loam	2.40	3.70	C
25		DB7	Grassy (80%) land	Loam	2.00	3.70	C
26		DB8	Grassy (80%) land	Loam	1.80	3.70	C
27	Dainadubi	DB9	Barren land	Silty loam	0.60	3.70	D
28		DB10	Barren land	Silty loam	0.40	3.70	D
29		DB11	Barren land	Silty loam	0.60	3.70	D
30	Sarangma	S1	Agri.(harvested paddy field)	Silty loam	0.40	4.60	D
31		S2	Agri.(harvested paddy field)	Silty loam	0.60	4.60	D
32		S3	Agri.(harvested paddy field)	Silty loam	0.80	4.60	D
33	Sarangma	S4	Deforested land with stumps	Sandy loam	1.20	5.50	D
34		S5	Deforested land with stumps	Sandy loam	1.60	5.50	C
35		S6	Deforested land with stumps	Sandy loam	2.40	5.50	C
36	Sarangma	S7	Teak forest	Sandy loam	10.00	4.60	A
37		S8	Teak forest	Sandy loam	8.00	4.60	B
38		S9	Teak forest	Sandy loam	6.00	4.60	B
39	Sarangma	S10	Banana garden on deforested land	Sandy loam	6.00	5.50	B
40		S11	Banana garden on deforested land	Sandy loam	1.20	5.50	D
41		S12	Banana garden on deforested land	Sandy loam	4.80	5.50	C
42	Sarangma	S13	Shrub land	Sandy clay loam	1.60	4.60	C
43		S14	Shrub land	Sandy clay loam	1.20	4.60	D
44		S15	Shrub land	Sandy clay loam	1.20	4.60	D

Table - 5.12 : Soil Classification Based on Hydraulic Conductivity(Kfs) of Soils of Dudhnai

S. No.	Testing Location	Test No.	Soil Type	Kfs cm/sec	Kfs cm/hr	Matrix Flux Potential sq.cm/sec	Alpha constant /cm	Runoff Potential
1	Bangsiapal	B1	Sandy clay loam	1.1E-04	4.1E-01	1.4E-03	0.080	High
2		B2	Sandy clay loam	1.9E-04	6.8E-01	2.5E-04	0.762	Moderately High
3		B3	Sandy clay loam	2.4E-04	8.5E-01	2.6E-03	0.090	Moderately High
4	Bangsiapal	B4	Sandy clay loam	2.5E-04	9.1E-01	3.3E-04	0.762	Moderately High
5		B5	Sandy clay loam	1.0E-04	3.7E-01	2.7E-03	0.038	High
6		B6	Sandy clay loam	1.1E-04	4.1E-01	1.4E-03	0.080	High
7	Bangsiapal	B7	Silty loam	2.3E-04	8.4E-01	3.4E-03	0.069	Moderately High
8		B8	Silty loam	4.4E-05	1.6E-01	5.4E-03	0.008	High
9		B9	Silty loam	1.2E-04	4.1E-01	2.4E-04	0.479	High
10	Bangsiapal	B10	Silty loam	3.8E-04	1.4E+00	8.0E-03	0.047	Moderately High
11		B11	Silty loam	3.8E-04	1.4E+00	8.0E-03	0.047	Moderately High
12		B12	Silty loam	5.0E-05	1.8E-01	6.8E-04	0.073	High
13	Damra	D1	Loamy sand	2.2E-04	7.8E-01	1.9E-03	0.113	Moderately High
14		D2	Loamy sand	1.6E-04	5.7E-01	3.0E-03	0.052	Moderately High
15		D3	Loamy sand	2.0E-03	8.5E-01	5.8E-03	0.040	Moderately High
16	Damra	D4	Loamy sand	3.4E-04	1.2E+00	5.1E-03	0.067	Moderately High
17		D4	Loamy sand	2.0E-03	8.5E-01	5.8E-03	0.040	Moderately High
18		D6	Loamy sand	3.4E-04	1.2E+00	5.1E-03	0.067	Moderately High
19	Dainadubi	DB1	Silt	2.9E-04	1.1E+00	1.6E-02	0.019	Moderately High
20		DB2	Silt	2.9E-04	1.1E+00	1.6E-02	0.019	Moderately High
21	Dainadubi	DB3	Loam	1.0E-04	6.7E-01	3.9E-03	0.047	Moderately High
22		DB4	Loam	2.8E-04	1.0E+00	2.7E-03	0.104	Moderately High
23		DB5	Loam	3.0E-04	1.1E+00	1.9E-03	0.162	Moderately High
24	Dainadubi	DB6	Loam	3.6E-04	1.3E+00	1.0E-03	0.345	Moderately High
25		DB7	Loam	3.0E-04	1.1E+00	1.9E-03	0.162	Moderately High
26		DB8	Loam	2.8E-04	1.0E+00	2.7E-03	0.104	Moderately High
27	Dainadubi	DB9	Silty loam	1.2E-04	4.1E-01	2.4E-04	0.479	High
28		DB10	Silty loam	7.6E-05	2.7E-01	8.5E-04	0.090	High
29		DB11	Silty loam	4.4E-05	1.6E-01	5.4E-03	0.008	High
30	Sarangma	S1	Silty loam	8.5E-05	3.0E-01	3.1E-04	0.277	High
31		S2	Silty loam	5.0E-05	1.8E-01	6.8E-04	0.073	High
32		S3	Silty loam	2.3E-04	8.4E-01	3.4E-03	0.069	Moderately High
33	Sarangma	S4	Sandy loam	3.3E-04	1.2E+00	2.8E-03	0.117	Moderately High
34		S5	Sandy loam	1.7E-04	6.2E-01	3.8E-03	0.045	Moderately High
35		S6	Sandy loam	5.0E-04	2.0E+00	1.8E-03	0.297	Moderately High
36	Sarangma	S7	Sandy loam	9.5E-04	3.4E+00	3.5E-03	0.269	Moderately High to Moderately Low
37		S8	Sandy loam	9.0E-04	3.2E+00	3.9E-03	0.232	Moderately High to Moderately Low
38		S9	Sandy loam	1.7E-04	6.2E-01	3.8E-03	0.045	Moderately High
39	Sarangma	S10	Sandy loam	5.0E-04	2.0E+00	1.8E-03	0.297	Moderately High
40		S11	Sandy loam	5.0E-04	2.2E+00	1.4E-03	0.415	Moderately High to Moderately Low
41		S12	Sandy loam	3.3E-04	1.2E+00	2.8E-03	0.117	Moderately High
42	Sarangma	S13	Sandy clay loam	2.9E-04	1.0E+00	2.0E-03	0.145	Moderately High
43		S14	Sandy clay loam	2.4E-04	8.5E-01	2.6E-03	0.090	Moderately High
44		S15	Sandy clay loam	1.9E-04	6.8E-01	2.5E-04	0.762	Moderately High

Table - 5.13 : In Situ Soil Suction Record by Tensiometer

S. No.	Testing Location	Test No.	Land Use	Soil Type (USDA)	Tensiometer reading in centi-bars
1	Bangsiapal	B1	Banana garden (on urban land)	Sandy clay loam	6
2		B2	Banana garden (on urban land)	Sandy clay loam	3
3		B3	Banana garden (on urban land)	Sandy clay loam	4
4	Bangsiapal	B4	Banana + Betel Nut garden	Sandy clay loam	8
5		B5	Banana + Betel Nut garden	Sandy clay loam	10
6		B6	Banana + Betel Nut garden	Sandy clay loam	6
7	Bangsiapal	B7	Footway of grassy land	Silty loam	1
8		B8	Footway of grassy land	Silty loam	2
9		B9	Footway of grassy land	Silty loam	5
10	Bangsiapal	B10	Grassy (100%) land	Silty loam	3
11		B11	Grassy (100%) land	Silty loam	3
12		B12	Grassy (100%) land	Silty loam	4
13	Damra	D1	Betel Nut garden	Loamy sand	6
14		D2	Betel Nut garden	Loamy sand	5
15		D3	Betel Nut garden	Loamy sand	6
16	Damra	D4	Rubber garden	Loamy sand	2
17		D4	Rubber garden	Loamy sand	1.5
18		D6	Rubber garden	Loamy sand	2.5
19	Dainadubi	DB1	Rose garden	Silt	2
20		DB2	Rose garden	Silt	2
21	Dainadubi	DB3	Grassy with humus	Loam	3
22		DB4	Grassy with humus	Loam	6
23		DB5	Grassy with humus	Loam	3
24	Dainadubi	DB6	Grassy (80%) land	Loam	2.5
25		DB7	Grassy (80%) land	Loam	4
26		DB8	Grassy (80%) land	Loam	6
27	Dainadubi	DB9	Barren land	Silty loam	4
28		DB10	Barren land	Silty loam	3
29		DB11	Barren land	Silty loam	4
30	Sarangma	S1	Agri.(harvested paddy field)	Silty loam	2
31		S2	Agri.(harvested paddy field)	Silty loam	2
32		S3	Agri.(harvested paddy field)	Silty loam	1.5
33	Sarangma	S4	Deforested land with stumps	Sandy loam	7
34		S5	Deforested land with stumps	Sandy loam	9
35		S6	Deforested land with stumps	Sandy loam	6
36	Sarangma	S7	Teak forest	Sandy loam	4
37		S8	Teak forest	Sandy loam	3
38		S9	Teak forest	Sandy loam	2
39	Sarangma	S10	Banana garden on deforested land	Sandy loam	7
40		S11	Banana garden on deforested land	Sandy loam	6
41		S12	Banana garden on deforested land	Sandy loam	5
42	Sarangma	S13	Shrub land	Sandy clay loam	6
43		S14	Shrub land	Sandy clay loam	4
44		S15	Shrub land	Sandy clay loam	6

Table - 5.14 : Index Properties of Soils of Dudhnai

S. No.	Location	Test No.	bulk density gm/cc	dry density gm/cc	saturt. density gm/cc	submers. density gm/cc	moisture content (MC)%	moisture content V/V cm/m	degree of saturation %	MC at100% Saturat. %	MC at100% Saturat. V/V cm/m	sp. gravity	void ratio	porosity %	air content	air voids %	Cc	Cu
1	Bangsiapal	B1	1.91	1.60	2.04	1.04	19.59	31.25	70.51	27.78	44.32	2.87	0.80	44.32	0.29	13.07	0.19	153.8
2		B2	1.84	1.59	2.05	1.05	15.77	25.14	55.47	28.43	45.31	2.91	0.83	45.31	0.45	20.18	0.15	192.3
3		B3	1.71	1.45	1.93	0.93	17.93	26.04	55.04	32.57	47.30	2.76	0.90	47.30	0.45	21.26	0.30	200.0
4	Bangsiapal	B4	1.60	1.41	1.70	0.70	13.35	18.87	66.42	20.11	28.41	1.97	0.40	28.41	0.34	9.54	0.31	108.3
5		B5	1.73	1.43	1.79	0.79	21.15	30.15	82.92	25.51	36.36	2.24	0.57	36.36	0.17	6.21	0.14	250.0
6		B6	1.72	1.46	1.75	0.75	17.42	25.50	89.75	19.41	28.41	2.04	0.40	28.41	0.10	2.91	0.41	83.3
7	Bangsiapal	B7	1.56	1.41	1.74	0.74	11.05	15.55	46.58	23.73	33.38	2.11	0.50	33.38	0.53	17.83	0.06	94.1
8		B8	1.62	1.44	1.80	0.80	12.91	18.55	51.02	25.31	36.36	2.26	0.57	36.36	0.49	17.81	0.14	55.6
9		B9	1.55	1.41	1.72	0.72	10.39	14.60	46.50	22.33	31.39	2.05	0.46	31.39	0.53	16.79	0.05	117.6
10	Bangsiapal	B10	1.81	1.51	1.89	0.89	19.61	29.71	79.53	24.66	37.36	2.42	0.60	37.36	0.20	7.65	0.05	125.0
11		B11	1.90	1.61	1.97	0.97	18.19	29.27	80.49	22.60	36.36	2.53	0.57	36.36	0.20	7.09	0.05	125.0
12		B12	1.97	1.72	2.10	1.10	14.77	25.35	66.10	22.34	38.35	2.78	0.62	38.35	0.34	13.00	0.05	125.0
13	Damra	D1	1.81	1.53	1.93	0.93	18.19	27.88	70.85	25.67	39.35	2.53	0.65	39.35	0.29	11.47	6.40	40.0
14		D2	1.91	1.64	2.00	1.00	16.40	26.93	76.13	21.54	35.37	2.54	0.55	35.37	0.24	8.44	16.00	100.0
15		D3	1.76	1.52	1.89	0.89	15.57	23.70	65.17	23.89	36.36	2.39	0.57	36.36	0.35	12.67	12.00	75.0
16	Damra	D4	1.99	1.73	2.08	1.08	14.89	25.73	72.76	20.46	35.37	2.67	0.55	35.37	0.27	9.64	16.00	100.0
17		D5	1.75	1.47	1.92	0.92	19.01	28.02	63.22	30.06	44.32	2.65	0.80	44.32	0.37	16.30	12.80	125.0
18		D6	1.47	1.23	1.76	0.76	19.38	23.90	45.73	42.38	52.27	2.58	1.10	52.27	0.54	28.37	16.00	100.0
19	Dainadubi	DB1	1.78	1.58	1.84	0.84	12.91	20.39	77.16	16.74	26.42	2.15	0.36	26.42	0.23	6.03	0.06	100.0
20		DB2	1.78	1.59	1.89	0.89	12.02	19.10	62.85	19.13	30.40	2.28	0.44	30.40	0.37	11.29	0.05	94.7
21	Dainadubi	DB3	1.58	1.32	1.65	0.65	19.69	26.06	80.46	24.48	32.39	1.96	0.48	32.39	0.20	6.33	0.11	100.0
22		DB4	1.87	1.66	2.06	1.06	12.91	21.41	53.06	24.34	40.34	2.78	0.68	40.34	0.47	18.94	0.19	58.3
23		DB5	1.86	1.54	1.95	0.95	21.05	32.41	78.41	26.84	41.34	2.62	0.70	41.34	0.22	8.92	0.19	58.3
24	Dainadubi	DB6	1.74	1.46	1.92	0.92	19.69	28.66	61.90	31.81	46.31	2.71	0.86	46.31	0.38	17.64	0.08	83.3
25		DB7	1.89	1.64	1.99	0.99	15.02	24.68	71.80	20.92	34.38	2.50	0.52	34.38	0.28	9.70	0.35	50.0
26		DB8	1.87	1.67	2.19	1.19	12.05	20.15	38.55	31.27	52.27	3.50	1.10	52.27	0.61	32.14	0.52	33.3
27	Dainadubi	DB9	2.04	1.70	2.11	1.11	20.06	34.01	82.29	24.38	41.34	2.89	0.70	41.34	0.18	7.32	0.60	15.0
28		DB10	2.08	1.71	2.15	1.15	21.34	36.57	84.40	25.29	43.32	3.02	0.76	43.32	0.16	6.76	0.45	20.0
29		DB11	1.86	1.54	2.01	1.01	20.54	31.68	66.97	30.68	47.30	2.93	0.90	47.30	0.33	15.62	0.60	15.0
30	Sarangma	S1	1.78	1.55	1.80	0.80	14.90	23.13	94.69	15.73	24.43	2.06	0.32	24.43	0.05	1.30	0.67	16.7
31		S2	1.63	1.39	1.78	0.78	17.84	24.74	62.87	28.38	39.35	2.29	0.65	39.35	0.37	14.61	0.46	35.0
32		S3	1.71	1.47	1.82	0.82	16.28	23.93	67.67	24.06	35.37	2.27	0.55	35.37	0.32	11.43	0.53	30.0
33	Sarangma	S4	1.37	1.15	1.65	0.65	18.53	21.38	43.37	42.73	49.29	2.27	0.97	49.29	0.57	27.91	4.44	27.8
34		S5	1.99	1.65	2.05	1.05	21.15	34.80	86.27	24.52	40.34	2.76	0.68	40.34	0.14	5.54	1.12	200.0
35		S6	1.68	1.43	1.91	0.91	16.80	24.10	50.95	32.97	47.30	2.72	0.90	47.30	0.49	23.20	1.50	150.0
36	Sarangma	S7	1.42	1.27	1.70	0.70	11.81	14.95	34.52	34.23	43.32	2.23	0.76	43.32	0.65	28.37	0.56	100.0
37		S8	1.75	1.53	1.93	0.93	14.58	22.28	55.24	26.39	40.34	2.56	0.68	40.34	0.45	18.06	0.56	100.0
38		S9	1.60	1.40	1.70	0.70	14.13	19.82	67.40	20.96	29.40	1.99	0.42	29.40	0.33	9.59	0.38	150.0
39	Sarangma	S10	1.75	1.35	1.85	0.85	29.39	39.77	80.68	36.42	49.29	2.67	0.97	49.29	0.19	9.52	0.36	100.0
40		S11	1.74	1.51	1.78	0.78	15.22	22.93	83.65	18.19	27.41	2.08	0.38	27.41	0.16	4.48	1.00	100.0
41		S12	1.65	1.31	1.75	0.75	26.32	34.36	77.53	33.95	44.32	2.34	0.80	44.32	0.22	9.96	1.50	150.0
42	Sarangma	S13	1.70	1.42	1.82	0.82	20.19	28.63	70.98	28.45	40.34	2.38	0.68	40.34	0.29	11.71	0.10	166.7
43		S14	1.83	1.52	1.91	0.91	20.28	30.88	80.51	25.19	38.35	2.47	0.62	38.35	0.19	7.47	0.10	166.7
44		S15	1.81	1.47	1.87	0.87	22.75	33.50	85.15	26.72	39.35	2.43	0.65	39.35	0.15	5.84	0.10	166.7

soils, and the ease of root penetration. Moisture content plays an important role in understanding the behavior of fine grained soils. It is the moisture content which changes the soil from liquid to plastic and solid states. Density of soils are directly influenced by its value and are used in calculating the stability of slopes, bearing capacity of soil-foundation system, earth pressure behind the retaining walls and pressure due to overburden. Density is used in calculating the stress in the soil due to its overburden pressure. It is the density which controls the field compaction of soils. Permeability of soils depends upon its density. Void ratio, porosity and degree of saturation need the help of density of soils. Specific gravity of soil is also an important property and is used in calculating void ratio, porosity, degree of saturation if water content and density are known. Specific gravity helps in identification and classification of sils. It gives an idea about the suitability of the soil as a construction material, higher value of specific gravity gives more strength for roads and foundations. It is used in computing the particle size by means of hydrometer analysis. It is also used in estimating the critical hydraulic gradient in soil when a sand boiling condition is being studied and in zero air-void calculations in the compaction theory of soils. Summarized results in this respect have been furnished in Table-5.14.

6.0 CONCLUDING REMARKS

Soil classification is the placing of a soil into a group of soils of which exhibit similar behavior. Soil classification permits us to solve many types of similar soil problems and guide the test program if the difficulty and importance of the problem dictate further investigation. Soil classification has proved to be a valuable tool to the soil engineer.

The physical properties of soils-texture, structure, density, porosity, water content, consistency, temperature, and color-are dominant factors affecting the use of a soil. These properties determine the availability of oxygen in soils, the mobility of water into-or through soils, and the ease of root penetration. Soil moisture, a vital physical property. The physical properties of a soil have much to do with its suitability for the many uses to which it is put. The rigidity and supporting power, drainage and moisture storage capacity, plasticity, case of penetration by roots, aeration, and retention of plant nutrients are all intimately connected with the physical condition of the soil. It is pertinent, therefore, that persons dealing with soils know to what extent and by what means those properties can be altered. This is true weather the soil is to be used as a medium for plant growth or as a structural material in the making of highways, dams, and foundations for buildings, in building golf courses and athletic fields, or for waste disposal systems. Texture is perhaps the most permanent and important characteristic of soil

Since the soil's textural classification includes only mineral particles and those of less than 2 mm diameter, the sand plus silt plus clay percentages equal 100 percent. (Organic matter is not included.) Knowing the amount of any two fractions automatically fixes the percentage of the third one. In reading the textural triangle, any two particle fractions will locate the textural class at the point where those two intersect. As the soil is a mixture of various sizes of soil separates, it is, therefore necessary to establish limits of variation for the soil separates with a view to group them into different textural classes. Texture is a basic property of a soil and it can not he altered or changed.

Mineral fragments in the soil larger than 2 mm in diameter but less than 25 cm (gravels and cobbles) must be considered a part of the soil because they greatly influence its use.

Soil structure is the most important physical property in relation to plant growth, because it influences the amount and nature of porosity. The best structure for favourable physical properties of soil are spheroidal type of soil structure. Some structures are mechanically stable and strong but when they absorb moisture and are wet they become soft and lose their shape and size. Soils high in water stable aggregates are more permeable to water and air.

Soil texture, structure, and organic matter content have significant influence on hydraulic conductivity. Hydraulic conductivity is more in coarse textured. sandy soil but, capillary conductivity is higher in loam, sandy loam and clay loam soils than sandy soil, due to better continuity of pores in fine textured soils. Particle size distribution affects the continuity of capillary pores and appears as a dominant factor affecting water transmission characteristics.

Porosity and pore-size distribution are important soil properties in the disposition of water failing on the earth and the growth of plants. Soils with large and stable pores absorb rainfall and permit it to percolate downward rather than flow away over the surface. Maximum plant growth depends on suitable distribution of large, intermediate and small pores. Predominance of small pores favours waterlogged conditions and poor aeration whereas too many large pores make soils droughty.

The capacity of soil to hold water is related to surface area as well as pore space volume. Hence, Water holding capacity is related to both structure and texture of the soil. In general, fine textured soils have the maximum total water holding capacity, but maximum available water is held in medium-textured soils. Soil texture is especially important in subsurface drainage as it has a direct relationship with hydraulic conductivity and water retention

Soil properties change with time because of various external influence upon it. Therefore, monitoring of the soils resource needs to be reviewed from time to time for scientific watershed management practices.

Different soil classification systems use a host of terminologies and there is need for standardization of the systems for ease of handling them and also to avoid confusion. Further, it has been difficult to ascertain the percentage contribution of the individual parameters of a system to the objectives. Knowledge of the physics of soil water movement is crucial to the solution of problems in watershed hydrology. The planning and execution of hydrological and soil technical projects is almost always preceded by geo-hydrologic research. The utilization of rain and irrigation water received at the soil surface for the growing crops is controlled by the hydrophysical properties of the soil profile.

The present work constitutes a component part of the overall long term representative basin studies of the Dudhnai sub-basin. The information will be used in modeling the basin in the long run. However, with the progress of more investigations, there is scope of refinement and elaboration of the results.

Following conclusions can be drawn from the present study :

- None of the existing hydrologic soil classification schemes are robust enough to accommodate the all soil properties into a particular group.

- Soil texture alone cannot be taken as a single parameter for classification hydrologic soil groups, as same soil texture can give rise to different soil groups.

- Infiltration rate may be adopted as main parameter for hydrologic soil classification, as infiltration rate is affected by all other soil characteristics.

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