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MEASUREMENT OF SURFACE-SOIL HYDRAULIC PROPERTIES FOR GHATAPRABHA COMMAND AREA

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PREFACE

Estimation of hydraulic soil parameters for a region is very essential, since the conversion of rainfall to runoff is governed by the soil type of that region and its properties. The path taken by precipitation will determine the nature to be evaluated to allocate net precipitation at the soil surface into either surface or subsurface flow are particle size distribution, infiltration rate, hydraulic conductivity, soil moisture and its retention capacity.

In the present study, surface soil properties for Ghataprabha command area, which lies in Belgaum and Bijapur districts of Karnataka, are estimated and presented to determine the hydraulic characteristics of the soil in the region. Double ring infiltrometer is used to estimate infiltration rate, Guelph permeameter is used for the estimation of saturated hydraulic conductivity, pressure plates are used to find out the soil moisture retention curve and lab facilities are used to determine field capacity and grain size distribution.

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ABSTRACT

Study about the soil moisture in the unsaturated or vadose zone is important for vegetation growth and ecosystem. This zone is the link between surface and underground hydrologic processes. It also controls the amount of precipitation that enters the soil or remain on the surface. So, to quantitatively predict the movement of water through variably saturated soils, it is required to have detailed knowledge of the the hydraulic properties of the soil. Major hydraulic soil properties to be evaluated at the soil surface are particle size distribution, infiltration rate, hydraulic conductivity, soil moisture and its retention capacity.

This report presents the results of experimental studies conducted to estimate surface soil properties for Ghataprabha command area which lies in Belgaum and Bijapur districts of Karnataka. Field experiments were conducted using double ring infiltrometer to estimate infiltration rate and Guelph permeameter to estimate hydraulic conductivity. Laboratory tests were carried out for texture analysis and pressure plate apparatus is used to get the soil moisture retention curve.

From the texture analysis, it is found that the soil is well sorted over the region. Coarser sediments are distributed for most of the area. Sorting coefficient indicates that the sediments are not insitu, but are transported through geological and hydrological processes. Retention capacity shows an increasing trend with silt and clay content. Hydraulic conductivity values for the study area are very low and at few places, the values are out of possible range to be computed by the Guelph permeameter. Infiltration results indicate a wide variation in values spatially, possibly due to the type of soils, man's influences, etc. Final infiltration rate shows a decreasing trend with the percentage of silt and clay.

1.0 INTRODUCTION

Soil is an unconsolidated aggregate of mineral and rock fragments ranging in size from tiny clay and silt particles to sand and sometimes even to pebbles or boulders. For a hydrologist, soil is all of the unconsolidated, granular material, including organic material, overlying hard bed rock.

The water existing in the soil is called subsurface water and is of two kinds: soil water and groundwater. The zone in which soil water occurs is called the unsaturated zone, and the zone in which groundwater occurs is called the saturated zone. The two zones are fundamentally different because of the way water occurs in them. In the groundwater zone, all the soil or rock pores are completely filled by water. The top of this zone is termed as the water table. The soil water zone occurs above the water table all the way upto the soil surface. In this zone, some soil pores contain water, some are partially filled, and some are essentially empty. The space not occupied by water is filled by air. The unsaturated zone acts as a reservoir, containing water for vegetation growth, and as a conduit for water moving down to recharge groundwater. Infiltration supplies water to this zone. The water in this zone can remain in storage, move downwards by gravity to the water table and the groundwater, or move upwards through evaporation and transpiration.

When rainfall contacts the soil surface, part of the water find its way downward into the soil through its pore openings. soil is in general an consolidated aggregate of mineral and rock fragments that range in size. It is a complex system of organic as well as inorganic components. The water is driven into the porous soil by the force of gravity and by the capillary attraction of the soil pores. The portion of rainfall that infiltrates the soil will first replace any soil moisture deficit; then the remaining water will continue migrating downward until it joins the groundwater table.

Study about the water found in the unsaturated or vadose zone of the soil is important since this water is the direct source of moisture for vegetation and invaluable for food production and to the planet ecology. This zone is the link between surface and underground hydrologic processes. Water evaporated or transpired from this unsaturated region supplies a large portion of the atmospheric moisture. The water in the unsaturated zone also controls the amount of precipitation that will enter the soil or remain on the surface.

Soil moisture movement studies provide potential information in the field of hydrology. In the field of hydrology, it is important for understanding the mechanism of recharge through the soil and to provide soil moisture storage data for the water balance study. The allocation of net precipitation. at the soil surface into either surface or sub surface flow determines, the timing and amount of stream flow that occurs. The surface runoff, soil moisture storage and deep percolation due to infiltration from a storm are influenced by the soil characteristics of the watershed. Infiltration rate, the runoff, the evaporation rate and the storage available for infiltration water prior to groundwater recharge all influence the water balance of an area. Since soils vary significantly, both vertically and horizontally, collection of areal moisture content information is extremely difficult.

So, to quantitatively predict the movement of water through variably saturated soils, we need detailed knowledge of the hydraulic properties of the soil. There is likely to be a great variation in the water content and its energy status at different places in the same field. Therefore measurement of soil water content and other properties have received a great deal of attention. Several direct and indirect methods to evaluate and measure the soil hydraulic l properties have been developed and several alternative ways are available to express these quantitatively.

For a complete evaluation of soil water system, it is necessary to know the state of water and its movement in the soil. Such an evaluation is, however, difficult to make under field conditions but is possible under controlled laboratory conditions. Even under field conditions, if the basic principles governing the state and movement of soil water are known, we can easily select the appropriate measurement and evaluation technique suited for the purpose.

Soils differ greatly in their ability to accept, transmit or retain the water that reaches the surface of the ground. There has been considerable progress in the last decade or two in the understanding of the retention and movement of water in soil mass. There is, however, a large gap between these fundamental studies and their application to the understanding of the role of soils in basin hydrology. The number of measurements required to characterise several horizons of each of the soil types present in a basin requires the use of relatively simple and rapid methods to assess the properties, texture and structure, conductivity, suction in the soil, moisture content, and its moisture retention capacity.

The major hydraulic properties are enumerated in the following chapter.

2.0 HYDRAULIC SOIL PROPERTIES

2.1 PARTICLE SIZE:

Soil structure has been defined as the physical constitution of a soil material as expressed by the size, shape and arrangement of the solid particles and voids, including both the primary particles to form compound particles and the compound particles themselves. The quantity, size and continuity of voids are particularly important in Hydrology, since it is in them that water is stored or transmitted during the subsurface phase of the hydrological cycle.

From the particle size analysis, the nature of the particle size distribution in a given soil sample can be known. The particle size refers to the various size groups of individual particles constituting the soil solids and is known as mechanical composition, or textural composition. A knowledge of distribution of different size groups of the particles is essential for physical characterisation of the soil. There is sometimes a broad correlation between texture and hydrologic behaviour of soils. The particle size groups are called soil separates or textural separates. Sand, silt and clay are the main soil separates and each soil separates consists of particles varying in sizes within a range. The limits of sizes have been fixed differently under different classification systems. Particles less than 0.02 mm are classified as silt and clay in all systems. particle sizes between 0.02 and 2 mm generally known as sands and particles above 2 mm are known as gravel.

For quantitative determination of particle sizes, secondary particles and aggregates have to be separated from one another by physical and chemical processes. Once the particles are separated, depending upon the methods used, several arbitrary criteria can be applied to define the particle size. The coarser particles can be separated into desired size groups through direct sieving. It is not possible to determine the finer sizes through direct sieving. The diameter of such particles can be considered equivalent to the diameter of a sphere whose diameter, or density or settling velocity in a given fluid is equal to that of the soil particle in question. The particles can also be viewed in the microscopic field and actual sizes measured. The complete particle size analysis of soil involves two main processes:

1) dispersion or the separation of soil mass into its components or primary particles and stabilising the suspension, and

2) fractionation or the grading of different particle size groups or soil separates.

The first step for dispersion of soil mass is the soaking and mechanical trituration, removal of soluble electrolytes and divalent exchangeable cations. Calcium Magnesium carbonates are removed by treating and washing with diluted hydrochloric acid. Organic matter may be removed by the treatment of hydrogen peroxide. The removal of electrolytes can be achieved by dissolution and leaching with dilute acids.

After the complete dispersion of soil sample, next step in the particle size distribution analysis is the grading of the particles into a number of size groups in order to know the percentage distribution of groups of various sizes in the soil mass. The coarser particles are fractionated into desired size groups through direct sieving and the finer particles are quantitatively determined by sedimentation methods including pipette, hydrometer, elutriation, and centrifugation. For soil survey and field mapping, particle size is identified by feel or appearance.

In direct sieving, the soil sample is passed through a nest of sieves of different sizes. The particles of different sizes are separated and retained on different sieves. Suitability of this method is restricted to coarse fraction only. This is the oldest and most widely used for particles larger than 0.05 mm size. A weighted sample is transferred on the top sieve and the sieve nest is shaken for a prescribed time and the weight of samples retained on each sieve expressed as percentage of the total weight is calculated.

For fractionating the finer particles (sedimentation), a well dispersed soil suspension forming a liquid column is sampled at different time intervals and the concentration of the soil particles at a given depth is expressed as function of time. It is recognised that the rate of fall of particles through a liquid medium is a function of size, density, and shape of the particles and the viscosity and density of the medium. The larger the particles, the faster the rate of settling.

The detailed procedure and theory for particle size analysis is give in Appendix.

The results of particle size analyses can be expressed in two ways: 1) percentage distribution, and 2) summation curves.

The percentage distribution method to classify the textural soil type does not provide a complete picture of particle size distribution in different soils. The same textural soil types may have a completely different particle size distribution and may exhibit different properties. A better way is to present the results of particle size distribution analysis graphically as curves known as summation curves.

Summation curve is a graphical method of reproducing size distribution of soil particles. The result of particle size analysis are expressed by a graph showing the cumulative percentage of weight of all particles smaller than any given diameter as ordinate to an arithmetic scale and diameter of particles to a logarithmic scale as abscissa. With such a graphic representation, it is easy to compare the gradations of soils of different sizes.

2.2 SOIL MOISTURE AND SOIL MOISTURE RETENTION

Measurement of total soil water potential of a soil strata is essential for describing the energy status of water in it. The maximum amount of water that soil can hold in permanent storage is called field capacity. This can be defined as the volume of capillary water per unit volume of soil. The soil water in storage is depleted by the plant-root zone. When the capillary force exceeds the roots' suction force, the plants can no longer extract soil moisture, and the residual amount of soil water is called the permanent wilting point. Thus, soil water in storage in the root zone can vary from field capacity to the wilting point.

Soil moisture data, depending upon the discipline interested in this information, is expressed as

a) the average amount of water in a soil or soil layer at a specific time, or
b) the change in average amount of water in a soil or soil layer with time, or
c) as the availability of water in a soil or soil layer, expressed as the percentage difference between the field capacity and the wilting point.

Observation of soil moisture in the zone of aeration are made in-situ:

a) to calculate the moisture content and its variation with time,
b) to compute the soil moisture balance in this zone and to study its relationship with the groundwater balance,
c) to follow moisture movement in the zone of partial saturation under the influence of different factors, and
d) to study moisture dynamics and the transport of water soluble salts.

The existing methods for evaluating soil water can be classified under two broad groups:

1) determination of water content in a given mass or volume of soil which is required for determining the water retention properties of the soil

2) determination of water potential (the amount of work that must be done to remove a unit amount of water from the soil) which is required for studying the movement of water in the soil and the plant response to water. There is a close relationship between the amount of water held in the soil and its potential energy. Therefore, it is possible to infer one from the other, and under well-defined condition, it is possible to describe the entire soil water system by determining only one of the two properties.

The direct and indirect methods of measuring soil water content can be broadly classified into following main groups:

1) thermo-gravimetric, which can be used as standard for calibration of other methods,
2) lysimetric, for measuring the change in soil moisture with time,
3) penetrometer,
4) electrical,

5) nuclear, includes neutron scattering methods which are most accurate and time consuming,
6) acoustic (ultrasonic),
7) chemical and
8) thermal.

Pressure head of the water in the unsaturated soil arises from local interactions between soil and water. In wet, coarse textured media, capillary forces are dominant while in dry soils, adsorption is most important. In fine textured media, exhibiting colloidal properties, double layer effects may become significant. When the pressure head of the soil changes, its water content also will change. After exerting a certain pressure head or suction upon a soil sample, the equilibrium soil moisture content can be determined. Applying different pressure heads step by step, a curve of pressure head versus moisture content can be obtained. This is generally called the soil moisture retention curve.

Because water is held within the soil by capillary binding of water in the pores, adhesive binding of water on solid surfaces and osmotic binding in double layers, the shape of the soil water retention curve depends to a great extent on the pore size distribution of the soil and its clay content. In sandy soils, capillary binding is the most important binding mechanism, whereas in clay soils adhesive and osmotic binding dominates.

Most soils do not have a unique relationship between soil water content and soil water tension because the water content at a given soil water tension depends on the wetting and drying history of the soil. This effect is called hysteresis, and caused by irregular size and shape of soil pores, variation of contact angle between water and soil, air entrapment in the soil, and swelling and shrinking phenomena in clay soils.

The moisture retention curve of a soil sample can be determined by equilibrating a soil sample at a succession of known tension values and each time determining the amount of moisture retained. A soil sample cannot be exposed directly to a pressure because of danger of air entry into the soil. Therefore, a water saturated porous material is used as an intermediary.

Experimental procedure for the determination of soil water retention capacity using pressure plates is given in Appendix.

2.3 HYDRAULIC CONDUCTIVITY

An important characteristic in subsurface water movement is the constant K in Darcy's equation which is termed the hydraulic conductivity.

Hydraulic conductivity is defined as the volume rate of flow of water through a unit area of soil under a unit gradient and is a measure of the ability to conduct water under a unit hydraulic potential gradient. This term is dependent on available moisture.

Saturated conductivity represents the soil conductivity when the soil is saturated. Field saturated hydraulic conductivity refers to the saturated hydraulic conductivity of soil containing entrapped air. It is more appropriate than the truly saturated hydraulic conductivity for vadose (unsaturated) zone investigations because, by definition, positive pressure heads do not persist in unsaturated conditions long enough for entrapped air to dissolve.

A number of physical, chemical and biological processes occurring in the soil may also change the hydraulic conductivity of soil with respect to water. Rapid changes in hydraulic conductivity may occur after a heavy storm. Water characteristics that affect the hydraulic conductivity are the density and viscosity.

The value of hydraulic conductivity decreases as the soil water suction increases or with increase in water content, because movement of liquid water is confined to the water filled spaces. This relationship is called the conductivity-pressure head relationship. Once the soil water suction is measured, the hydraulic conductivity for tat soil at that soil water suction can be readily calculated. Curves relating conductivity to moisture content and suction are used in the analysis of infiltration, drainage and water transport towards roots of transpiring plants. Conductivity of a soil depends to a large extent on the pore geometry which is determined by soil texture and structure. The maximum value attains when the soil is saturated and decreases with decreasing water content or increasing water tension.

The ranges of hydraulic conductivity of the different soil particle textures overlap so that water will move smoothly from one texture class to another if there is physical continuity of sizes. If that continuity is broken, water may not flow at all.

Measurement of hydraulic conductivity of soil to water or the ability of the soil to transmit water is of considerable importance for irrigation, drainage, and evaporation studies. For a saturated soil, it is a constant which relates the rate of water flow in the soil to the hydraulic gradient. Since the saturated soil transmits water at much higher rate than the unsaturated soil, the methods used for the measurement of conductivity of the latter are different from those used for the former.

In saturated soils, conductivity may be measured in the field by a number of methods or in laboratory on soil cores taken with a minimum of disturbance. While measurements of the conductivity of saturated soil may be useful, many of the processes of hydrological interest occur in unsaturated soils. Attempts have been made to calculate the conductivity of unsaturated soils (capillary conductivity) from the pore size distribution. The techniques are, however, difficult and subject to improvement in many ways. It can also be obtained from field studies of water movement using tensiometers to follow changes in suction.

Laboratory methods - constant head method, falling head method

Field methods -
below water table - piezometer method, auger hole method
above water table - shallow well pump-in method, cylinder permeameter method, double tube method.

Evaluation of field saturated conductivity using Guelph Permeameter is described in Appendix.

Empirical evidence and intentive reasoning indicate that conductivity increases with increasing particle size. It was generally found that hydraulic conductivity is proportional to the second power of particle size. Later on researchers replaced the particle diameter with the effective diameter, since the diameter of soil particles is not uniform. Small particles mixed into a soil will decrease its hydraulic conductivity. It is obviously affected by structure as well as by texture, being greater if the soil is highly porous, fractured, or aggregated than it is highly compacted and dense.

2.4 INFILTRATION

Infiltration is defined as the movement of water from the atmosphere to the soil across some definable but intangible interface. It is reported in units of depth per hour. Infiltration might best be regarded as a concept because one cannot see or directly measure it without influencing its value. However it may be approximated by a variety of different methods and the concept itself is useful in understanding the critical zone where precipitation or snowmelt first encounters the porous medium, the properties of which will determine how the water ultimately arrives at the stream.

Infiltration results from the combined forces of capillary and gravity. The initial high rate is due to the physical attraction of soil particles to water or the metric potential gradient. The rate at which net precipitation enters the soil surface depends upon several soil surface conditions and the physical characteristics of the soil. The maximum rate at which water can enters the soil surface is called infiltration capacity. The actual infiltration rate equals the infiltration capacity only when the rainfall rate equals or exceeds the infiltration capacity. When rainfall intensity is less than the infiltration capacity the rate of infiltration equals rainfall intensity.

The infiltration proce. s is of great importance and it affects many aspects of Hydrology and Agriculture. Runoff, one of the important component of the hydrologic cycle, is determined by subtracting from precipitation, the abstractions that occur in the drainage basin. The most important abstraction affecting runoff is the portion of precipitation that is lost to infiltration. It determines the water content of the soil and also related to evapotranspiartion.

In water management and conservation studies, accurate information on the rate at which different soils will take water under different field conditions is required. The rate of water entry into soil varies widely between different soil types and also within a single soil type, depending upon the soil water content and management practices. Quantitatively, infiltration rate is the volume of water entering into the soil per unit area in unit time, when the soil is subjected to a shallow depth of ponding at the surface.

The infiltration rate as a function of time defines the infiltration curve. This rate is determined by several factors. Since the capillary forces are the strongest when the soil is dry, the rate of infiltration is more at the beginning of precipitation, for a soil type and antecedent moisture condition. As the time progresses, the resistance to the forces acting on the water increases and the rate of infiltration decreases; as a result a constant rate of infiltration attains after some interval when the soil is fully saturated. This is known as ultimate infiltration capacity. Soils with different characteristics and different cover have different infiltration capacities. It is possible to modify infiltration through suitable soil and crop management practices.

Thé parameters, infiltration rate and ultimate infiltration capacity, and the decay of infiltration capacity are function of the soil, moisture condition, vegetation, rainfall intensity, and soil surface conditions.

Horton infiltration equation is,

$$f = f_C + (f_0 - f_C)\ e^{-\alpha t}$$

f_o , f_C and α are parameters to be estimated from data.

In very large areas, for slow responses, and for storms of long duration, the time distribution of infiltration may not be very important. Under these conditions, we may assume that infiltration occurs at a constant rate.

The infiltration capacity of a soil depends on several factors, including texture, structure, surface conditions, the nature of soil colloids, organic matter content, soil depth or presence of impermeable layers, and the presence of micropores within the soil. Soil water content, soil frost, and the temperature of soil and water all influence infiltration characteristics of a soil at any point in time. Many of the above factors are also influenced by landuse and vegetation management practice.

Factors affecting infiltration:

1. Factors that affect the surface entry, profile transmission characteristics and water storage capacity (texture, structure, organic matter, soil compaction, hydraulic conductivity, soil water content, pore size distribution, swelling, and shrinking etc).
2. Factors that affect properties of water (quality, temperature and viscosity).
3. Rainfall characteristics.
4. Factors that are affected by surface features (slope, vegetation and surface roughness).

Measurement of infiltration:

Measuring infiltration and infiltration capacity is difficult, since both are influenced by the rate of application. However, the generally used methods are given below.

1. Flooding infiltrometers:

The flooding type infiltrometer uses a cylinder that is driven into the soil. Water is added and maintained at a specified depth in the cylinder and the amount of water needed to maintain the constant depth is recorded at specific times. There are different types of flooding infiltrometers.

a)Single ring infiltrometer - rejected because of errors due to lateral movement of water in the soil under the ring.

b)Double ring infiltrometer - outer ring will supply the water that might migrate laterally and at the same time saturate the soil next to the inner ring.

c)Single ring portable infiltrometer - provides an inexpensive, simple way to make infiltration measurements.

Most often, a double-ring infiltrometer is used in which one cylinder is placed inside another. Water is added to both cylinders or rings but measurements are made only in the inner ring. The outer ring provides a buffer that reduces boundary effects caused by the cylinder and by lateral flow at the bottom of the ring.

This method is easy and relatively inexpensive to apply, but the positive head of water usually is thought to cause higher infiltration rates than might occur from rainfall. Double ring infiltrometers are useful for obtaining comparisons of infiltration rates for different soils, sites, vegetation types, and treatments.

2. Rain simulators:

Objection to flooding infiltrometer is the necessary ponding of water and the accompanying hydrostatic head such infiltrometers place on the infiltrating water. A further objection is the absence of the effect of raindrop impact on soil. In order to cope with these, a rainfall simulator infiltrometer is developed. These, either apply water to the soil surface in a manner that simulates rainfall (sprinklers) or provide a system for which natural rainfall events can be evaluated. The runoff plot has a boundary strip that forces any surface runoff to flow through a measuring device. Rainfall simulators can be adjusted to represent different drop sizes and rainfall intensities. This approach is more costly and difficult to apply in remote areas. Infiltration capacities determined by this approach should be more representative of actual infiltration capacities than those determined by flooding type infiltrometers. However, studies have shown that there is a consistent relationship between infiltration capacities determined by the two methods.

3. Hydrograph analysis:

It is possible to obtain a reasonable estimate of infiltration of a drainage basin by analysing the runoff hydrograph and measured rainfall. The hydrologic budget requires accounting for evapotranspiration, depression storage, and interception.

4. Empirical evaluation of average infiltration:

a)Correlation with related variables - drainage basin infiltration can be related to such variables as median-grain diameter, drainage density, runoff volume, and sediment yield.

b)Indices - ϕ index is the mean infiltration rate occurring for the duration of the storm. This means infiltration rate is the rainfall rate above which the rainfall volume is equal to the runoff volume. W index refines the ϕ index, by including interception and depression storage.

Infiltration application focus mainly on increasing the natural supply of underground water, both for use by plants and for recharging the underlying groundwater reservoir.

Large quantities of water can readily infiltrate sandy soils as there are considerable large, interconnected pores. However the tensions at which much of the water is held in sands is quite low and water will penetrate the profile rapidly and drain out. There is no sufficient tension to hold the water back against the force of gravity. In contrast, clay hold more of the water at very high tensions; more water may be drawn into a clay soil rapidly by capillarity, and a greater proportion of the water in the pore space will be held at higher tensions than in the sand. The result is that, clays will not give up drainage water rapidly since the force of gravity is too weak to remove the water from its high tension bond with the small clay particles. Water may be held at even higher tensions and in response to chemical bonds too in colloidal suspensions within the soil. Viscosity plays a major role here, its influence in retarding flow being greater in the fine- textured soils.

Under natural, undistributed condition in the forest, infiltration capacity is almost always high enough to preclude overland flow. If the soil surface is severely distributed infiltration rates may suffer drastic reduction, sometimes to as low as zero. With varying degrees of disturbance and protection, infiltration may recover to pre-disturbance rates, especially with adequate protection and occurrence of frost which restores permeability. On natural rangelands, where there is often insufficient annual precipitation. to support forest growth and to attend faunal activity within the soil, recovery of infiltration will need assistance from man, including removal of the reduced infiltration and mechanical breakup of the surface. In contrast, infiltration rates that have been decreased by the logging activities on forest lands will tend to recover without assistance other than cessation off logging.

Quantification of infiltration and infiltration capacity has been the subject of a large number of studies, with most of the successful measurement being made on disturbed, nonforested lands, especially crop and rangelands. The sprinkling infiltrometers appear to be most successful but cannot be used on forested lands. The only way in which to obtain reliable infiltration capacity data for forested soils is to combine precipitation, and runoff records with the field observations.

3.0 PRESENT STUDY

3.1 STUDY AREA

Our country was faced with difficult food situation in early seventies which was further aggravated during the severe drought of 1972. To improve the food productivity through irrigated agriculture, the area development approach was devised and thus, the Command Area Development (CAD) was evolved during 1973-74 and in 1974, Command Area Development Authorities were constituted for selected minor irrigation project, command areas.

Eastern part of Belgaum district and the whole of Bijapur district are frequently subjected to famine and scarcity conditions with frequent crop failures. Large scale irrigation facility by utilising the water resources of the rivers and streams that flow through this region can redress these situation. By considering this fact and in sequence to the national policy, the CADA for Malaprabha and Ghataprabha Projects was constituted in 1974 by Karnataka State.

To harness the waters of the Malaprabha and Ghataprabha rivers, the two main tributaries of river Krishna, storage reservoirs at Naviluteerth in Soundatti taluka and Hidkal in Hukkeri taluka were constructed to impound 1877 M cum and 2202 M cum respectively, running two canals on either banks and, coupled with weirs and lift irrigation schemes on the foreshores. These two projects envisage irrigation of 2.17 lakh hectares and 3.18 lakh hectares respectively, in Belgaum, Bijapur and Dharwad districts.

These two projects are designed to utilize the allocated water of 1877 M cum and 2202 M cum respectively. The cropping pattern assumed, during design is 40% kharif, 20% biseasonal and 40% rabi in case of Malaprabha project and 40% kharif, 10% biseasonal, 10% perennial (water given for 8 months) and 40% rabi for Ghataprabha project.

The command area of Ghataprabha lies between 16°00'08" to 16°88'09" N latitudes and 74°26'43" to 75°56'33" E longitudes. The entire area is undulating. Elevation of command area ranges from 1700 ft to 2520 ft. The left branch canal which is operational, runs along the ridge line West to East, almost dividing the area between the river Krishna in the North and Ghataprabha in the South, into two. In general, soils of Ghataprabha flanks are coarser textured than the soils of Krishna flank. The location of the study area is shown in figure 1.

The climate is semi arid with moderate to severe summer and moderate and low erratic rainfall. This area receives rains during both SW and NE monsoons. Dry weather with high temperature prevails during April and May, creating drought conditions. The areas of Jamkhandi, Biligi, and Gokak taluk receive comparatively more rainfall (516 mm) with Mudhol, Raibag areas receive 346mm and 250mm rainfall respectively.

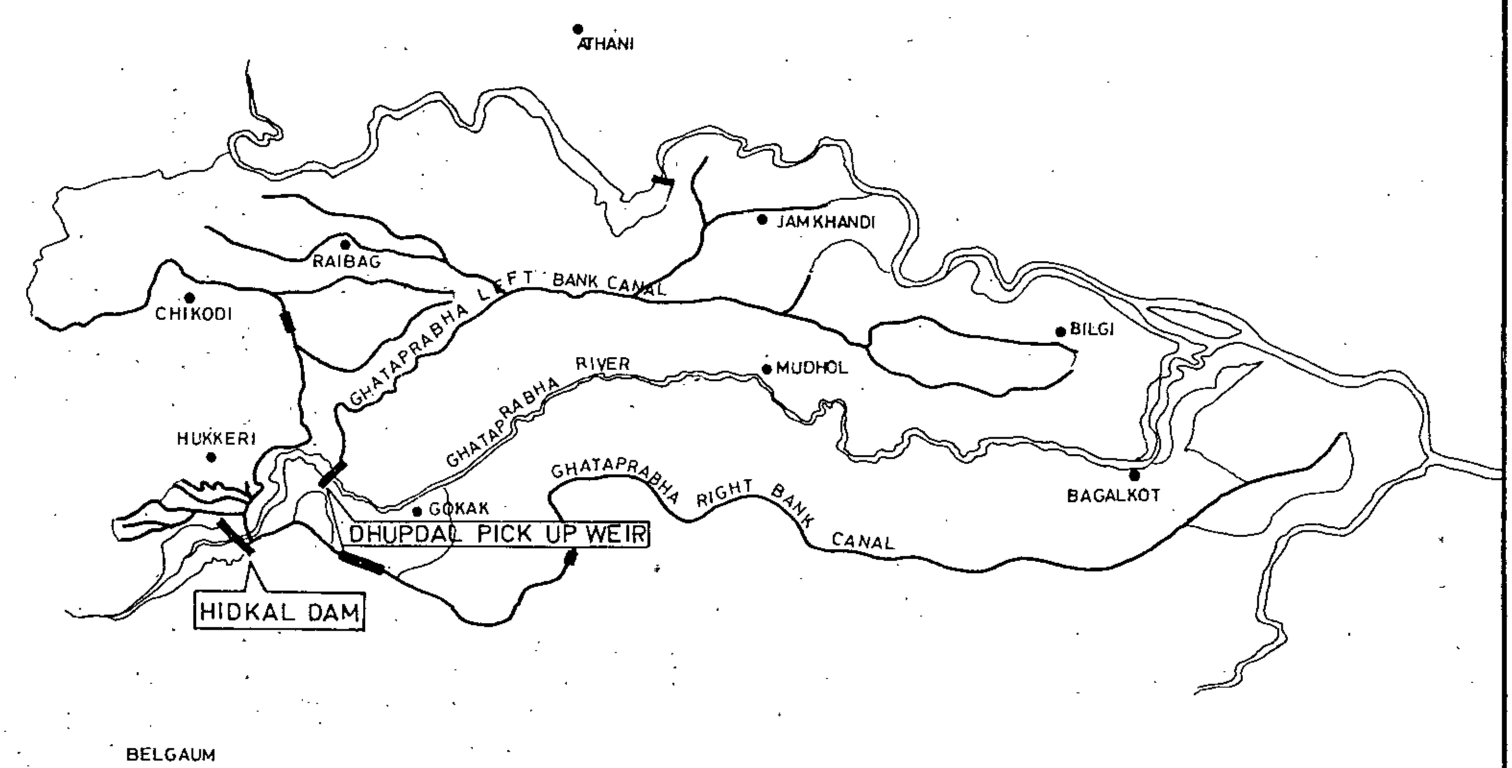

FIG-1 LOCATION MAP OF GHATAPRABHA COMMAND AREA.

In the North and North-East, there are quartzite ridges in Mudhol and Jamkhandi taluks having maximum elevation of 1998 to 2137 ft. The ridges are covered with shrubs, grasses and mixed trees. There are isolated resistant quartzite hillocks in some parts of Jamkhandi taluk, the maximum height of which varies from 1750 ft to 1998 ft. Besides this, there are some small ridges with poor vegetative growth throughout the area. The ridges are strewn with boulders and stones. Shallow and coarser soils occur on the uplands and deeper finer soils in the low lying area and along the nallas.

Geological features of the area are:

1. Archean - These occupy very small areas of Biligi and Gokak. Granites and Gneisses are grey to greyish white, hard and compact and comprise quartz, feldspar and ferromagnessium minerals. They generally disintegrate and weather into reddish to reddish brown soil.

2. pre-cambrian - The Kaldgi rocks constitute the East West ridge covering Jamkhandi, and consist of conglemerates, grits, sand stones and quartizites. Very small portion around Gokak falls are covered by thick pile of sand stone and qurtizite beds. On disintegration and weathering, these give rise to loose sandy soils. Low lying areas are covered by shales, phyllites and lime stones.

3. Secondary - The Deccan trap, the most widely occuring rock formation in the area comes under this group. These are the most recent formation in the area. The basalt occupy low lying areas and overlaying the kaladgi series of rocks.

The flora is distinctly of dry deciduous type. Hariyali grass is the most common variety of grass. Uplands are covered by long and short varieties of foxtail grass.

Out of the total geographical area of 394710 acres, an area of about 132453 acres come under Kharif, and 298462 acres under Rabi. Mainly Cotton, Jower, Wheat, Bajra and Maize with ground nut, and pulses are grown. Oilseed crops are also grown as mixed crop to a small extent. Sugarcane, Hybrid Maize, Cotton, Vegetables, Fruit crops are grown under irrigation to a small extent.

The entire command area is irrigated by a network of a number of distributaries and outlets. Each distributory serves as an independent area which is separated from the other distributaries by natural drains. At places the natural drains have been blocked, which have given rise to water logging problem.

The violation of cropping pattern is more common and the feeling of scarcity of water supply makes the farmer to draw more water than necessary. Thus, equitable distribution of water is totally disrupted. The total absence of constructed field drains coupled with over irrigation has resulted in raising up of ground water table and in certain patches of vertisole, the water logging and salinisation has damaged the valuable lands to the extent of 8606 hectares in these two projects together.

Different measures are being taken up to reclaim the damaged land. The link and natural drains are desilted and deepened to drain off the subsoil water. Studies conducted by the combined efforts of University of Agricultural Sciences, Dharwad and ICAR have shown that application of chemicals like gypsum etc will solve the problem to some extent. Efforts are afoot to formulate schemes for reclaiming the damaged land. Conjunctive use of water, which is in vogue in parts of Ghataprabha command is promoted on an extensive scale in the commands of either schemes.

3.2 METHODOLOGY

For the estimation of hydraulic soil properties, 7 typical regions were selected, having different combinations of soil-geology combinations, in the Ghataprbha Command Area. On natural catchments, there are spatial variations in the supply rate to the surface of the soil. They arise from not only spatial variations in the properties of the soil matrix but also due to many other factors such as land use pattern, geology etc. To understand such variations under different land use pattrens, in each of these regions, test sites were fixed on agriculture and fallow land.

For the estimation of infiltration and saturated hydraulic conductivity, double ring infiltrometer and Guelph permeameter were set up side by side with sufficient gap between them which ensures undisturbed field conditions.

Both the inner and outer rings of double ring infiltrometer is driven into the ground for about 20 cms. Water is supplied to inner and outer rings. The fall of the water level in the inner ring indicates the depth of water infiltrated. The amount of water to replenish the water level in the inner ring to reach a pre-determined level is measured which represents the amount of infiltration. The readings were taken at definite intervals till a constant amount of water to replenish the water level is obtained. This constant value is the ultimate infiltration capacity. Infiltration curves were drawn for each sites with time on X-axis and infiltration rate in cm/hr. on Y-axis.

For the determination of saturated conductivity, a hole was made to 1 feet depth and the Guelph permeameter set up is centrally placed over it. With all the valves of the permeameter closed, water is filled through the reservoir top cap. A pressure head of 5 cm is established by slowly raising the air inlet tube. This pressure head allows the water to flow into the hole and move through soil strata. The flow rate is noted periodically as the rate of fall of water in the inner reservoir / in the combined reservoir of the permeameter. When the rate showed a constant value for consecutive time intervals, the pressure head is increased to 10 cms. and the procedure is repeated. Using the constant rate of fall for both the pressure heads and reservoir constants for the permeameter used, saturated hydraulic conductivity is calculated for that site. Soil samples were collected from all test sites by excluding the topmost soil layer and is used for laboratory tests.

Sieve analysis has been performed for each of the samples (for particles greater than 75 microns) to get the particle size distribution curve for the samples. For the samples less than 75 microns, pipette analysis was performed to estimate the percentage of silt and clay.

Pressure plate apparatus was used to determine the water retention capacity of each of the soil sample for 0.3, 0.5, 0.7, 1.0, 5.0, 10.0, 15.0 bar pressures and for atmospheric pressure (0 bar). Curves were drawn for each site with pressure on X-axis and percentage water retention on Y-axis, which are called soil water retention curves.

3.3 SITE DESCRIPTION

MUDHOL - It lies about 120 km North East of Belgaum at an elevation of 590 m in Bijapur district. Ghataprabha river flows through this area.

First site selected for conducting tests was a fallow land which lies about 1 km from Mudhol on Yadwad - Mudhol road. The site is characterised by a top layer of loose sandy light brown coloured soil having high pebble content with patches of heavy weathered soil. This layer is followed by weathered basaltic rock and followed by massive less weathered rocks.

2nd site selected was an agriculture land which lies 2 km from Mudhol on Mudhol - Jamkhandi road. The site is situated about 1 km from GLBC. The readings were taken just after a moderate rainfall. Soil is of heavy loamy in texture and black coloured with 20-25 % pebbles. About 30 cms of soil is underlained by basaltic rock. main crops are Jower and Soya bean. Water logging problems exist because of the proximity to canal.

JAMKHANDI - Situated 140 km North East of Belgaum at an elevation of 650 m in Bijapur district.

First site selected was in the heart of the city. A fallow land near the BLDE College ground is used which is characterised by a top layer of fine soil underlained by sandy soil and then rock formations. Soil is dark brown in colour with medium loam texture.

Agricultural land selected for tests is located 2 km away from the city where Jower is the main crop. It is a plane land with black soil in which clay content is more.

BILIGI - Situated 150 km North east of Belgaum at an altitude of 550 m in Bijapur district.

Fallow land is selected on Mudhol-Biligi road, 5 km outside city. It is a patch of land in between predominantly agriculture area where there is no cultivation was possible for some years. Reason may be waterlogging and saltation. Upper soil layer is whitish in colour. Here also canal passes very near to area and from local farmers it is understood that this condition prevails since the inception of canal.

2nd site was agricultural land which lies 1 km away from the Biligi city. This site is characterised by lateritic soil, light brown in colour with high percentage of coarse particles.

BAGALKOT - The area is situated 170 km North East of Belgaum at an altitude of 530 m in Bijapur district.

Fallow land is selected on the side of Mudhol-Bagalkot road, 5km from Bagalkot. It is partially covered with shrubs. The site is characterised by loose black soil at the top layer and clayey soil of heavy loam texture at the bottom. Gravels/pebbles of different sizes are seen above the soil layer.

Agriculture land is selected again on the outskirts of the city where the major crops are onion, tur daal etc. Black, clayey soil with loose soil in the top layer and sticky in the bottom layer.

GOKAK - Gokak lies about 50 km. North East of Belgaum at an altitude of 740 m in Belgaum district. Tests were conducted on an agricultural land where sugarcane is grown. Ghataprabha river flows very close to this area. Topographically, there are lot of variations. It consists of black soil with medium loam texture. Soil is salty as per the information received from local farmers and water logging problems exist.

Fallow land selected for the tests is located adjacent to the above site. Soil properties are almost the same as the agriculture land.

RAIBAG - Raibag lies about 75 km. North East of Belgaum at an elevation of 630 m. Ghataprabha Left Bank Canal passes through this area. Agriculture land where tests were performed shows natural terraced structure. Soil is light coloured with light loamy texture. Tests were also conducted on a fallow land where the soil is black cotton with heavy loam texture.

HIDKAL - Hidkal is situated about 45 km. North of Belgaum at altitude of 660 m in Belgaum district. The dam is located across Ghataprabha river at Hidkal in Hukkeri taluk, which supplies water to the command area.

Agriculture land where test were performed lies very close to the reservoir. Land is covered by coconut plantation. It is characterised by light loam soil with light reddish colour.

Most of the area of this taluk is covered by agriculture land. A small portion is covered by barren land where land is very hard and it was not possible to conduct tests since it was not possible to drive the rings.

4.0 RESULTS AND DISCUSSION

The results from the field and laboratory tests for the different regions in the Ghataprabha Command Area are as given below:

4.1 Particle Size Distribution

The grain size analysis and its interpretation has a fundamental role in irrigation, hydraulics, geomorphology and sedimentology.

Sieve analysis and sedimentation analysis were performed on 11 samples collected from the study area. Particle size distribution curves for the particles upto 75µ are presented in Figures 2 to 8. Also Table 1 shows the sand - silt - clay percentages of each of these samples.

The mean grain size of the soils varies from 218µ to 6166µ . Median values range from 170µ to 6600 µ . Statistical analysis of the grain size indicates that in most of the region, the samples are well sorted. However, at Mudhol, soils are moderately to poorly sorted. By analysing the (silt+clay) percentage for the samples, it can be seen that out of 11 samples, 7 samples are having more finer particles and 4 samples are having a major portion of coarser particles.

The results show that the two samples from Biligi differs widely in distribution of its constituent particle sizes. Coarser particles are predominant in the agriculture land whereas fallow land consists of finer particles in large percentage. For the other regions, from where two samples were collected, the samples show almost same distribution pattern for the two land use pattern selected.

Sand, silt, and clay percentages show that coarser sediments are distributed at Mudhol (both for agriculture and fallow land), Biligi (agriculture land), Jamkhandi (fallow land) and at Hidkal. These grain size parameters play a major role in the process of hydraulic conductivity, infiltration and soil moisture retention. Sorting coefficient indicates that the sediments are not insitu in nature, except at Mudhol agriculture land, these are transported through geological and hydrological processes and distributed over that region. Therefore the surficial characteristics alone will not reveal the natural process and it requires subsurface studies.

4.2 Soil Moisture retention

Percentage moisture retention values were determined (as shown in Table 2) for the 11 samples collected from the study area for 0.1, 0.3, 0.5, 0.7, 1, 5 10, 15 bar pressures and for atmospheric pressure (0 bar). The retention curves for the samples are shown in Figures 9 to 15. Generally it is expected that the dry soils of fallow land may show higher affinity towards water. However this is controlled by distribution of

TABLE:1 PARTICLE SIZE DISTRIBUTION FOR THE STUDY AREA

	SAND	SILT (PERCENTAGE)	CLAY
MUDHOL			
FALLOW	83.2	14.2	2.7
AGRI.	76.4	14.5	9.0
JAMKHANDI			
FALLOW	67.0	27.0	6.0
AGRI.	26.2	57.3	16.4
BILIGI			
FALLOW	31.0	41.0	28.0
AGRI.	79.0	18.5	2.5
BAGALKOT			
FALLOW	24.0	61.0	15.0
AGRI.	29.6	60.9	9.6
GOKAK	26.1	20.1	53.8
RAIBAG	40.9	37.3	21.8
HIDKAL	85.0	16.2	8.8

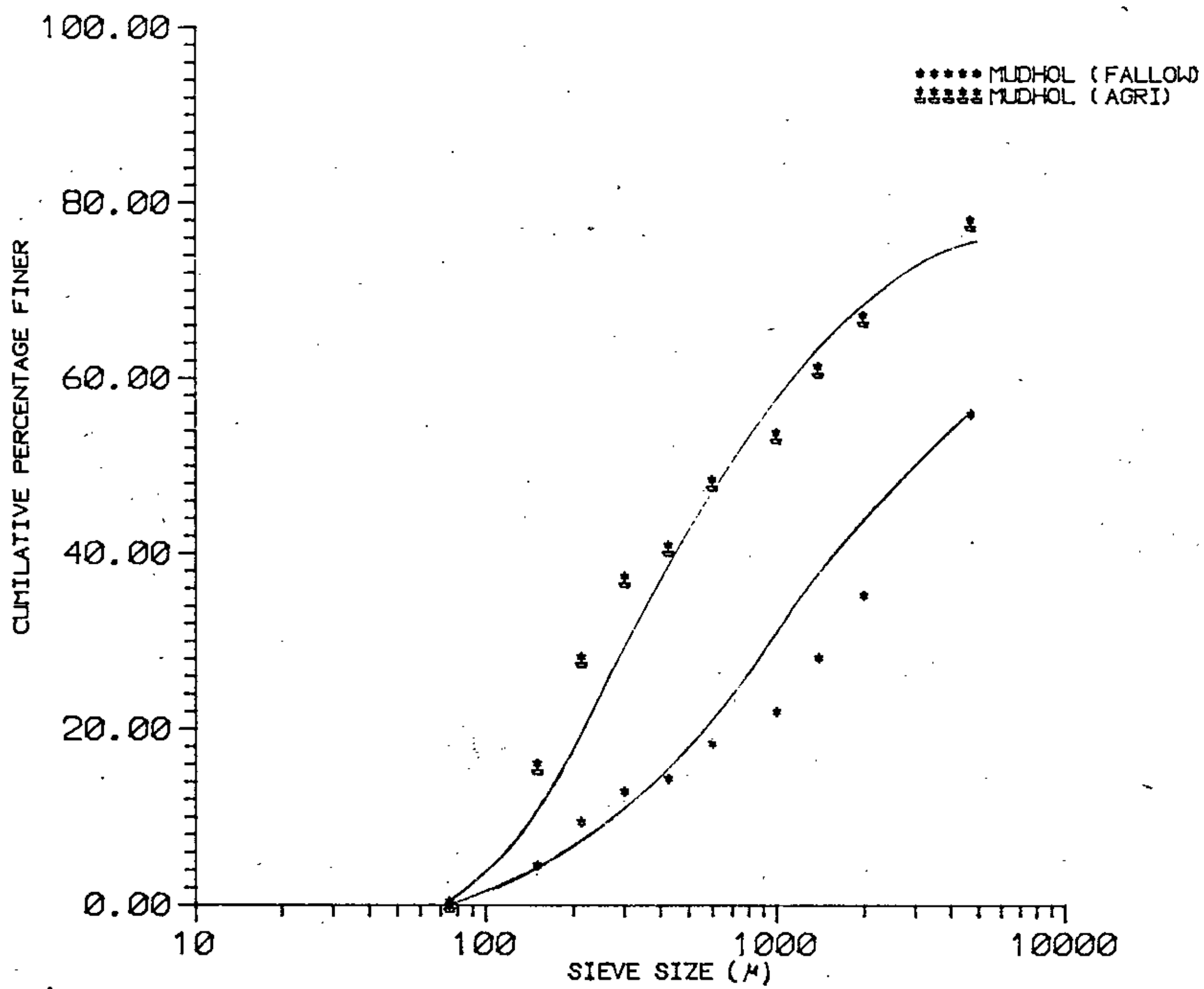

FIG: 2 PARTICLE SIZE DISTRIBUTION CURVES FOR MUDHOL

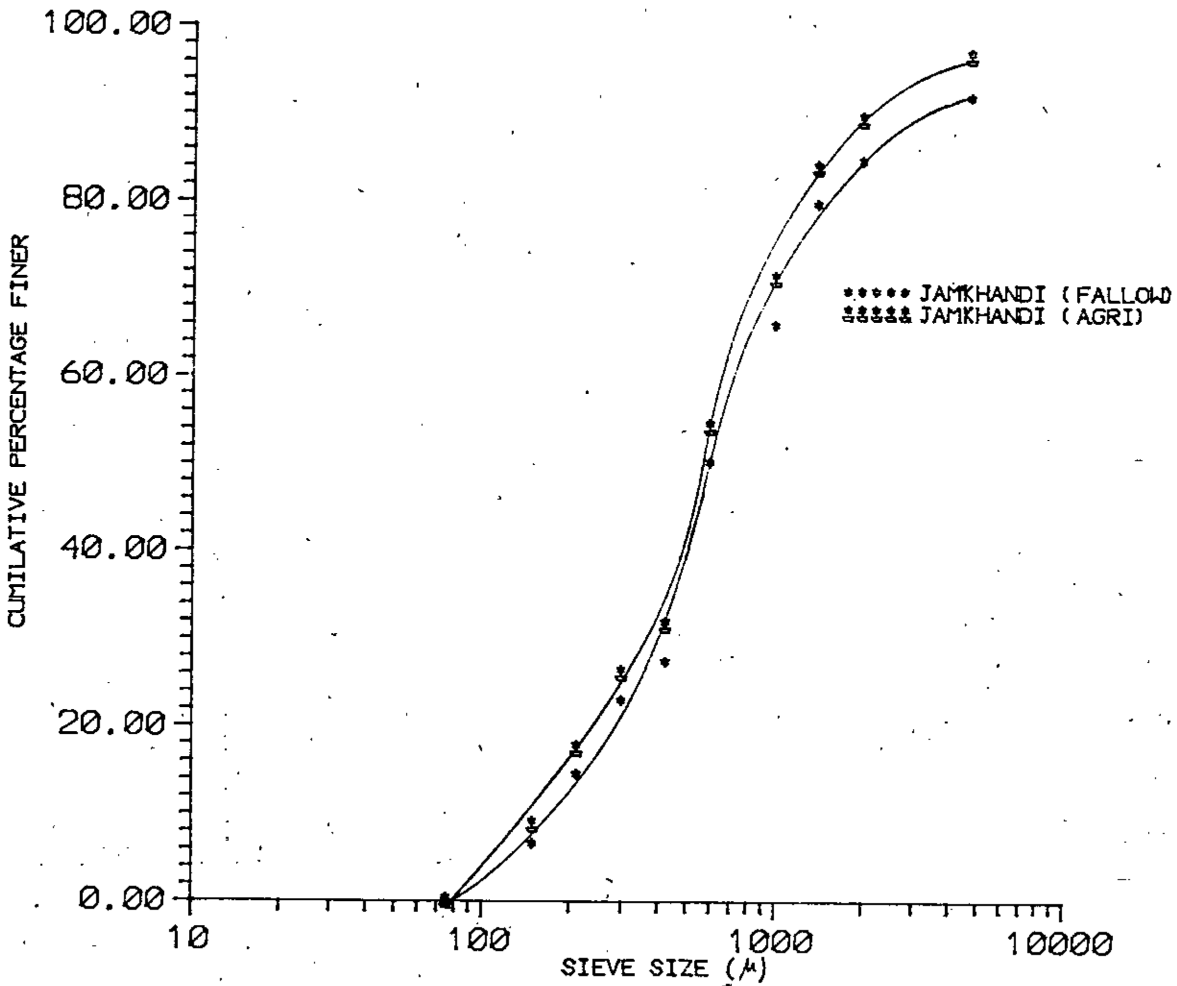

FIG: 3 PARTICLE SIZE DISTRIBUTION CURVES FOR JAMKHANDI

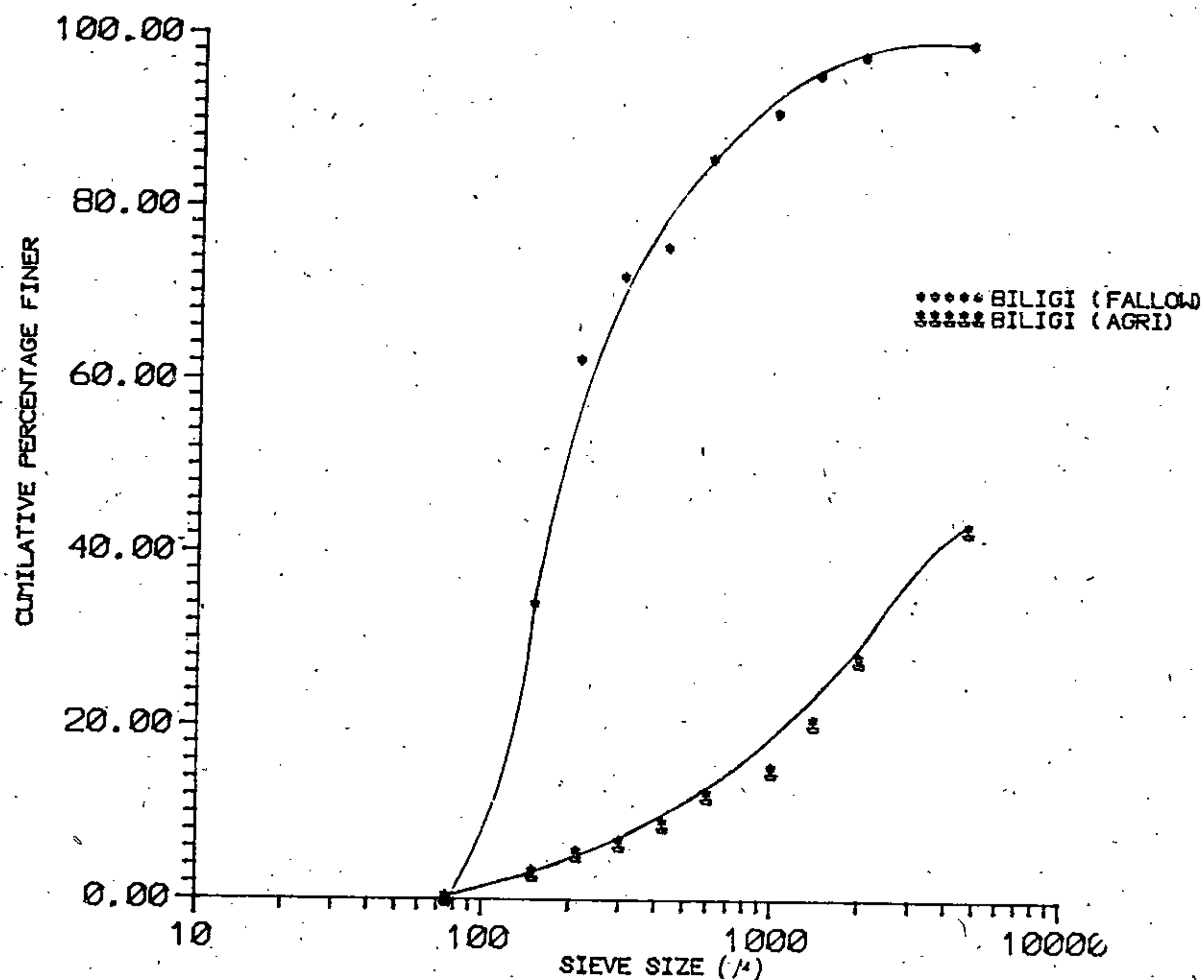

FIG: 4 PARTICLE SIZE DISTRIBUTION CURVES FOR BILIGI

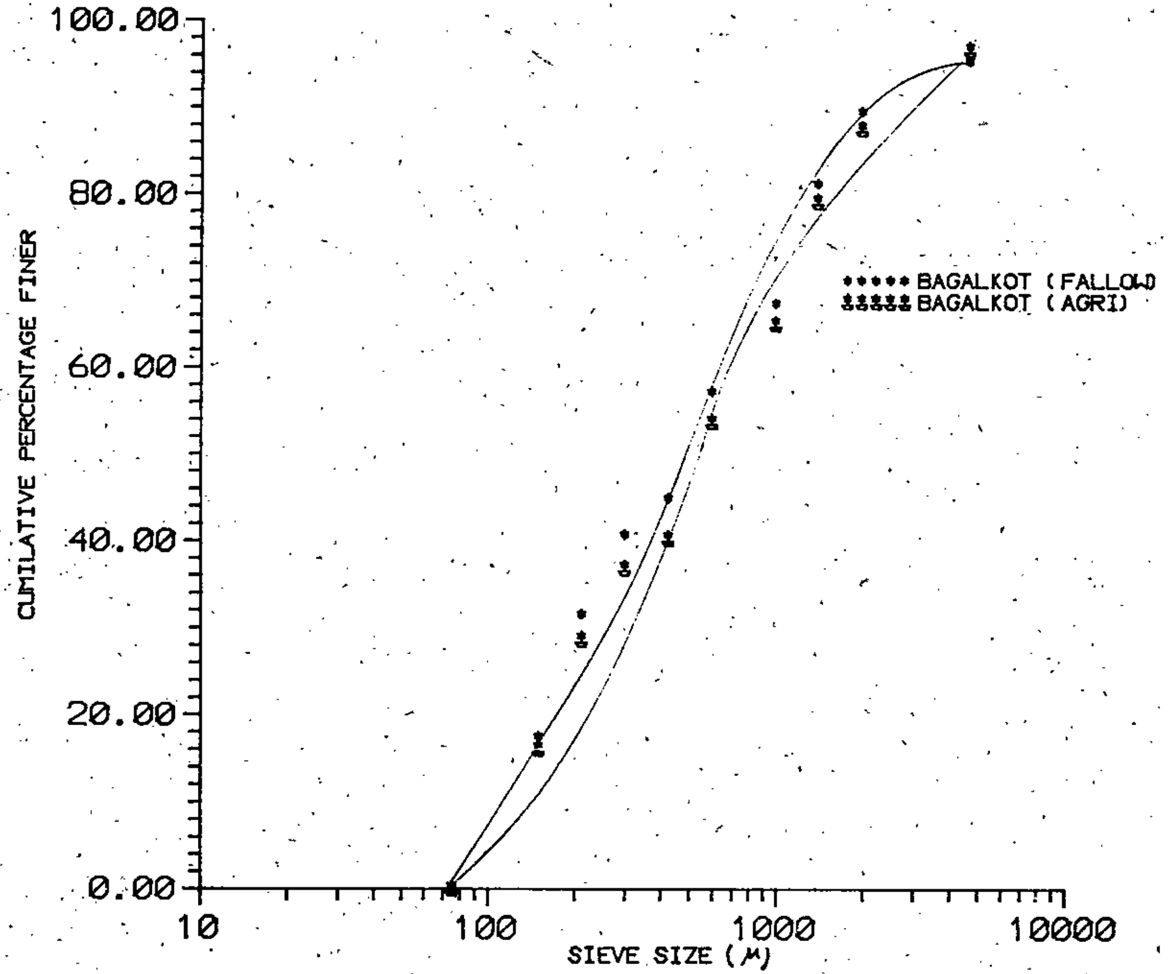

FIG:5 PARTICLE SIZE DISTRIBUTION CURVES FOR BAGALKOT

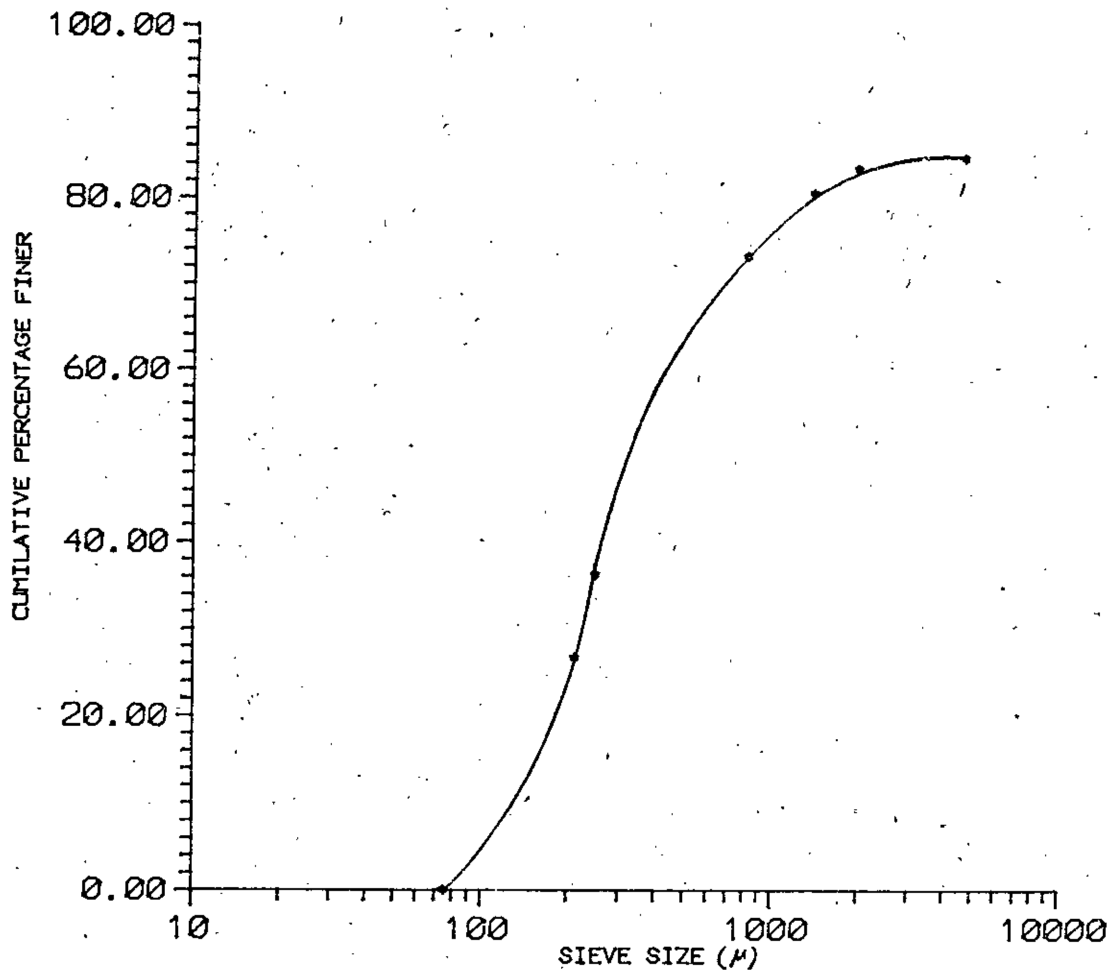

FIG: 6 PARTICLE SIZE DISTRIBUTION CURVE FOR GOKAK

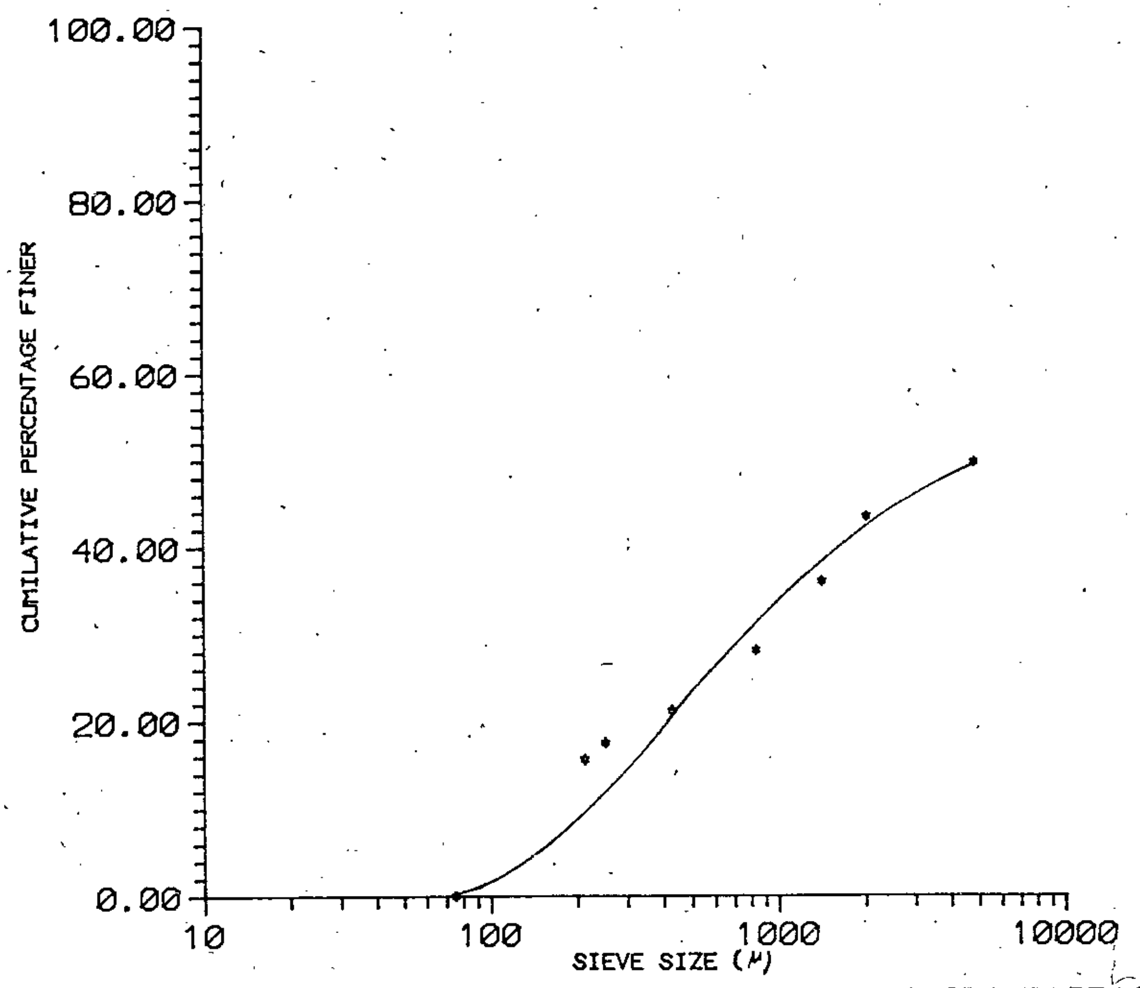

FIG: 7 PARTICLE SIZE DISTRIBUTION CURVE FOR RAIBAG

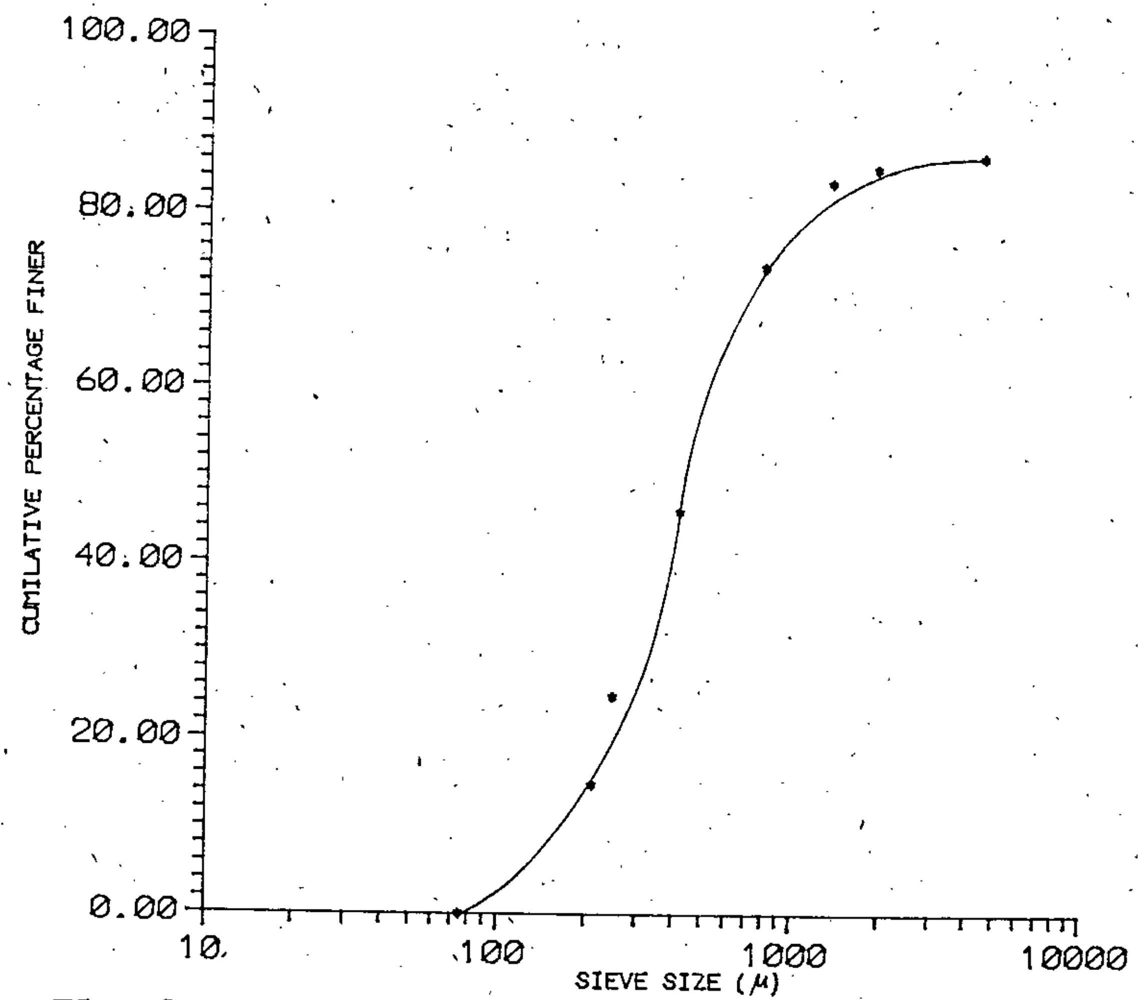

FIG: 8 PARTICLE SIZE DISTRIBUTION CURVE FOR HIDKAL

TABLE:2 SOIL WATER RETENTION (%)

PRESSURE (BARS)	0	0.1	0.3	0.5	0.7	1.0	5.0	10	15
MUDHOL									
FALLOW	49.3		23.9	19.1	19.6	18.8	15.0	12.6	12.0
AGRI.	41.2		19.2	17.0	15.0	14.1	11.3	10.0	8.7
JAMKHANDI									
FALLOW	48.7		20.1	17.3	15.2	13.2	12.6	10.8	10.0
AGRI.	88.4		33.1	30.1	29.4	24.4	23.5	22.0	22.1
BILIGI									
FALLOW	81.5		32.3	31.6	29.2	23.5	21.2	18.9	18.1
AGRI.	48.9		22.3	24.3	18.4	16.9	15.6	13.1	12.4
BAGALKOT									
FALLOW	79.6		32.1	28.1	27.4	24.1	23.5	23.9	18.8
AGRI.	80.3		28.9	28.6	28.3	22.3	21.9	22.7	17.3
GOKAK		48.9	40.4	35.3	36.8	30.9	28.7	23.2	21.1
RAIBAG		42.0	33.2	30.0	28.3	24.3	21.6	19.4	19.1
HIDKAL		13.4	7.9	6.4	6.2	6.0	5.3	4.0	4.2

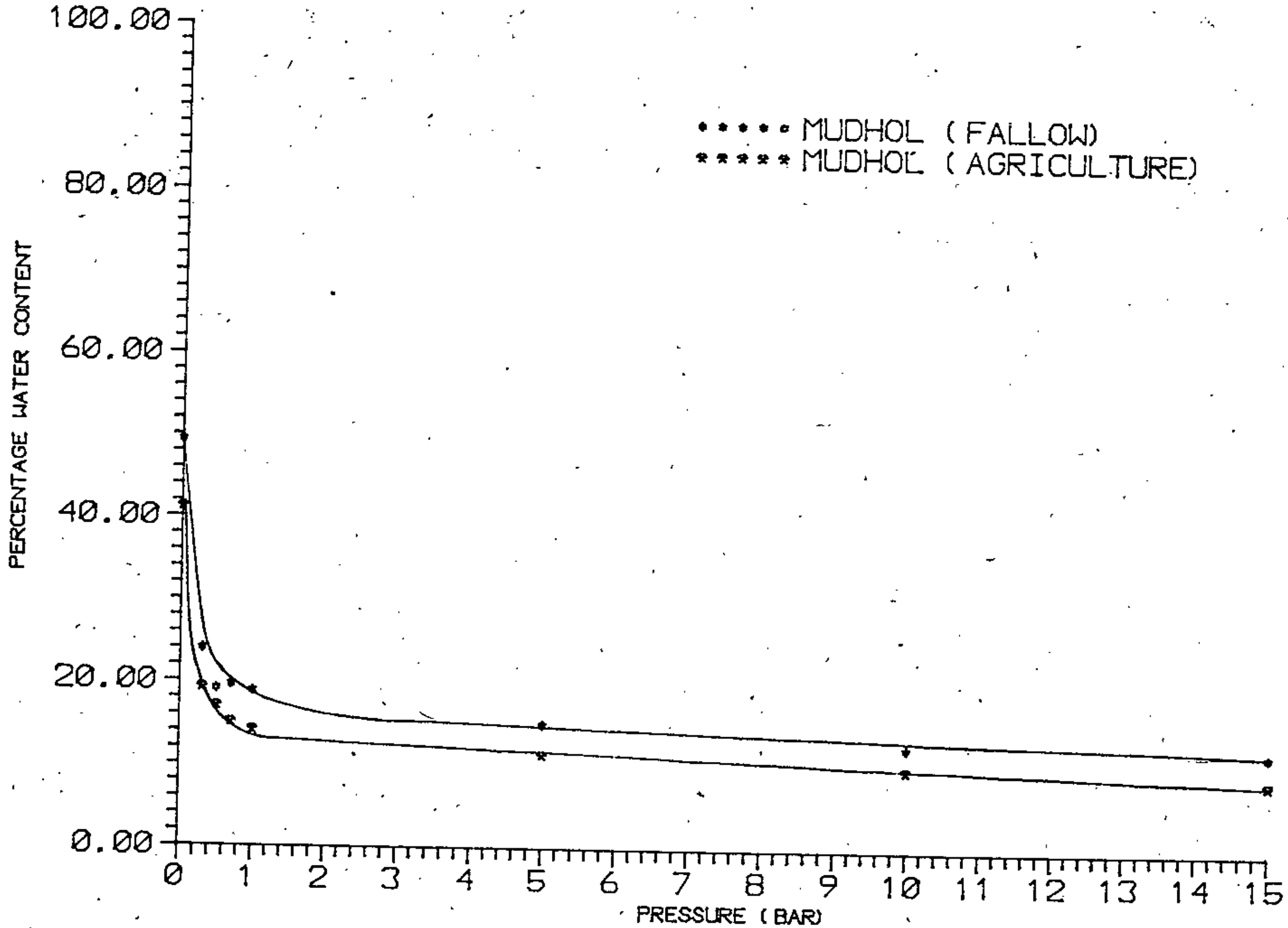

FIG: 9 SOIL WATER RETENTION CURVE FOR MUDHOL

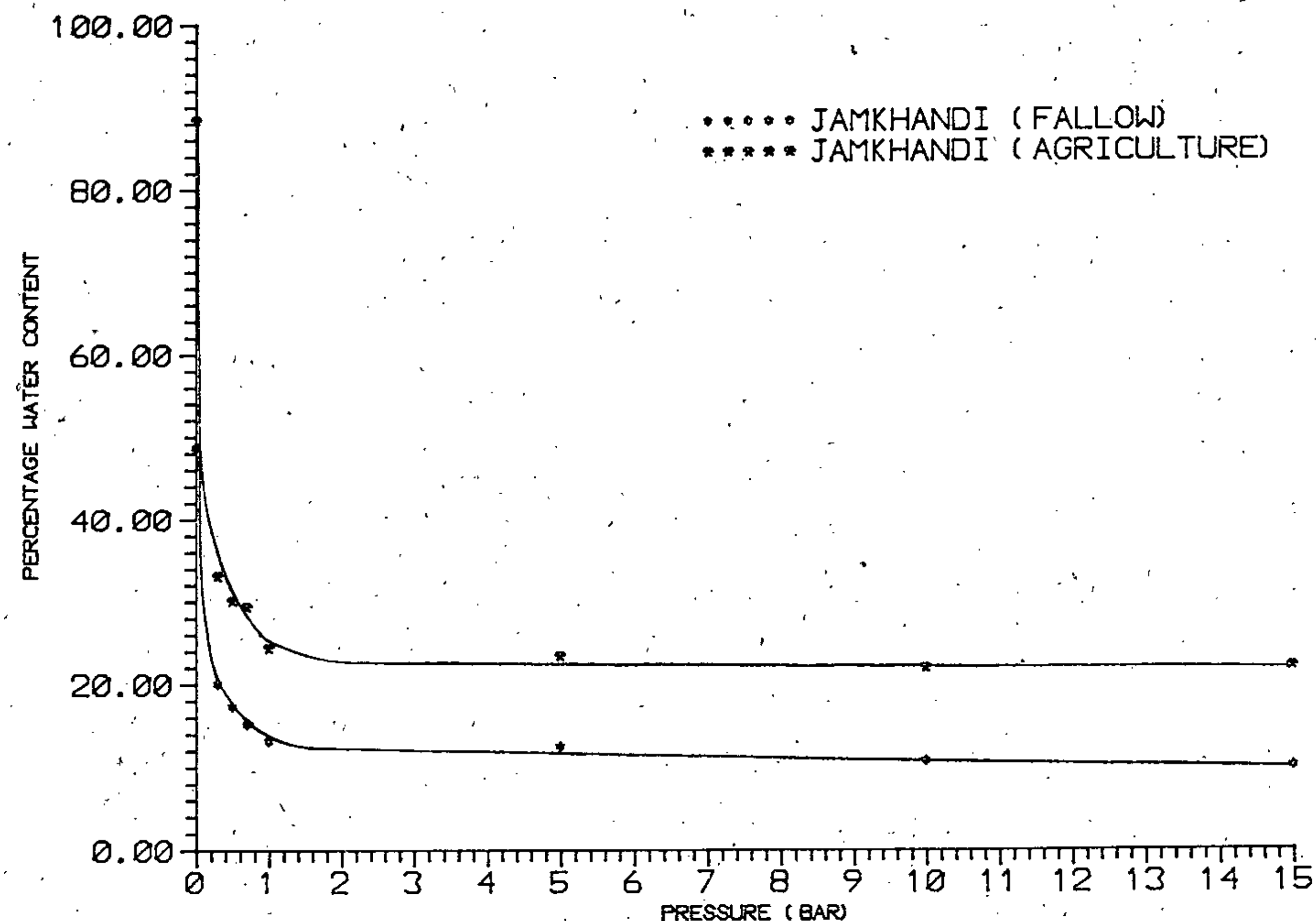

FIG: 10 SOIL WATER RETENTION CURVE FOR JAMKHANDI

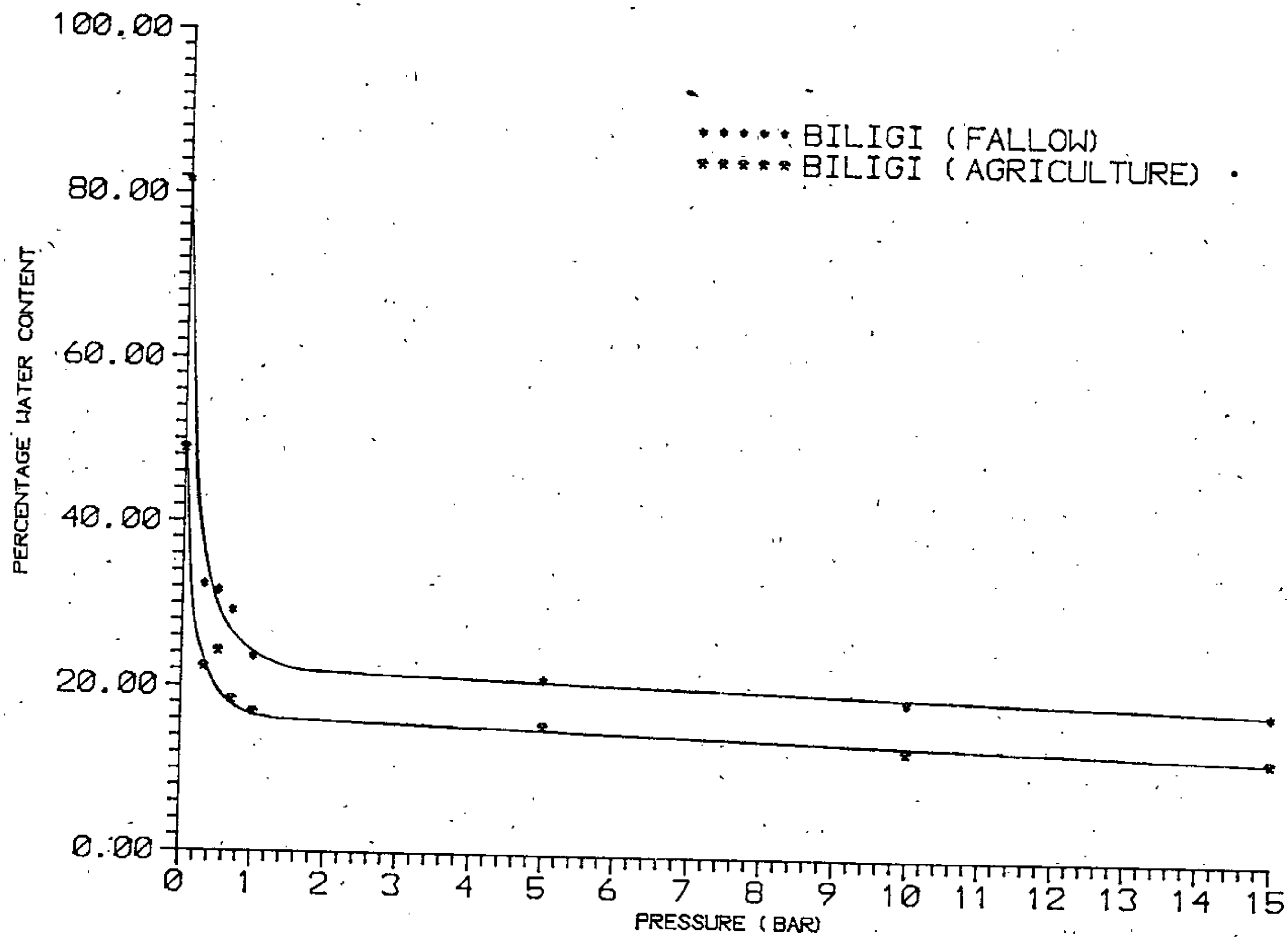

FIG: 11 SOIL WATER RETENTION CURVE FOR BILIGI

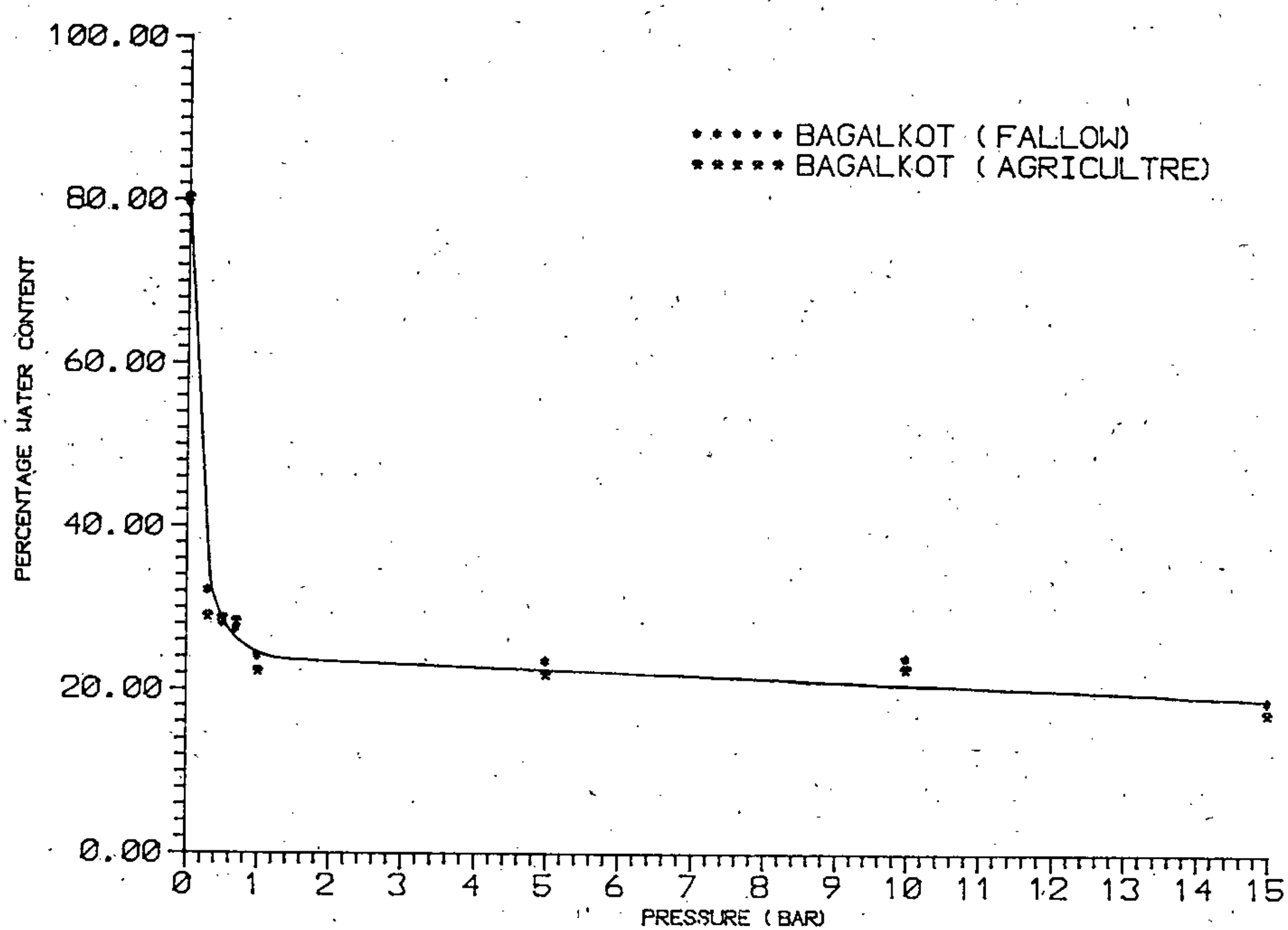

FIG: 12 SOIL WATER RETENTION CURVE FOR BAGALKOT

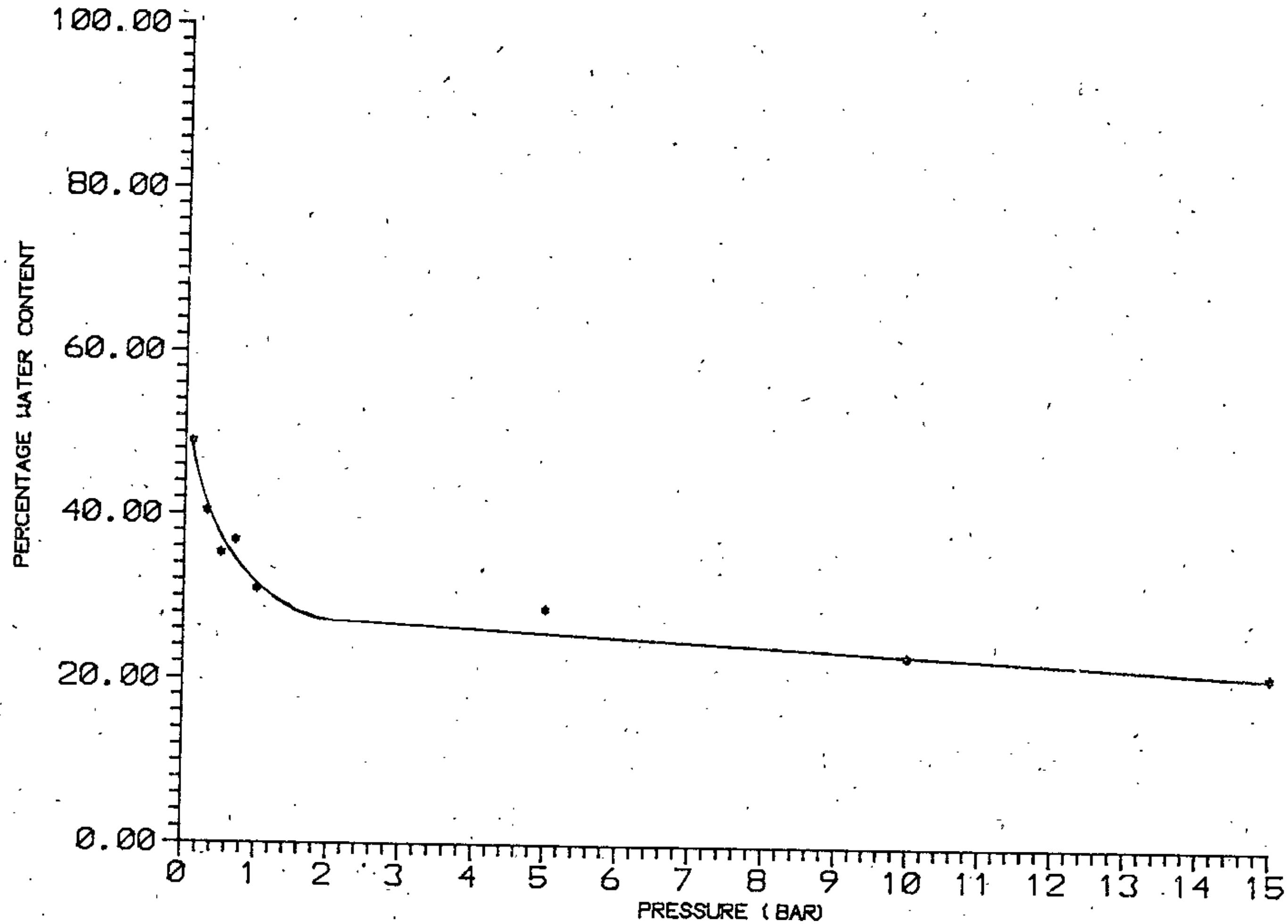

FIG: 13 SOIL WATER RETENTION CURVE FOR GOKAK

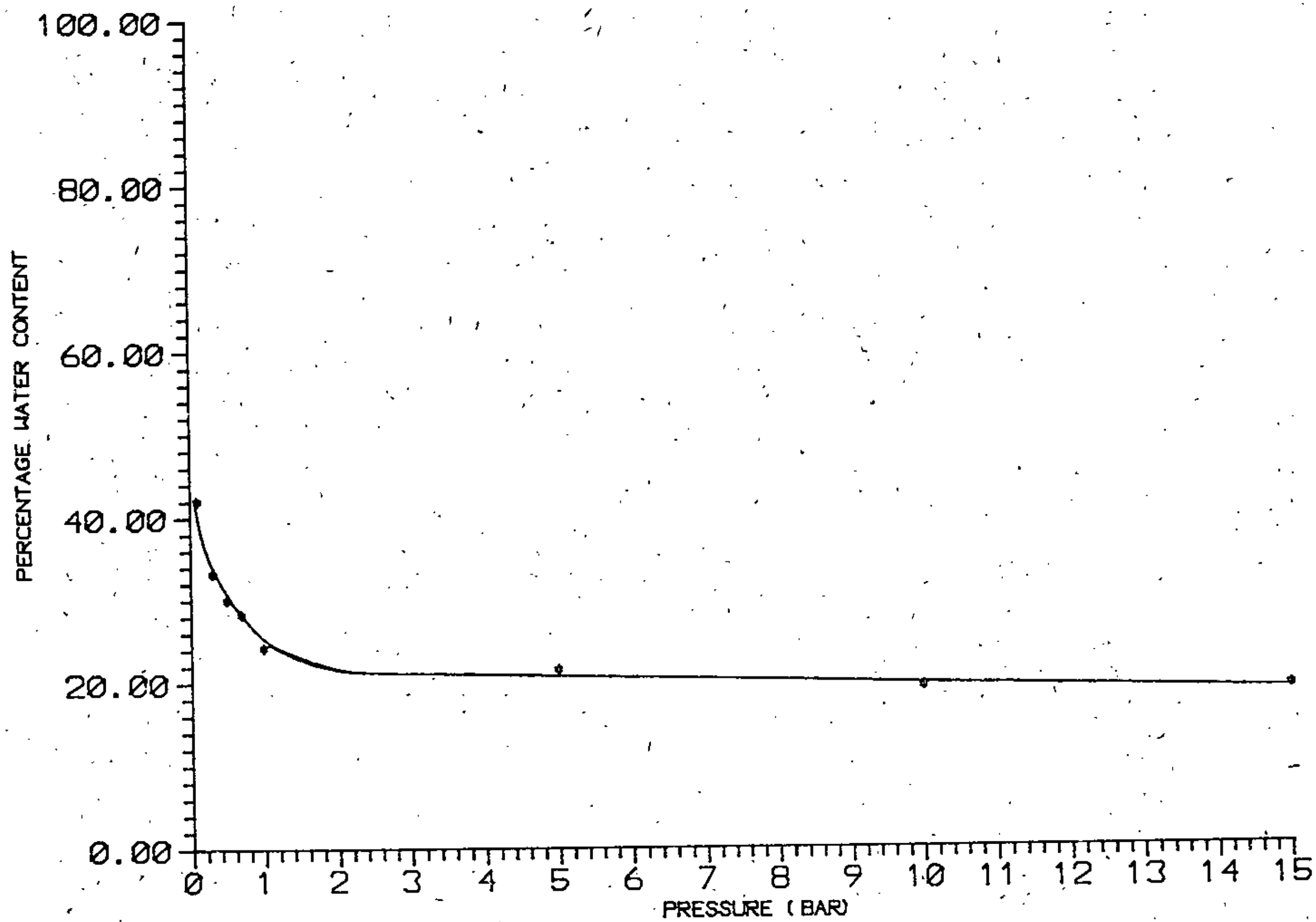

FIG: 14 SOIL WATER RETENTION CURVE FOR RAIBAG

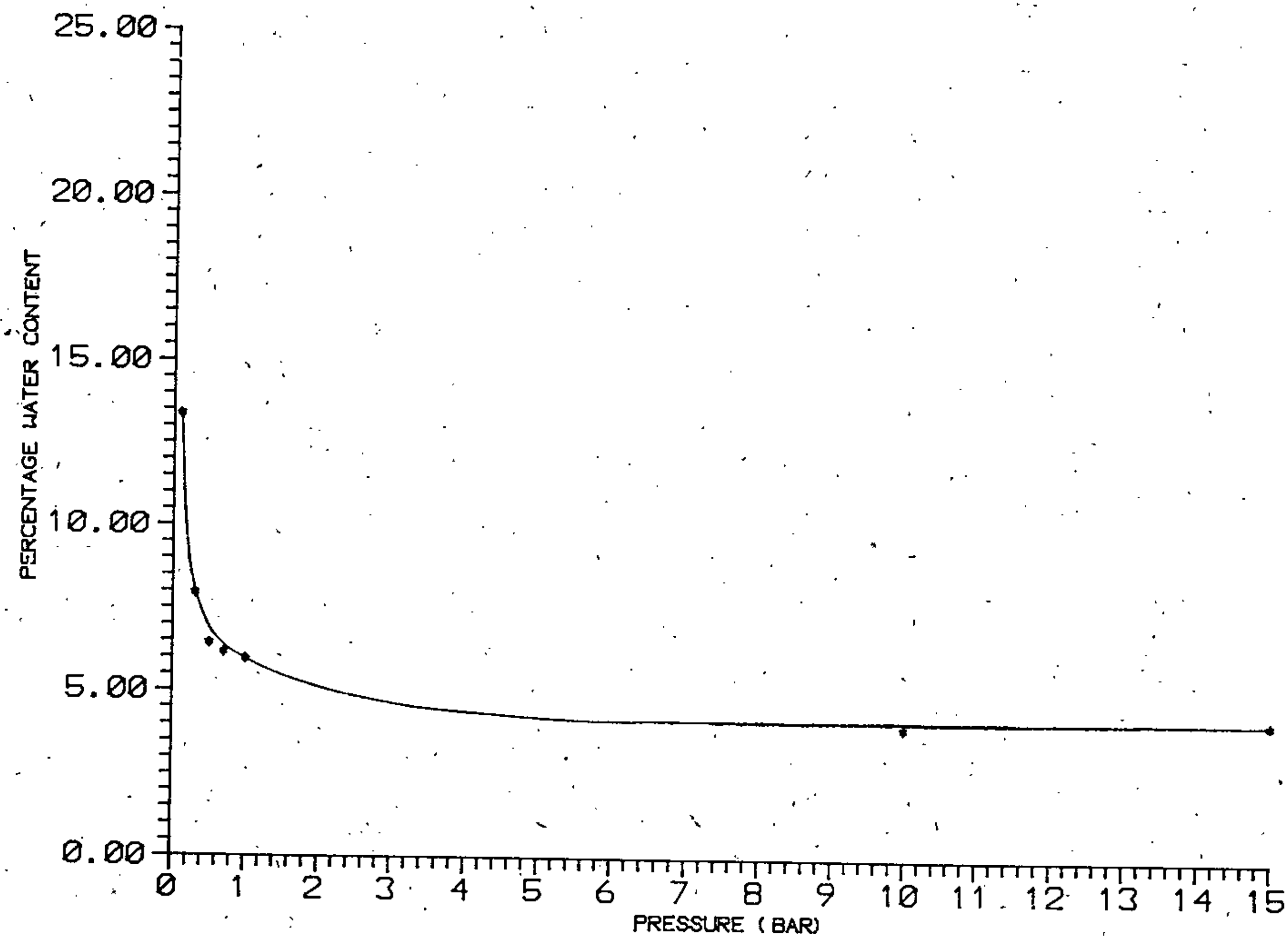

FIG: 15 SOIL WATER RETENTION CURVE FOR HIDKAL sand, silt and clay fractions of the soil strata. It can be seen from Figure 16 and 17, that the retention capacity shows an increasing trend with the (silt + clay) content.

Also it is found that the retention values for Hidkal is very low compared to the other sites. It is due to a very high percentage of coarser particles at that area.

Depending on the field capacity (at 0.3 bar pressure) and wilting point (at 15 bar pressure), it is possible to divide the samples into 4 distinct classes: Hidkal, where the retention value is very low; Mudhol (agri.) and Jamkhandi (fallow) having moderate value; Mudhol (fallow), Biligi (agri.) and Bagalkot (agri.) having high values; and Jamkhandi (agri.), Biligi (fallow), Bagalkot (fallow), Gokak and Raibag where the retention values are very high.

4.3 Hydraulic Conductivity

The two fundamental hydraulic properties which govern the status and movement of water in soil are the soil water characteristic $\psi(\theta)$, and the hydraulic conductivity function $K(\psi)$. Here ψ is soil water matric potential and θ the volumetric soil water content. If we take λ as a characteristic pore dimension, then theory of microscopic scaling shows that K is proportional to λ^2 while ψ is proportional to $1/\lambda$. Both are therefore related to soil structure. In heterogeneous medium, $K(\psi)$ and $\psi(\theta)$ depend on spatial position, and perhaps soil composition, pressure of trapped air, and time for wetting and drying. Field saturated hydraulic conductivity refers to hydraulic conductivity at $\psi = 0$.

Generally, hydraulic conductivity values for the study area (Table 3) are very small and at some of the sites the values are out of possible range of the Guelph permeameter. The lower values of conductivity may be due to local field conditions. Further, at zero metric potential, most soils contain 10 - 15 % trapped air, which may or may not eventually dissolve depending on the duration of ponding and mislead the values of hydraulic conductivity. The values show that the conductivity is relatively higher in fallow lands than agriculture lands. The higher values are due to i) higher percentage of coarser particles, and ii) well sorted distribution of sediments.

4.4 Infiltration

Tests were conducted at 13 sites in agriculture and fallow lands for the study area. Results are given in Table 4 and shown as infiltration curves in Figure 18 to 30. The results indicate a wide variation in infiltration characteristics spatially for reasons associated with soil property, mans' influences, etc. The final rate of infiltration in the case of agriculture land is comparatively lesser than that of fallow land. As the fallow land remains unused for any agricultural purposes, it takes a long time to reach the saturation.

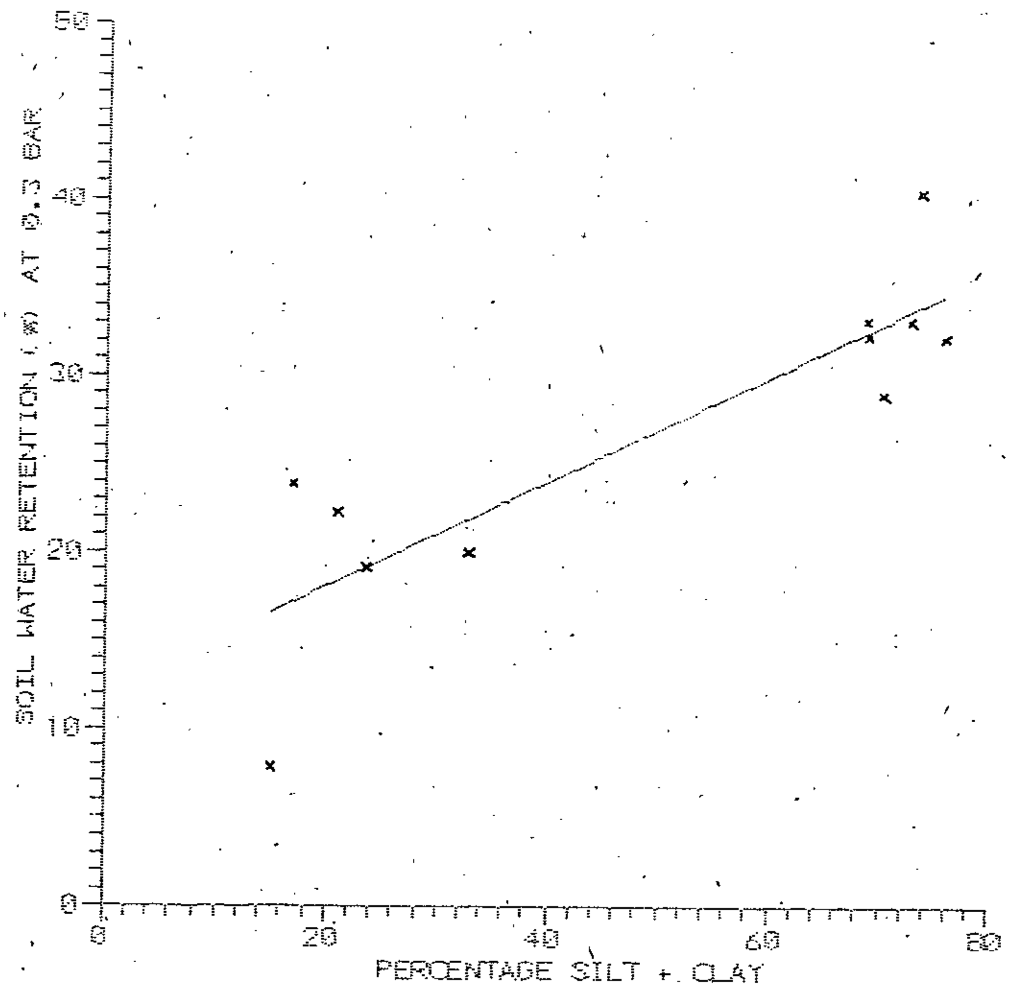

FIG: 16 RETENTION CAPACITY (AT 0.3 BAR) Vs (SILT+CLAY) PERCENTAGE

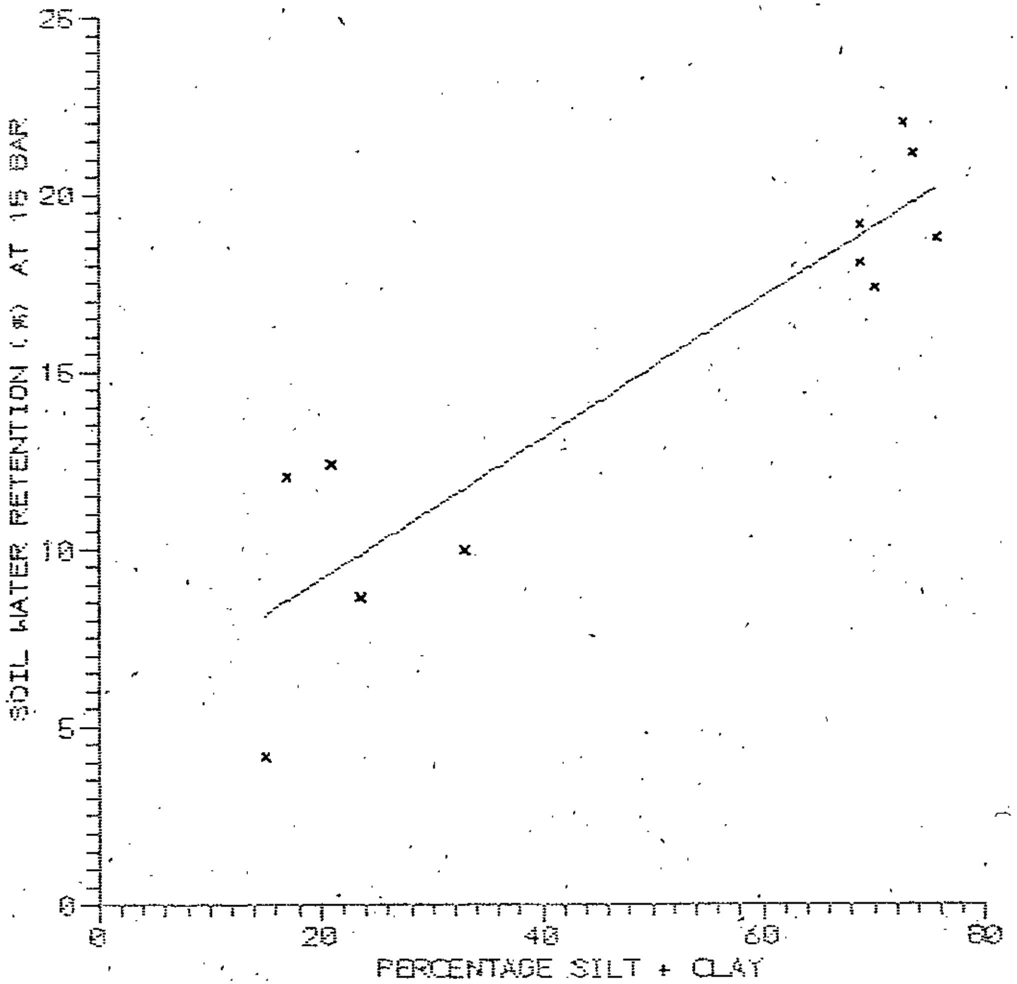

FIG:17 RETENTION CAPACITY (AT 15 BAR) Vs (SILT+CALY) PERCENTAGE

TABLE: 3 HYDRAULIC CONDUCTIVITY FOR THE STUDY AREA IN CM/SEC

	AGRI. LAND	FALLOW LAND
MUDHOL	0.5 10^{-4}	8.6 10^{-4}
JAMKHANDI	0.4 10^{-4}	1.5 10^{-3}
BILIGI	**	**
BAGALKOT	**	**
GOKAK	**	-
RAIBAG	0.1 10^{-4}	-
HIDKAL	2.4 10^{-4}	-

** indicates the conductivity value which is out of possible range of Guelph Permeameter.

TABLE:4 INFILTRATION VALUES (CM/HR.) FOR THE STUDY AREA

	AGRI. LAND		FALLOW LAND	
	IR	FR	IR	FR
MUDHOL	6.6	4.8	51.0	29.4
JAMKHANDI	4.2	0.6	15.0	6.0
BILIGI	13.2	8.4	12.0	1.2
BAGALKOT	6.0	1.2	42.6	22.8
GOKAK	12.0	0.6	54.0	13.2
RAIBAG	24.0	5.4	39.0	12.2
HIDKAL	12.0	3.0	-	-

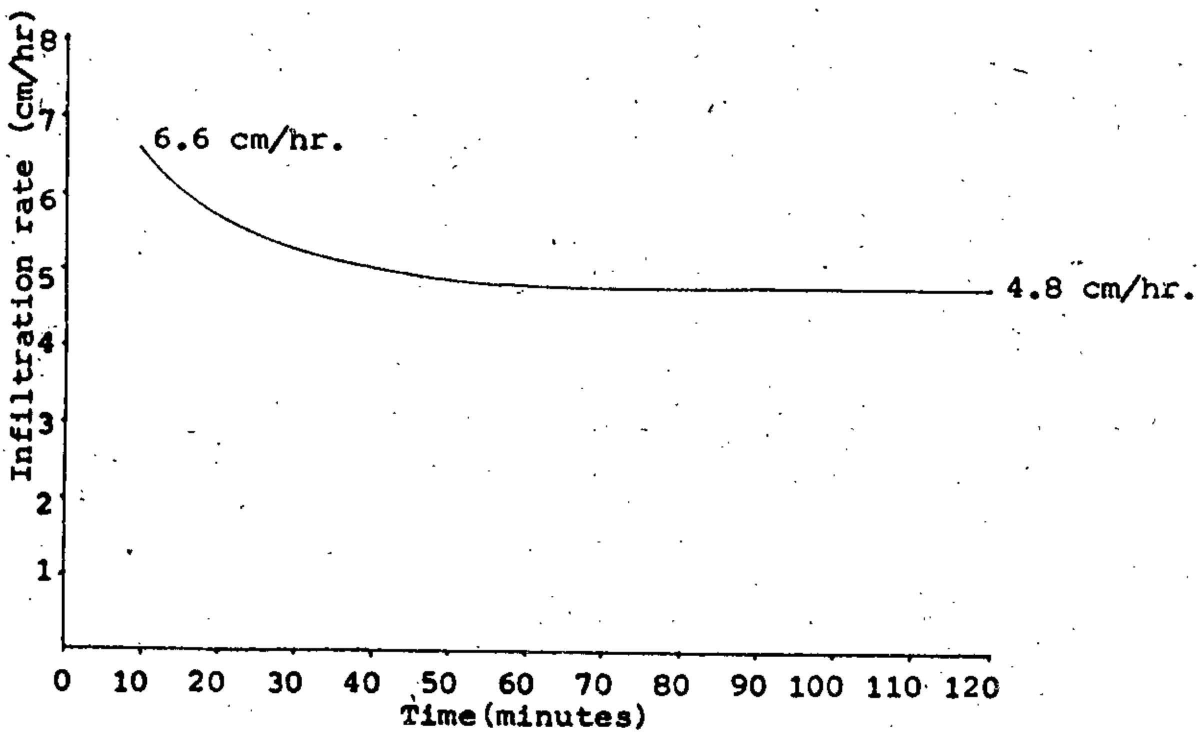

FIG.18 Infiltration Curve at Mudhol on Agriculture land.

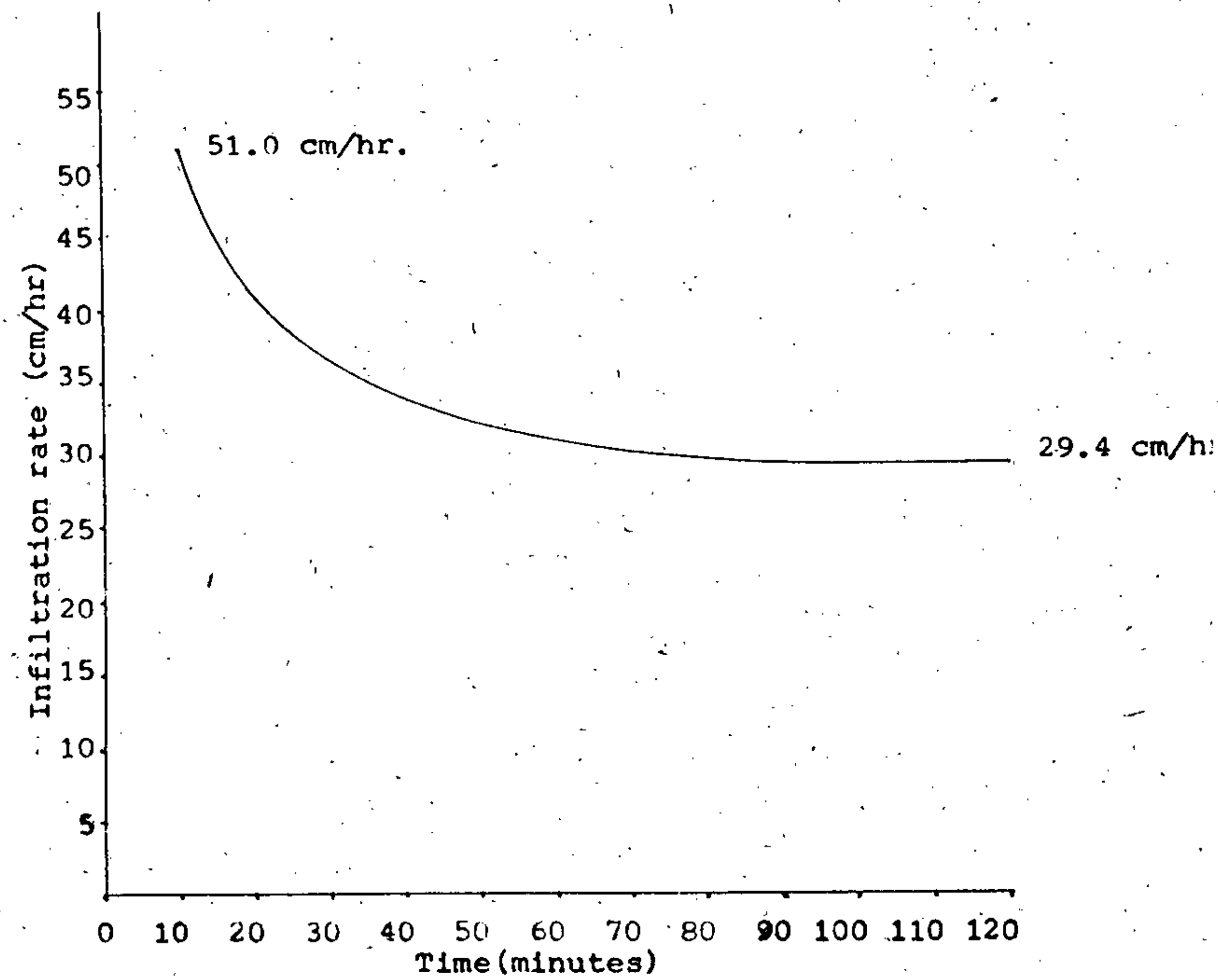

FIG.19 Infiltration Curve at Mudhol on Fallow land.

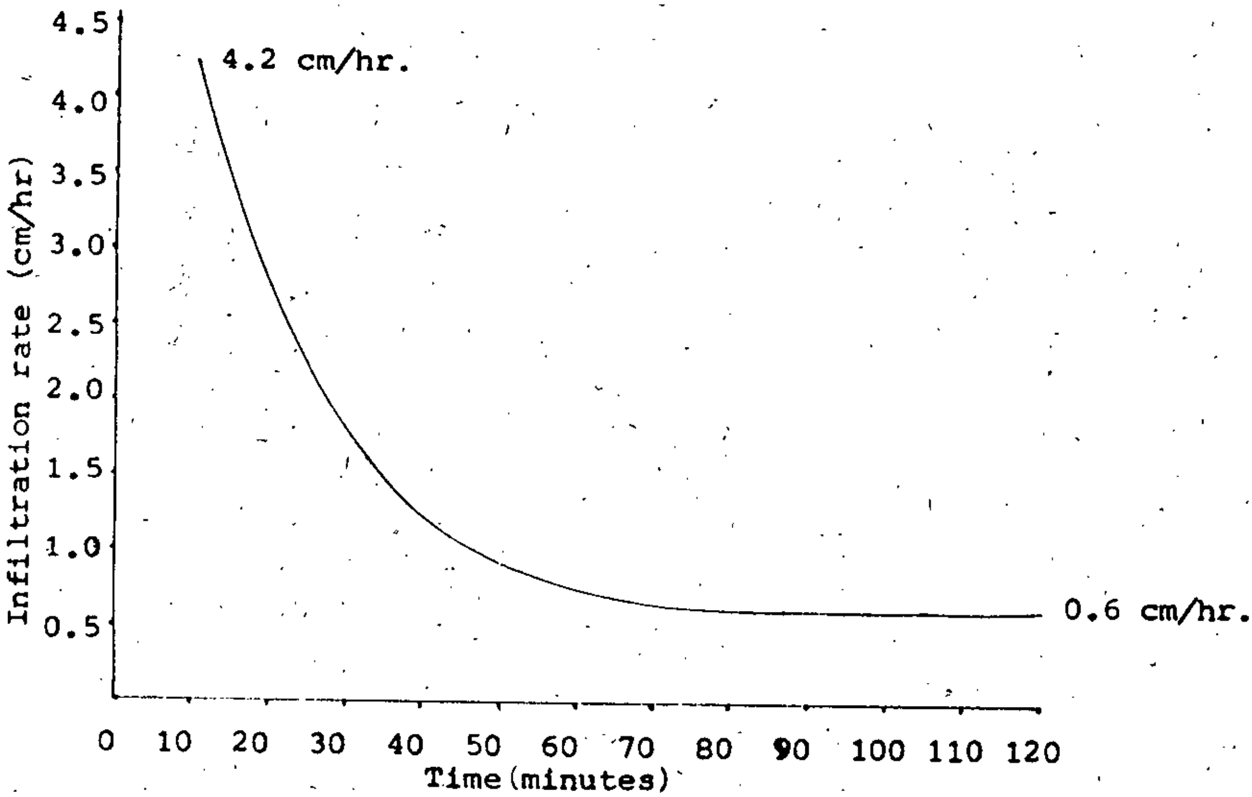

FIG. 20 Infiltration Curve at Jamkhandi on Agriculture land.

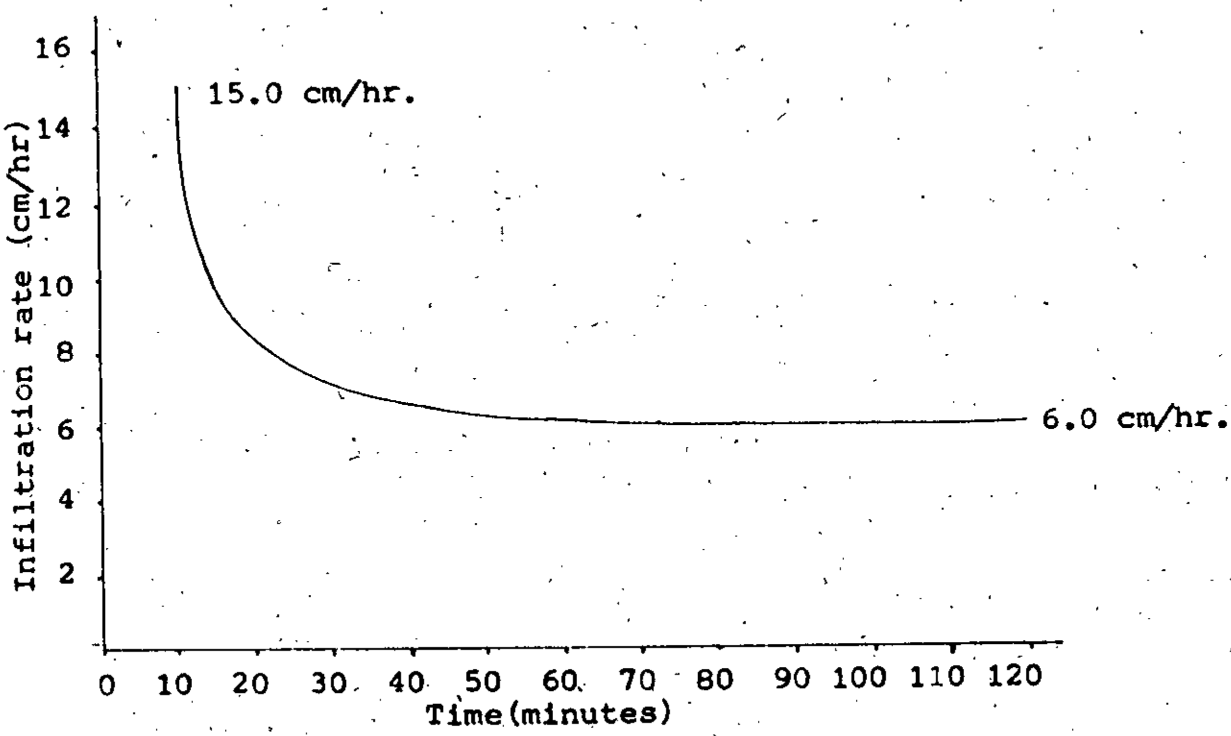

FIG.21 Infiltration Curve at Jamkhandi on Fallow land.

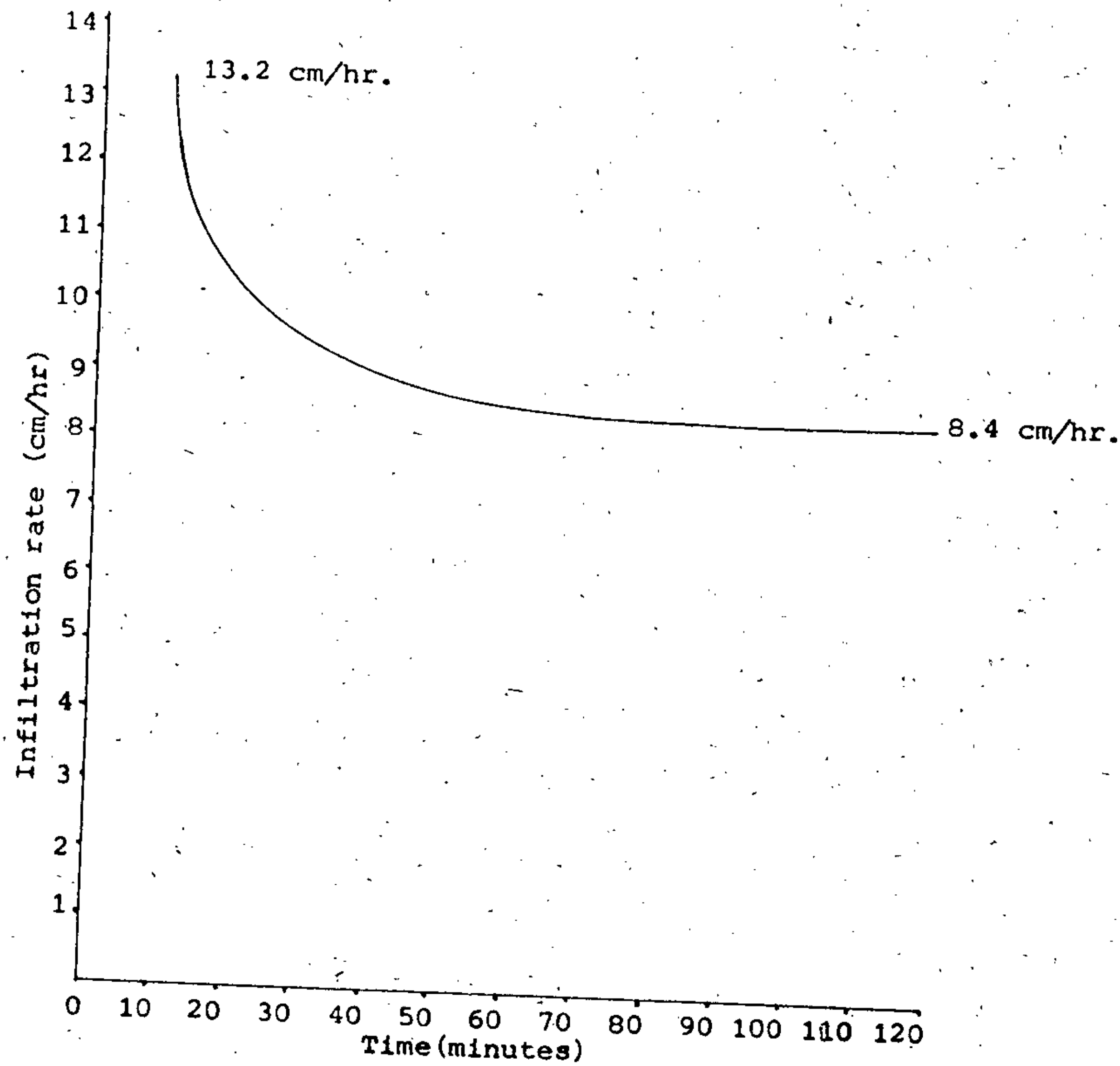

FIG.22. Infiltration Curve at Biligi on Agriculture land.

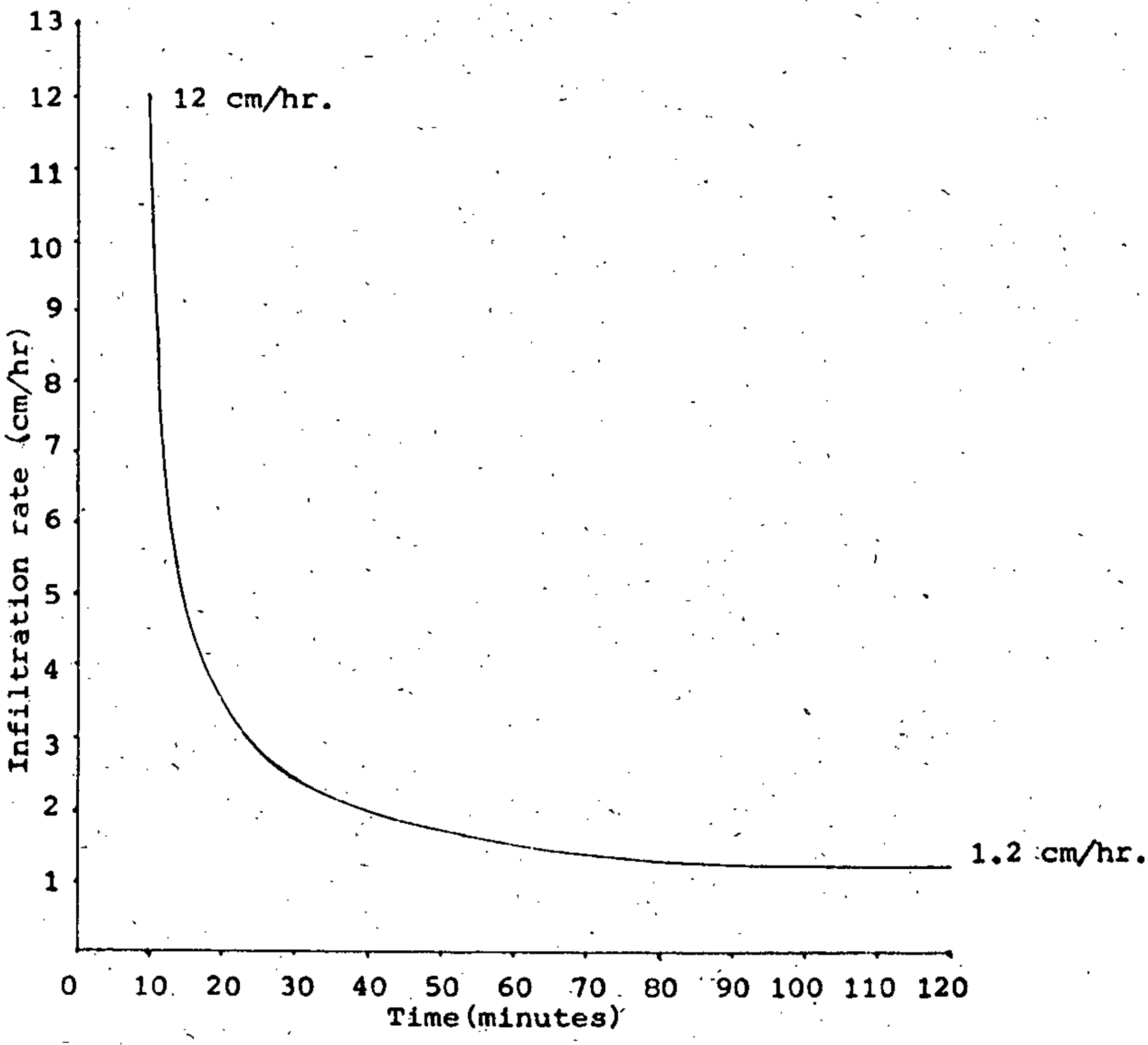

FIG.23 Infiltration Curve atBiligi on Fallow land.

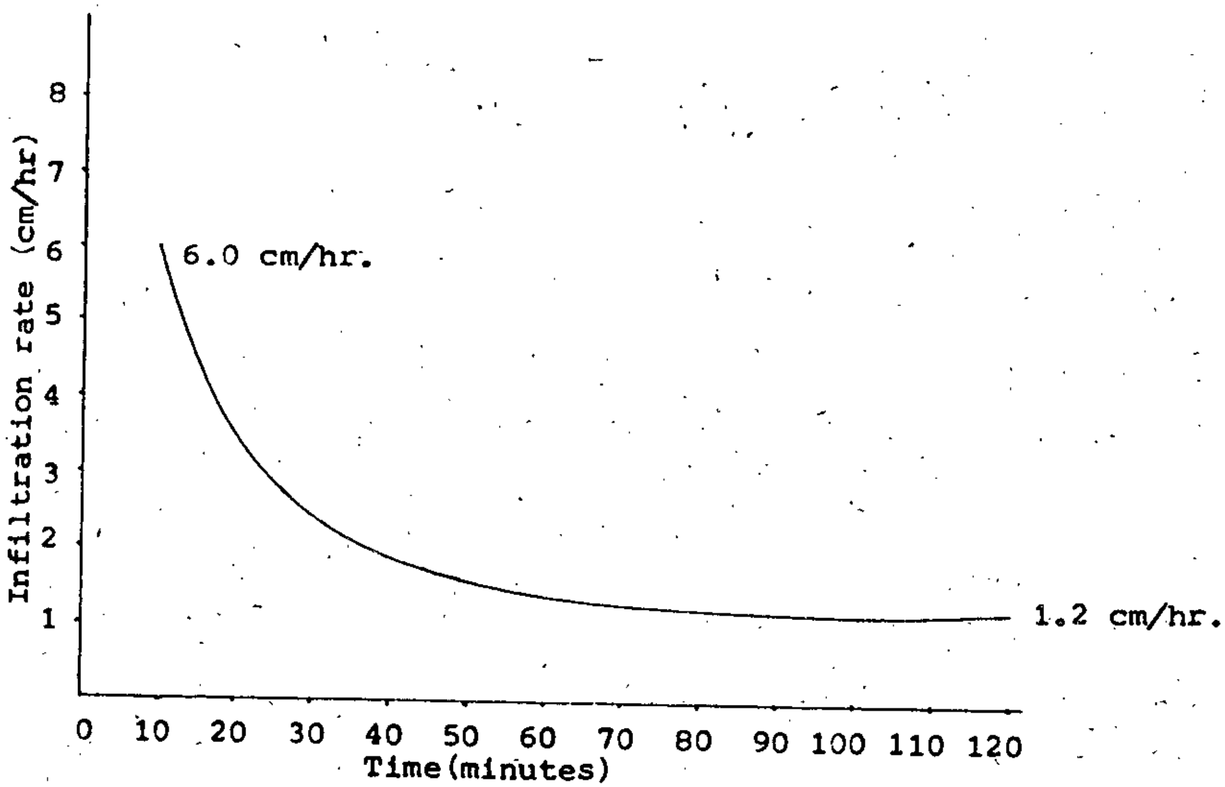

FIG.24 Infiltration Curve at Bagalkot on Agricluture land.

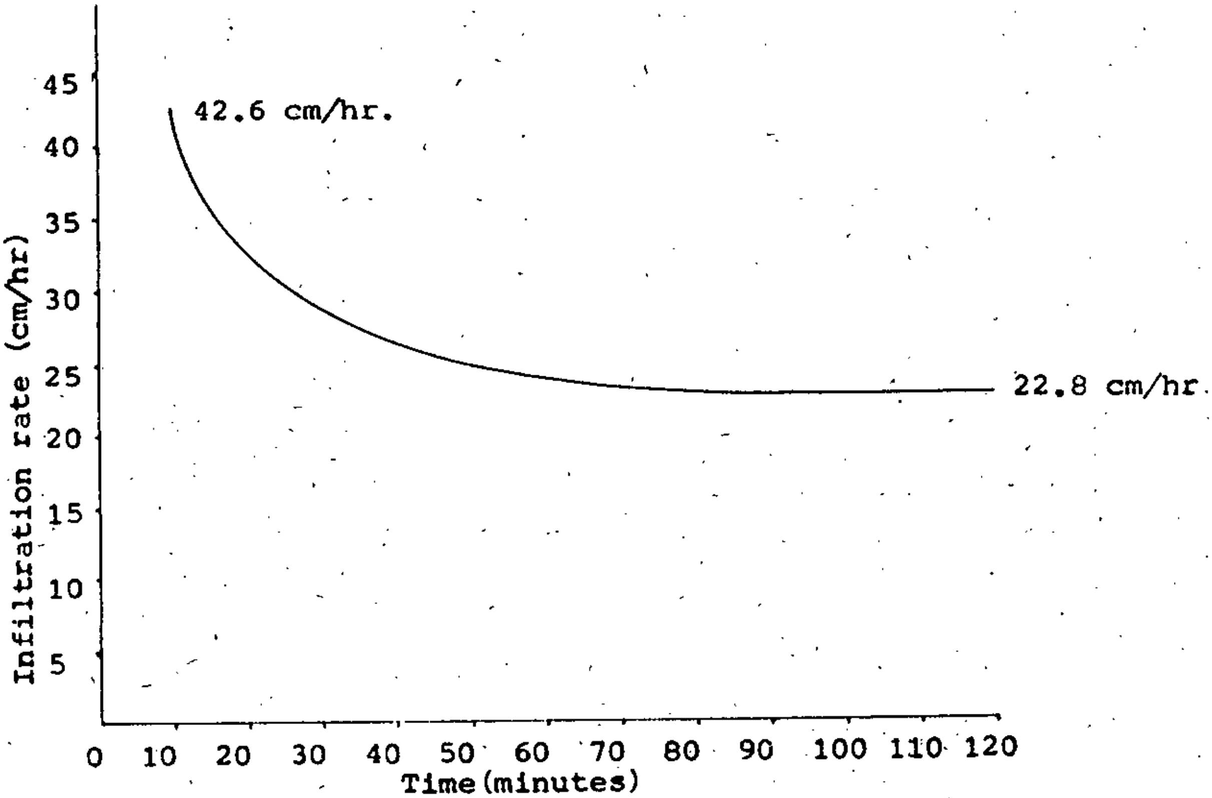

FIG. 25 Infitration Curve at Bagalkot on Fallow land.

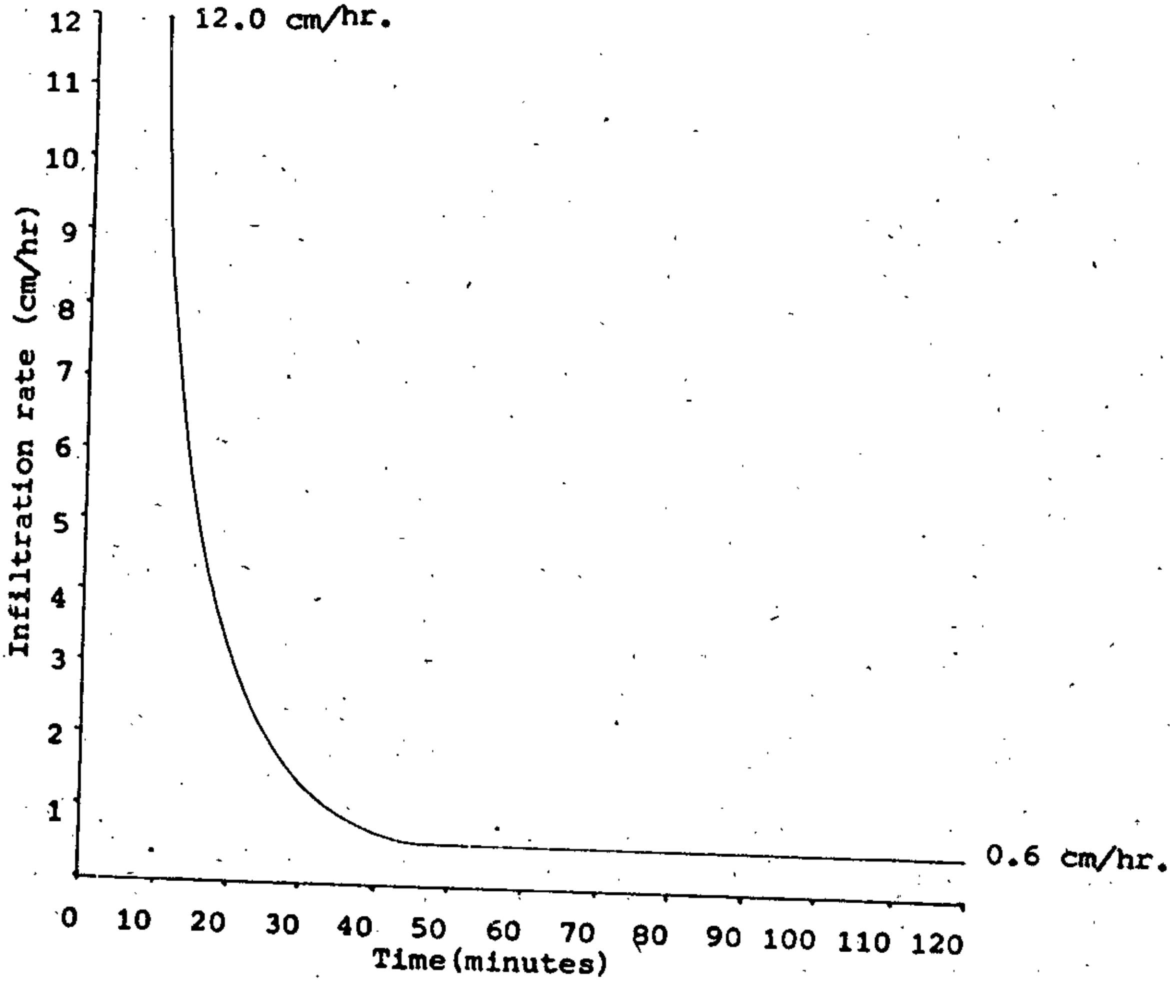

FIG.26 Infiltration Curve at Gokak on Agriculture land.

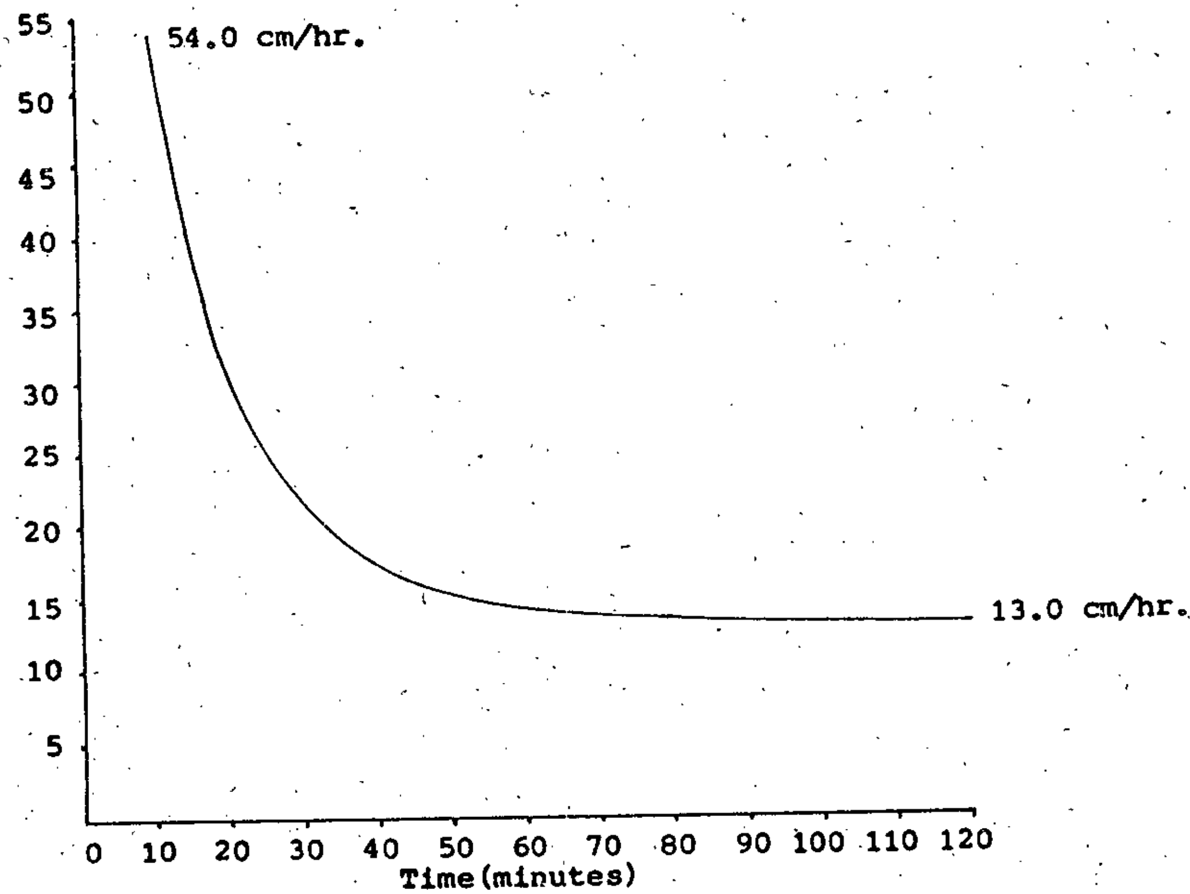

FIG. 27 Infiltration Curve at Gokak on Fallow land

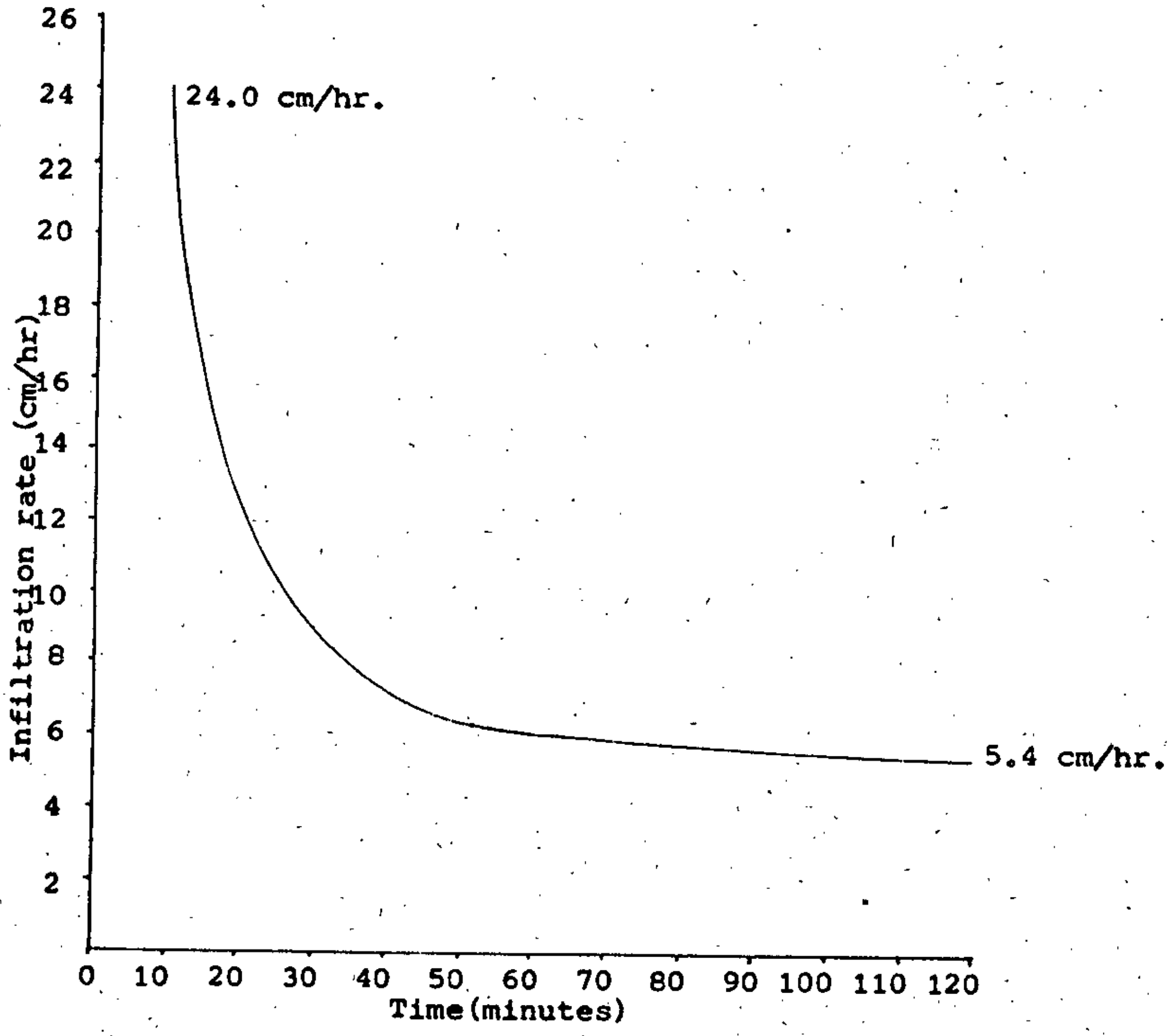

FIG. 28 Infiltration Curve at Raibag on Agriculture land.

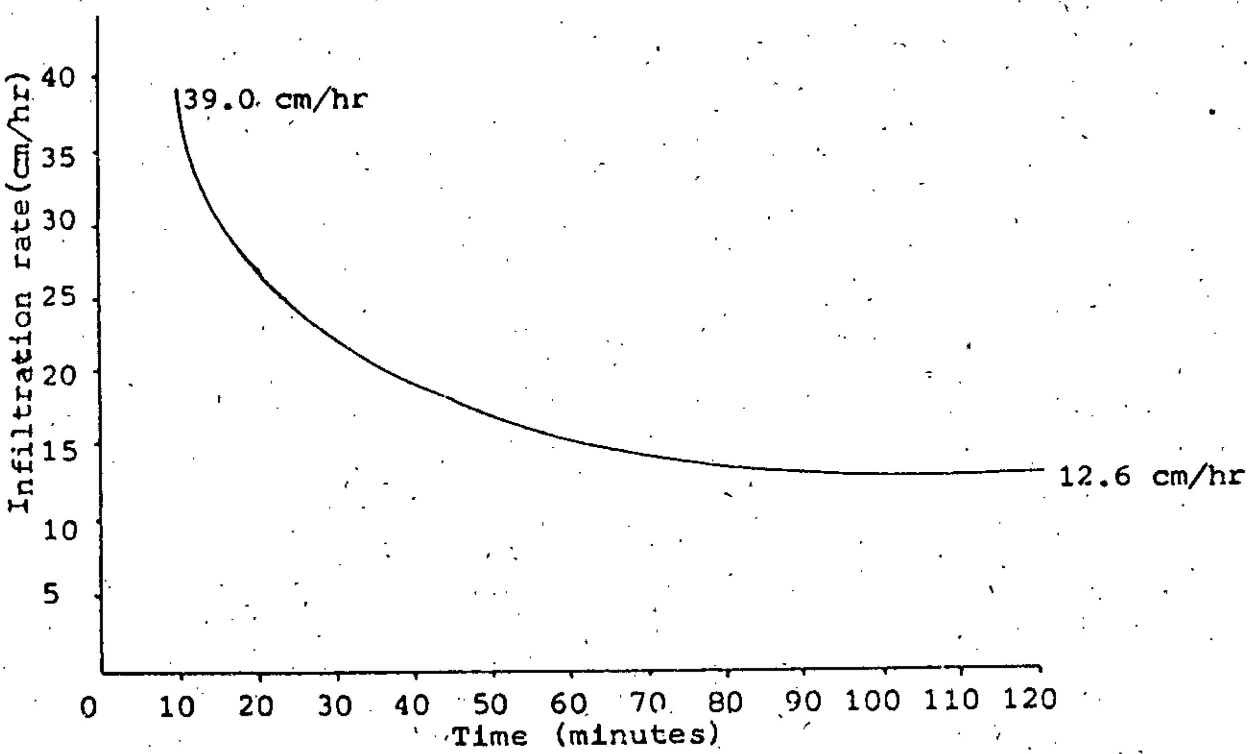

FIG.29 Infiltration curve at Raibag on Fallow land.

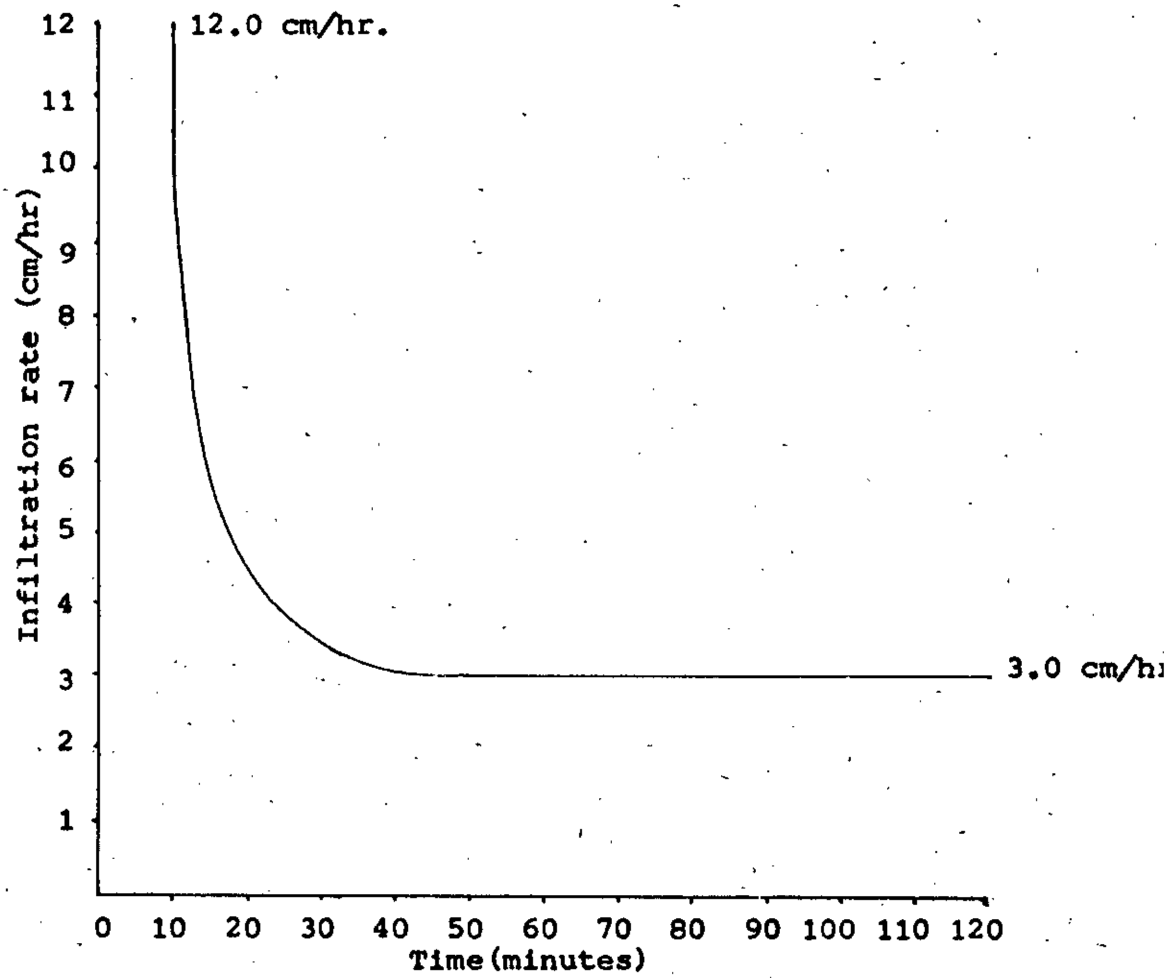

FIG. 30 Infiltration Curve at Hidkal on Agriculture land.

In the study area, except at Biligi, all the stations show higher rate of infiltration in fallow lands than in agriculture land. At Biligi, agriculture land is composed of sandy soils (79 % sand and 21 % silt and clay). Grain size analysis further indicate that the mean grain size of the soil in agriculture land is 6166 μ where as mean grain size of fallow land is only 218 μ. It is also found that the soils are well sorted in the case of agriculture land and is moderately sorted in fallow land. Infiltration value and field study at Biligi indicate that the region may soon become a waterlogged area.

Final infiltration rate shows a decreasing trend with the percentage of (silt + clay) content as shown in Figure 31.

The infiltration rate also depend upon the exchange reaction of cations and anions present in the soils, ie. swelling and non-swelling soils generally show wide variation in their infiltration rates. Further, Kijnee and Bisay (1974) and Agarwal etal (1974), arrived at a conclusion that, there are number of non-capillary pores in any cross section of soils which influences the rate of infiltration. It is also found that the soil genesis has also play an important role in determining infiltration rate. As the study area is mainly composed of Basalt, Granites and Gneisses, the parent rock is dominated by Na^+ ions, which exhibit exchange reaction and thereby dispersing the clay and clogging of the non-capillary pores. Similar observations in regions covered by granite Gneisses was reported by Bharambe etal (1987). In the study area, Jamkhandi and Gokak show comparatively lower infiltration which could also be due to the compositional variation.

Generally, one of the parameter which influences the runoff potential is the rate of infiltration. Present study indicates that the whole region may be classified as moderately low to moderately high, based on their runoff potential.

The results show that the initial rate of infiltration is very high in fallow lands. This is due to the undisturbed condition of the soils since long time, the presence of lower percentage of non-capillary pores at lower depth and due to higher bulk density of soils. However, in the case of agriculture land, due to tillage practices, soils are disturbed and mixes with different layers which may lead to lower initial infiltration rate.

From the above result, it can be seen that the soil properties for the study area varies in space and with landuse. However, these variations are random. From the field visits, it was seen that lithology and soil types of the area varies drastically in a short span of distance. This may be the reason for the non uniform variations. For a better understanding of the surface soil hydraulic properties, a detailed micro level study is required whereby it is possible to relate the variation of soil property with soil and land cover properties.

Prediction of infiltration and other soil hydraulic properties are important in the formulation of irrigation planning and for the estimation of runoff in catchment studies. Also it is important to assess the impact of both soil management practices and natural processes on surface soil properties.

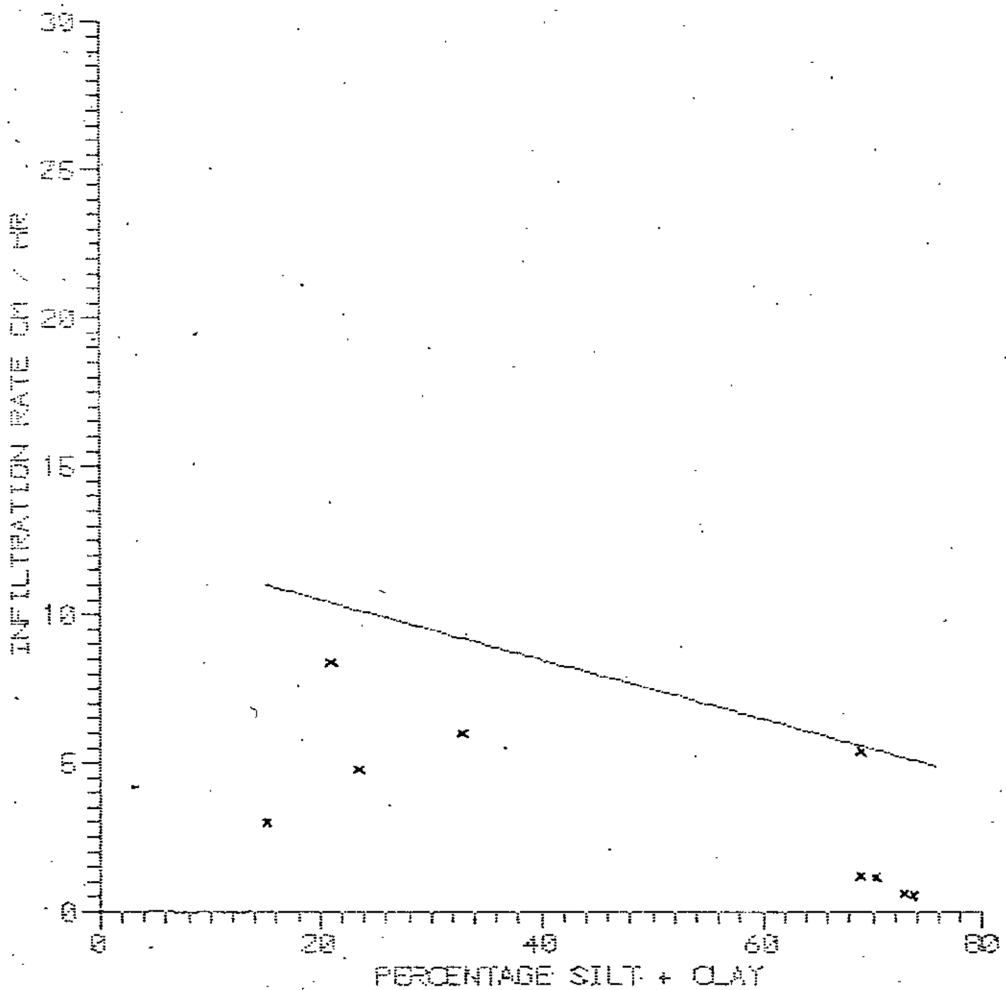

FIG: 31 INFILTRATION Vs (SILT + CLAY) PERCENTAGE

Many in Hydrology search for a standard technique for determining in situ soil hydraulic properties. Soils, and particularly surface soils, are complex materials and as such are not often readily amenable to simple solutions. The selection of measurement techniques for field studies must be based on the problems being addressed and on the perceived ease of use, rapidity, reliability and robustness of technique.

For a better understanding and utilisation of the soil properties, it is required to formulate procedures for parameterization of these properties at watershed scales and to develop accurate and economical field measurement procedures for the estimation of these properties. It is also important to determine the effect of soil management and treatment practices on soil properties affecting soil water flow parameters and processes.

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APPENDIX

1.GUELPH PERMEAMETER

Numerous methods have been developed for measuring saturated hydraulic conductivity in the field. The Guelph permeameter is used to determine saturated hydraulic conductivity of a particular soil. Once the soil water suction is measured, the hydraulic conductivity for that soil at that soil water suction can be easily estimated.

Guelph permeameter is a constant head device which operates on the Mariotte siphon principle and provides a quick and simple method for simultaneously determining field saturated hydraulic conductivity, matrix flux potential and soil sorptivity in the field.

It is an in-hole constant head permeameter, which involves measuring the steady state rate of water recharge into unsaturated soil from a cylindrical well hole, in which a constant depth of water is maintained. Constant head level in the well hole is established and maintained by regulating the level of the bottom of the air tube which is located in the centre of the permeameter. As the water level in the reservoir falls, a vacuum is created in the air space above the water. When the permeameter is operating, an equilibrium is established.

Once the of water from the well reaches a steady state, flow rate can be measured. The rate of this constant outflow of water, together with the diameter of the well and height of water in the well can be used to determine the field saturated hydraulic conductivity of the soil. The Richard analysis of steady state discharge from a cylindrical well in unsaturated soil, as measured by Guelph permeameter technique accounts for all the forces that contribute to three dimensional flow of water into soils.

The reservoir assembly provides a means of storing water and measuring the outflow rate while the Guelph permeameter is in use. For studies in very low permeability soils, use of the inner reservoir alone is required to provide adequate resolution of outflow rate when making a reading. When working in a moderate to high permeability soil, the reservoir combination is used. A scale, delineated in centimeters, is stamped on the inner reservoir tube for measuring the rate of fall of water out of the reservoir in both situations. Fittings are located at the top and bottom of the reservoirs to allow filling and selection of the proper reservoir.

Hydraulic conductivity range 0.01 to 0.000001 cm/sec.

Soil typically have three dimensional heterogeneity. The Guelph permeameter method yields essentially a point measurement. The size of land under investigation, degree of soil heterogeneity, soil type, and kind of application will dictate the number of measurements needed to adequately characterise a given area and depth of soil.

A soil profile description and soil survey report will greatly enhance the value and understanding of data obtained with the Guelph permeameter.

2.PRESSURE PLATES

This is a standard method for obtaining the retention curve. Pressure plate apparatus consist of a pressure chamber in which a saturated soil sample is on a porous ceramic plate through which the soil solution passes but no soil particle or air can pass. The soil solution which passes through the membrane is in contact with the atmospheric pressure. As soon as the air pressure inside the chambers is raised above atmospheric, it takes excess water from the soil out of the chamber through the membrane outlet. Soil water will flow out from the soil sample until the matric potential of the unsaturated flow is same as the applied air pressure. The air pressure is then released and the moisture content of the soil is gravimetrically determined.

During a run, soil moisture will flow from around each of the soil particle and out through the ceramic plate until such time as the effective curvature of the water film throughout the soil is the same as at the pores in the plate. when this occur, an equilibrium is reached and the flow of moisture ceases. when air pressure in the chamber is increased, flow of water from the samples starts again until a new equilibrium is reached. A source of regulated gas at pressure is required for all extraction work. Compressed air from a compressor is the most efficient source of supply.

Ceramic plates are available in different ranges from 1bar to 15 bar. The moisture retention curve of a soil sample can generally be determined by equilibrating a soil sample at a succession of known tension value and each time determining the amount of moisture. A graph is plotted between the tension and corresponding soil moisture value to obtain soil moisture retention curve. different types of soils yield different retention curves.

3. PARTICLE SIZE DISTRIBUTION

The percentage of various sizes of particles in a given dry soil sample is found by a particle-size analysis or mechanical analysis. Mechanical analysis is meant for the separation of a soil into its different size fractions. Mechanical analysis is performed in two stage: sieve analysis, and sedimentation analysis or wet mechanical analysis.

The first stage is meant for coarse-grained soils only, while the second stage is performed for fine-grained soils. In general, a soil sample may contain both coarse-grained particles as well as fine particles, and hence both the stages of the mechanical analysis may be necessary. The sieve analysis is, however, the true representative of grain size distribution, since the test is not affected by temperature etc.

Sieve Analysis

In the BS and ASTM standards, the sieve sizes are given in terms of the number of openings per inch. The number of openings per square inch is equal to the square of the number of the sieve. In the Indian Standard (IS: 460-1992), the sieves are designated by the size of the aperture in mm.

The complete sieve analysis can be divided into two parts the coarse analysis and fine analysis. An oven-dried sample of soil is separated into two fractions by sieving it through a 4.75 mm IS sieve. The portion retained on it (+ 4.75 mm size) is termed as the gravel fraction and is kept for the coarse analysis, while the portion passing through it (- 4.75 mm size) is subjected to fine sieve analysis. The following set of sieves are used for coarse sieve analysis, IS 100, 63, 20, 10 and 4.75 mm. The sieves used for fine sieve analysis are, 2 mm, 1.0 mm, 600, 425, 300, 212, 150 and 75 micron IS sieves.

Sieving is performed by arranging the various sieves one over the other in the order of their mesh openings, the largest aperture sieve being kept at the top and the smallest aperture sieve at the bottom. A receiver is kept at the bottom and a cover is kept at the top of the whole assembly. The soil sample is put on the top sieve, and the whole assembly is fitted on a sieve shaking machine. The amount of shaking depends upon the shape and the number of particles. At least 10 minutes of shaking is desirable for soils with small particles. The portion of the soil sample retained on each sieve is weighed. The percentage of soil retained on each sieve is calculated on the basis of the total of soil sample taken and from these results, percentage passing through each sieve is calculated.

It is advisable to wash the soil portion passing through 4.75 mm sieve over 75 micron sieve so that silt and clay particles sticking to the sand particles may be dislodged. Two grams of sodium hexametaphosphate is added per liter of water used. Washing should be continued until the water passing through 75 micron sieve is substantially clean. The fraction retained on the 75 micron sieve is dried in the oven. The dried portion is then sieved through 2 mm, 1 mm, 600, 425, 300, 212, 150 and 75 micron IS sieves. The portion passing 75 micron sieve (while washing) is also dried separately and its weight is determined to get the particle size distribution finer than 75 micron size. If the portion passing 75 micron size is substantial, wet analysis is done for further sub division of particle size distribution.

Sedimentation Analysis: Theory

In the wet mechanical analysis, or sedimentation analysis, the soil fraction, finer than 75 micron size is kept in suspension in a liquid (usually, water) medium. The analysis is based on Stokes' law, according to which the velocity at which grains settle out of suspension, all other factors being equal, is dependent upon the shape, weight and size of the grains. However, in the usual analysis, it is assumed that the soil particles are spherical and have the same specific gravity (the average specific gravity). With this assumption, the coarser particles settle more quickly than the finer ones. If 'v' is the terminal velocity of sinking of a spherical particle, it is given by

$$v = 1/18\ [D^2\ (\gamma_S - \gamma_W / \eta]$$

D = diameter of the spherical particle
v = terminal velocity
γ_S = density of particles
γ_W = density of water/liquid
η = viscosity of water/liquid
g = acceleration due to gravity

If water is used as the medium for suspension, γ_W is equal to 1 g/cubic cm. Similarly, in C.G.S. units, $\gamma_S = G\gamma_W = G$. Substituting these in above equation, and expressing the diameter of the particle in millimeter, we get

$$v = 1/18\ (D/10)^2\ (G-1/\eta)$$

or $D = [1800\ \eta\ v/(G-1)]^{1/2}$ mm

If a particle of diameter D mm falls through a height H cm in t minutes,

$$v = H/60t$$

therefor, $D = 10^{-5}\ M\ (H/t)^{1/2}$

where M is a constant for given values of η and G.

At 20°C, the viscosity η of distilled water is approximately 0.01 poise and by taking an average value of G = 2.68,

$$v = 91.5\ D^2$$

which is an approximate version of Stokes' law, and can be easily remembered for rough determinations. Based on this, the time of settlement of particles of various diameters, through and height of 10 cm are as given

Diameter (mm)	Time
0.06	32 sec
0.02	4 m 40 sec
0.01	12 m 36 sec
0.006	51 m 48 sec
0.004	1 hr 56 m 24 sec
0.002	7 hr 46 m 12 sec
0.001	31 hr 6 m

The sedimentation analysis is done either with the help of a hydrometer or a pipette. In both the methods, a suitable amount of oven dried soil sample, finer than 75-micron size, is mixed with a given volume V of distilled water. The mixture is shaken thoroughly and the test is started by keeping the jar, containing soil-water mixture, vertical. At the commencement of sedimentation test, soil particles are assumed to be uniformly distributed throughout the suspension. After any time interval t, if a sample of soil suspension is taken from a height H, (measured from the top level of suspension), only those particles will remain in the suspension which have not settled during this time interval. The diameter of those particles, which are finer than those which have already settle, can be found from the above equation. The greater the time interval t allowed for suspension to settle, the finer are the particle sizes retained at this depth H. Hence sampling at different time intervals, at this sampling depth H, would give the content of particles of different sizes.

If, at anytime interval t, W_D is the weight, per ml, of all particles smaller than the diameter D still in suspension at the depth H, the percentage finer than D is given by

$$N = [W_D / (W_d / V)] * 100$$

where N is the percentage finer than the diameter D
Wd is the total dry wt. of all particles used
V is the volume of suspension

Thus, we can get various diameters D and the percentage of particles finer (N %) than this diameter.

Limitations of Sedimentation Analysis:

The analysis is based on the assumptions that (i) soil particles are spherical, (ii) particles settle, independent of other particles and the neighbouring particles do not have any effect on its velocity of settlement, and (iii) the walls of jar, in which the suspension is kept, also do not affect the settlement. In actual practice, the fine particles of soil, for which this analysis is primarily meant, are not truly spherical. The particles of fine grained soils are thin platelets which do not settle out of suspension in the same manner and at the same rate as smooth spheres. Thus, the sedimentation analysis gives the particle size in equivalent diameter. The upper limit of particle size for the validity of the law is about 0.2 mm beyond which the liquid tends to develop a turbulent motion at the boundaries of the particles. The lower limit of particle size is about 0.0002 mm. For particles smaller than 0.0002 mm diameter, Brownian movement affects their settlement, and Stokes' law no longer remains valid. Also it is assumed that the soil has an average specific gravity, the value of which is used in computing the diameter D. Actually, different particles may have different specific gravity, depending upon their mineral constituents. The settlement of the particles is influenced by the surrounding particles as the liquid is not of infinite extent. The particles falling near the wall of the jar are also affected.

Pipette Method

The pipette method is the standard sedimentation method used in the laboratory. The equipment consists of a pipette, a jar and a number of sampling bottles. Generally, a boiling tube of 500 ml capacity is used in place of a jar. The pipette consists of (i) a 125 ml bulb with stopcock, for keeping distilled water, (ii) a three way stopcock, (iii) suction and waste water outlets, and (iv) sampling pipette of 10 ml capacity (including the capacity of the stopcock). The method consists in drawing off samples of soil suspension, 10 ml in volume, by means of this pipette from a depth of 10 cm at various time intervals after the commencement of the sedimentation. The recommended time intervals are 0.5, 1, 2, 4, 8, 15 and 30 minutes, and 1, 2, 4, 8, 16 and 24 hours, reckoned from the commencement of the test. The pipette should be inserted in the boiling tube about 27 seconds before the selected time interval, and the time taken for sucking the sample should not be more than 10 to 20 seconds. Each sample, so taken, is transferred into suitable sampling bottles and dried in an oven. The weight W of solids per ml of suspension is thus found by taking the dry weight and dividing it by 10.

Method of Preparing Soil Suspension:

In the sedimentation analysis, only those particles which are finer than 75 micron size are included. Hence the soil sample is washed through a 75 micron sieve. About 12 to 30 g of oven-dried sample (depending upon the type of soil) is accurately weighed and mixed with distilled water in a dish or beaker to form a smooth thin paste. To have proper dispersion of soil, a dispersing agent (deflocculating agent) is added to the soil. Some of the common dispersing agents are: sodium oxalate, sodium silicate, and sodium polyphosphate compounds, such as tetra sodium pyrophosphate, sodium hexametaphosphate (calgon) and sodium tripolyphosphate. IS : 2720 (Part IV)-1965 recommends the use of dispersing solution containing 33 g of the sodium-hexames taphosphate and 7 g of sodium carbonate in distilled water to make one liter of solution. 25 ml of this solution is added to the dish (containing the soil and distilled water) and the mixture is warmed gently for about 10 minutes. The contents are then transferred to the cup of a mechanical mixer, using a jet of distilled water to wash all traces of the soil out of the evaporating dish. The soil suspension is then stirred well for 15 minutes or longer in the case of highly clayey soils. The suspension is then washed through 75 micron sieve, using jet of distilled water and the suspension, which has passed through the sieve, is transferred to the 500 ml capacity boiling tube (sedimentation tube). Care should be taken that all the particles finer than

75 micron size are transferred to the tube. The tube is then put in a constant temperature water bath. When the temperature in the tube has been stabilised to the temperature of the bath, the so l suspens on s thoroughl shaken b n ert ng the tube several times, and then replace in the bath. The stop watch is then started, and soil samples are collected at various time intervals, with the help of pipette.

Those soils, which contain organic matter and calcium compounds, are pretreated before the dispersing agent is mixed (as explained above), since these contents act as cementing agents and cause the particles to settle as aggregations of particles instead of as individuals. The process of removal of organic matter and calcium compounds is known as pretreatment. The soil is first treated with hydrogen peroxide solution to remove the organic matter by oxidation. The mixture of soil and hydrogen peroxide is kept warm at a temperature not exceeding 60 C, till no further evolution of the gas takes place. The remaining hydrogen peroxide in the solution is then decomposed by boiling the solution. To remove the calcium compound, the cooled mixture of soil is then treated with 0.2 hydrochloric acid. When the reaction is complete, the mixture is filtered and the filtrate is washed with distilled water until it becomes free from the acid. The filtrate is then dried in the oven, to know the loss of weight due to pretreatment.

Calculations of D and N

10 ml samples are collected from the soil suspension (sedimentation tube) from a depth of 10 cm, with the help of the pipette, at various time intervals. The samples are collected into the weighing bottles (sampling bottles), and kept in the oven for drying. The weight W_D , per ml of suspension so collected is calculated as under:

W_D = dry wt. of sample in the weighing bottles / volume of the pipette (10 ml)

The percentage finer $N = [(W_D - w/V)/(W_d/V)] * 100$

The corresponding diameter D of the particle, to which the above percentage of soil is finer, is also calculated.

The pipette method, though very simple, requires more time and is not suitable for routine control tests. The apparatus is very sensitive, and very accurate weighings are required. Due to these reasons, sometimes the hydrometer method of sedimentation analysis is preferred.

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