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INFILTRATION MEASUREMENT TECHNIQUES/EQUIPMENT

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAVAN
ROORKEE (UP) -247 667

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PREFACE

In water management and conservation studies, accurate information on the rate at which different soils will take in water under different field conditions is required. The rate of water entry into soils varies widely between different soil types and also within a single soil type, depending upon soil water content and management practices.

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. The 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. Quantification of infiltration and infiltration capacities has been the subject of a large number of studies, with most of the successful measurements being made on disturbed, non-forested lands, especially crop and rangelands.

Measuring infiltration and infiltration capacities is difficult, since both are influenced by the rate of application and several other factors associated with the phases through which the infiltrating water passes. Hydrologists, soil scientists and irrigation engineers have developed several equipment and techniques for the determination of the infiltration rate of a soil.

The National Institute of Hydrology, Roorkee has taken up developemnt of an electronic infiltrometer for efficient as well as reliable measurement of infiltration rate in field. In order to ascertain the state-of-art of infiltration measuring equipment and techniques, an exhaustive literature survey was conducted for this purpose. The present report summarises the literature survey, and has been prepared by Sri V C Goyal and Sri B P Roy, Scientists of the Institute.

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(S.M.Seth)
DIRECTOR

CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

The flow of water through the soil surface is called infiltration. Horton (1933) defined infiltration in terms of infiltration capacity as the maximum rate at which the soil, in a given condition, can absorb the falling rain. Fletcher (1949) defined infiltration as the total amount of water entering the soil from the time of its addition to the end of the first hour. Richards (1952) also defined the infiltration rate of the soil as the maximum rate at which a soil, in a given condition, at a given time, can absorb water applied in excess to the soil surface, either as rainfall or shallow impounded water. Quantitatively, infiltration rate is defined as the volume of water passing into the soil per unit area per unit time and has the dimension of velocity.

The process of infiltration is best regarded as a concept since it is impossible to see or directly measure without influencing its value. It may, however, be approximated by a variety of instruments and calculations (Black, 1991). Infiltration affects many aspects of hydrology. It influences the runoff and depends upon the moisture of the soil and the evapotranspiration. Besides hydrologist, infiltration is of interest to the soil conservationist and the farmers.

2.0 FACTORS AFFECTING THE INFILTRATION PROCESS

The maximum rate that the air-soil will take is known as the infiltration capacity. This attribute of the soil is a function of soil surface conditions and surface horizon characteristics. It is further influenced by the rate at which the water is supplied to the soil and by the percolation rate, which in turn is dependent upon the amount of water in the soil at the start of the event and the time since the event began.

The rate at which infiltration actually occurs varies, and is always equal to or less than the infiltration capacity. Generally, both infiltration and infiltration capacity are influenced by the rate (e.g. rainfall intensity) at which water is supplied to the soil surface. Infiltration and infiltration capacity are coincident if the rate at which water supplied to the soil surface exceeds the infiltration capacity. They decline during a runoff event and tend to equilibrate after about an hour (Kane and Stein, 1983). Generally infiltration has a high initial rate that diminishes during continued rainfall toward a nearly constant lower rate.

The factors affecting infiltration have been studied by Baver (1933), Lewis and Powers (1938), Horton (1940), Fletcher (1949) and others. Some of the most common factors affecting infiltration are : soil properties (including grain size and its distribution, porosity, compactness, etc.), soil moisture, plant cover, rainfall intensity and duration, slope, and position of the water table.

2.1 SOIL PROPERTIES AND MOISTURE

Horton (1940) studied the maximum and minimum infiltration rates of a soil. The maximum infiltration rate for a given soil occurs at the beginning of the rain. He has indicated that the infiltration rate decreases rapidly because of changes in the structures of the surface soil and increase in soil moisture and then gradually approaches to a somewhat stable minimum. Powell and Beasley (1967) have reasoned that when the soil is dry the high initial infiltration rate is primarily the result of the filling of the pore spaces larger than the capillary size. Once these pores are filled, the infiltration is due to the advance of water by capillary potential.

Musgrave and Horton (1964) have shown that infiltration characteristics are affected by the grain size and its distribution in the soil. The grains are relatively stable in sands while soils with appreciable amounts of clay may provide large pores because clay swells appreciably upon wetting. During a storm, sands may slowly rearrange themselves into a more dense mix than before, whereas in silts and clays the soil aggregates break due to the impact of raindrops, causing the clay and silt particles to flow and penetrate into the previously existing pores, thus clogging them and greatly reducing the infiltration.

Rauzi and Fly (1968) found that the unfavorable surface soil conditions markedly reduce water intake rates. They found that soils with compact or blocky clay have low intake rates. Clay soils with good structure take water at rates three or four times that of dense clay soils with poor structure i.e. the degree of surface soil compactness is a major factor affecting the infiltration rate.

Many experiments have shown that pore sizes and pore-size distribution are greatly affected by the content of organic matter, because both the sizes and soil aggregates and their stability in water are related to the amount of soil organic matter. The addition of organic matter or its removal changes the prevailing permeability.

2.2 PLANT COVER

Musgrave and Horton (1964) stated that vegetation is one of the most significant factors affecting infiltration of water and that it protects the soil surface from rainfall impact. Massive plant root systems, such as grass, keep the soil unconsolidated and porous. The organic matter from crops promotes a crumb structure and improves permeability. Forest litter, crop residues and other humus materials protect the soil surface.

The density of herbaceous vegetation is closely related to infiltration. Packer (1951), for instance, found that the percent of the soil covered by living or dead plant parts was closely related to runoff and, therefore, to infiltration. The great influence of vegetated cover on infiltration is further evidenced by the fact that bare-soil infiltration capacity can be increased 3 to 7.5 times with good permanent forest or grass cover, but little or no increase results with crops grown in rows (Jens and McPherson, 1964).

2.3 RAINFALL

Linsley et. al (1949) have reported that rainfall intensity has little effect on the rate of infiltration when it exceeds the capacity rate. Willis (1965) found that the infiltration rate of a bare soil was reduced by an increase in kinetic energy of rainfall, which is the function of the velocity of impact of raindrops and of the rainfall intensity. Local experiments on the variation of infiltration capacity with rainfall intensity showed predominant variation for bare soil, and a lesser amount of variation for sodded areas.

Green (1962) also concluded that surface sealing diminishes the effect of antecedent moisture on infiltration because the hydraulic conductivity of immediate soil surface controls water flow into the soil and surface sealing does not allow suction gradients to control the rate of infiltration.

2.4 SOIL SURFACE SLOPE

Infiltration tests on soils with different slopes have shown that there is a tendency for the amount of water intake to decrease slightly with increase in slope. The greatest intake is found on the gentlest slope.

2.5 FROST

The frozen ground affects the infiltration. If frozen when very dry, some soils are fluffed up and frost is discontinuous, as in the honey comb and stalactite types. A soil under this condition may be permeable as, or even more permeable than, frost-free soil. On the other hand, if the soil is frozen while saturated, concrete frost in the form of a very dense, nearly impermeable layer often results. The occurrence of a light frost at the soil surface (also affected by water vapour content) may enhance infiltration (Striffler, 1959); Kane and Stein (1983) reported soil that had gone through a freeze/thaw cycle exhibits a higher infiltration capacity.

3.0 INFILTRATION MEASUREMENT TECHNIQUES

Measuring infiltration and infiltration capacity is difficult, since both are influenced by the rate of application. There are two general approaches to determine the infiltration/infiltration capacity of a soil cover and its moisture content. One of these is the analysis of hydrographs of runoff from natural rainfall on plots and watersheds. The other is the use of infiltrometers with artificial application of water to enclosed sample areas.

3.1 RING INFILTROMETERS

A metal ring of about 12 inches in diameter is inserted in the soil and flooded with an inch of water. The time it takes for that water to infiltrate may be converted to the infiltration rate in inches per hour. The water in the ring may be maintained at a constant depth from a convenient reservoir, which is then monitored to provide the rate of infiltration.

To avoid movement of water horizontally outward from the ring, a second, larger ring is used to surround the ring in which the measurements are made and is flooded at the same time. The size of the device has not been standardized, and varies from 9 inches to 36 inches in diameter (Black, 1991). Flooding has also been employed on plots to evaluate infiltration rates.

Major disadvantages of this type of infiltrometers are that (1) air may be entrapped, thus precluding normal movement of water downward into and through the soil profile, (2) in sandy soils the water cannot be applied rapidly enough to maintain a saturated surface without also washing fine particles into the interstices, and (3) the introduction of the ring itself disturbs the soil and provides for potentially rapid travel pathway for the water at the interface between the metal and the soil.

The ring infiltrometers may be used repeatedly, however, to illustrate the depletion of infiltration capacity over time. It is also useful for demonstrating radically different infiltration capacities and rates under different soils and land uses.

3.1.1 Single Ring Infiltrometer

In this type only one ring, of about 22.5 cm diameter, is used to flood the water and the infiltration rate is measured either by maintaining a constant head and estimating the amount of water being added or by observing the rate at which the water level is lowered in the cylinder (figure 1). The inaccuracies may result due to uncontrolled lateral movement of water below the bottom of the ring which otherwise is neglected.

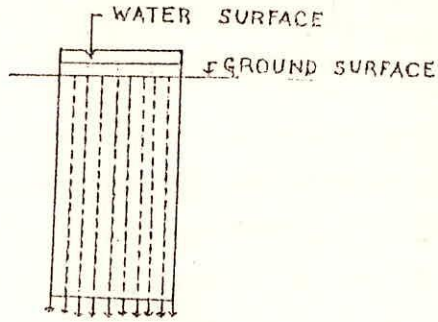

Fig.1 Single-ring infiltrometer

In order to characterize the spatial variability of infiltration across a catchment, Loague (1990) used a set of five single-ring infiltrometers. Each ring was of 1 m diameter, and was driven approximately 50 mm into the ground with the help of a driving stand (figure 2a). A water distribution manifold was used for watering the five sites simultaneously (figure 2b). With this arrangement, the final infiltration rate measured was assumed to be the steady-state infiltration rate for that location.

3.1.2 Double Ring Infiltrometer

The most common type consists of two shallow concentric rings of sheet metal, usually ranging from 22.5 to 90 cm diameter. These rings are placed with their lower edges a few cms below the ground surface and with the upper portion projecting above (as shown in figure 3).

Water is applied in both apartments 'a' and 'b' and is always kept at the same level in both the apartments. The function of the outer ring is to prevent the water within inner space from spreading over a larger area after penetrating below the bottom of the ring. From the rate at which water must be added to the inner ring in order to maintain a constant level, the infiltration capacity and its variation are determined.

3.1.3 Self Dispensing Infiltrometer

This infiltrometer consists of a cylindrical galvanised iron sheet container with two sets of small tubular outlets each on opposite sides as near the ends of the cylinder as possible to one set of outlets is attached a graduated glass tube by means of rubber tubing (Rege and Srinivasan, 1959) (figure 4). This would give readings of water within the cylinder. With regard to the other set of outlets, a longer glass tube is connected to the upper outlet and this outlet serves as an air inlet tube. To the lower outlet a relatively smaller glass tube is connected and this acts as a water supply tube. It is, however, necessary to see that both the glass tubes are of the same diameter as otherwise a little delay is caused in the discharge of water from the regulator to the soil core.

3.2 CLOSED TOP INFILTROMETER

The design of this closed top infiltrometer is based on the principle that natural positive soil air pressure may be simulated by creating an equivalent negative air pressure above ponded surface water (Dixon, 1975). Effective surface head h_s, defined as the difference between the ponded water depth h_w and the actual soil air pressure head h_a, is negative when $h_a > h_w$. Under natural field conditions, negative h_s causes counter flow of soil air during water infiltration.

Closed top infiltrometers made possible realistic infiltrometer measurements under the negative h_s commonly produced by rain and irrigation waters as they infiltrate natural soils. When water infiltrates a soil, soil air is displaced with some consequent compression. Compression is of measurable magnitude where a large expense of the soil surface becomes saturated by rain or irrigation water. These air pressures are negligibly small compared to the negative capillary pressure associated with dry micro porous media that are strongly hydrophillic. The force of the air pressure acting upward tends to counterbalance the force of surface water acting downwards. The imbalance between these two forces determines the surface water head that affectively contributes to infiltration.

In natural field situation, the bottom of the infiltration system is usually partially closed by air impeding subsurface layers such as wet clay, subsoils, hard pans, water tables and rock strata, and it works as an open top device. Generally under the open top devices $h_a = 0$, $h_s = h_w$ and $h_s > 0$, whereas under the close top infiltrometer $h_a > h_w$, $h_s = h_w - h_a$, and $h_s < 0$.

3.2.1 Single Ring Type

It consists of an acrylic ring (15 cm in dia) closed at the top except for connections to two water manometers and to an air pressure regulator. Three principal modes of operation are possible. First with the needle valve closed (figure 5), h_s and h_w decreases during the progress of infiltration, whereas h_a increases. Antecedent soil air volumes can be simulated by connecting an air container to the top of the closed ring, the air capacity of which can be varied by water displacement. Second with the needle valve open, h_a can be held constant by means of the air pressure regulator and the air supply system while h_s and h_w decreases. Third with the needle valve open, constant h_s can be maintained manually by raising the vertically adjustable bubbling tube in the air pressure regulator to achieve a constant water elevation h_x in manometer number 1 i.e. h_a is reduced manually to compensate for the decreasing h_w.

To initiate an infiltration run, the closed top ring is (i) closed at the bottom with a disc of plastic film, (ii) filled with water, (iii) placed upon the soil surface area to be tested, (iv) opened at the bottom by slipping out the plastic film, and (v) sealed on the soil surface with a wet soil paste. Cumulative infiltration or reservoir depletion h_w isdetermined manuallyby either directly observing h_w decline or by calculating h_w using the equation $h_w = h_s + h_a$, where h_s and h_a are determined in turn, from manometers number 1 and 2, respectively. The single ring closed top infiltrometer is designed for studying infiltration effects of naturally varying effective surface heads and soil air pressures.

3.2.2 Single Square Type

The single square closed top infiltrometer consists of one meter square plot frame which is enclosed at the top with an acrylic plate, except for connections to one meter square water reservoir, an air pressure indicator, and an air pressure regulator (figure 6).

Under normal operation h_s, h_a and h_w are held constant automatically. If desired, however, h_s can be realistically varied with time by manually increasing negative h_a via the spring tension adjustment on the air pressure regulator. To facilitate imposition of realistic variable negative h_s, the air pressure indicator can be replaced with an air pressure recorder bearing a pretraced curve based on the equation $h_a = h_w - h_s$, and solved with h_s values from natural infiltration.

To initiate an infiltration run, the float switch is positioned vertically to give the desired constant h_w, and the bubbling tube of the air pressure indicator is set at a desired constant negative h_a. Then the large air pressure pump is switched on and the air pressure regulator is adjusted to produce the desired constant negative h_a. The small air pump is plugged in and the air flow regulator is adjusted to produce a slow rate of bubbling from the water pressure sensing tube. Then, the solenoid valve is manually energized to open and thereby allow water to flow from the reservoir to the plot frame to, in turn, build the pounded water surface head to the control level h_w. A constant level is maintained by the float switch and the isolation transformer relay which serve to automatically energize and de-energize the solenoid valve in response to water losses and additions to the plot frame. Cumulative infiltration or reservoir depletion is determined automatically by measuring hydrostatic pressure decline h_r near the bottom of the water reservoir with the air pressure recorder. Cumulative infiltration may also be determined manually by direct observation of reservoir water depletion, thereby eliminating the need for the recording system components.

The single square closed top infiltrometer is especially well suited for studying the infiltration effects of natural surface roughness and macro porosity of the magnitude and geometry that can be adequately sampled by the 1 meter square frame.

3.2.3 Double-cap Type

Constantz (1983) designed a double-cap infiltrometer as a portable alternative to the ASTM double-ring infiltrometer for use in areas with limited access such as sloping terrain, stream beds, or dense forests. The principle of the double-cap infiltrometer is similar to the double-ring type, but the latter instrument has been scaled down for use with a portable water supply and designed for convenient insertion into sloping soils.

The double-cap infiltrometer used by Constantz (1983) was made of a circular plate welded to the top edges of two concentric cylinders with 150 mm and 360 mm diameters (figure 7). When the infiltrometer is driven in the soil, two enclosed compartments are formed above the soil surface. Water is supplied to each compartment via tubing through hose-ports in the top plate, and ponded water heads are monitored through water manometers attached through the top plate above both compartments.

The inner cylinder was so designed to reduce disturbance of the soil beneath the inner cylinder during the insertion. Three hose fittings attached to the top plate provided two ports to the outer compartment and one to the inner compartment. A hole in the plate above each compartment vented air during insertion, and was used for water manometer fitting during testing. The design of the complete assembly resulted in no measurable evaporative losses during infiltration measurement.

Two 25 litre polyethylene carboys were used as mariotte reservoirs to supply water through vinyl tubing to the hose-ports in the top of the double-cap infiltrometer. The flux into the inner compartment is measured using a calibrated flow-tube type flowmeter. The water head in each compartment is controlled by adjusting the elevation of the bubbler tube inside the mariotte reservoir.

The double-cap infiltrometer is reported to be better suited than the ASTM double-ring infiltrometer on three major counts : (1) its installation is considerably easier; requires approximately 30 seconds at each site, (2) it is less destructive to the soil surface within the inner cylinder, and (3) gives more representative measurements at sloping surfaces. This variation of the ring infiltrometers seems to be a convenient alternative to the conventional double-ring infiltrometer, being especially useful in areas where access and water supply are limited.

3.3 AUTOMATED TENSION INFILTROMETER

Infiltration rates can be measured from the change in water height in a Mariotte column. Water height is automatically measured by using the difference in tension between two pressure transducers, one installed at the top, and the other at the bottom, of the Mariotte column (Ankeny, et. al, 1988). This infiltrometer, useful for a range of water tensions from 0.02 to 0.05 m and for infiltration rates of 1×10^{-8} to 5×10^{-4} ms^{-1}, is a modification of the original design of Clothier and White (1981).

The major components of the infiltrometer (figure 8) are a bubble tower, a Mariotte column (water reservoir), a base for soil contact and a transducer equipped data logger for data collection and storage. The bubble tower has four air entry ports that control tension by allowing air entry at different distances below the water level. The ports can be preset to tensions from 0.02 to 0.05 m, and valves are used to switch from one port to another. The bubble tower is connected to the Mariotte column with a small diameter bubbling tube. Electronic monitoring of tension at rapid infiltration rates ($>5 \times 10^{-4}$ ms^{-1}) has shown that air flow through the bubbling tube is sufficient to limit the flow induced tension increase at the soil surface to < 5 mm of water above that imposed by the bubble tower. Interchangeable Mariotte columns of different diameters are used because the volume of water infiltrating into the soil is calculated from the height change of water in the column.

Measurement of infiltration has been automated by the use of a data logger with two pressure transducers (as shown in the figure). When calibrated with a water manometer, these transducers give a linear voltage output as a function of tension. Head-space tension in the Mariotte column is linearly related to the height of the water in the column. A unit change in height causes a unit change in the tension. Thus infiltration can be calculated from the change in head space tension measured by the transducer. One pressure transducer is mounted in the head space at the top of the Mariotte column and the second transducer is mounted near the base of the column. The data logger is programmed to record paired readings of top and bottom transducers at regular intervals. Additional relevant information, such as Mariotte column diameter and run identification, can also be recorded.

The main advantages of this tension infiltrometer include : (1) automatic measurement and data collection, which increases measurement speed and eliminates bubbling induced variability, (2) operation over a tension range from 2 to 50 cm of water, and (3) effective measurement precision at very low infiltration rates.

3.4 SUCTION CRUST INFILTROMETER

The laboratory crust test, used to measure unsaturated hydraulic conductivity, was modified by Booltink, et. al (1991) into a suction crust infiltrometer. If a negative pressure head is applied to the crust by moving the Mariotte device, as shown in figure 9, conductivities are defined by the measured flux at a given pressure head of unit gradient. By varying the level of the Mariotte tube inside the feeder burette, different negative pressure heads can be imposed on a soil sample. Pressure heads are measured with transducers, facilitating calculation of the infiltration rate. Unit gradient during the measurement was ensured by adjusting the water level in the draining column under the sample. Perfect contact between crust and soil surface makes the infiltrometer particularly suitable for measurements in structured soils with macropores.

3.5 RAINFALL SIMULATOR

Although the infiltration measurement by flooding type ring infiltrometer is simple, quick and cheap, it gives higher values of infiltration due to the constant head of water maintained on the soil surface during the observation period and the absence of raindrop impact effect. Since infiltartion depends on the properties of both the soil through which water must filter and the water itself, the raindrop impact effect, which changes these properties, is certain to be an important factor affecting the infiltration process.

The design of a rainfall simulator infiltrometer is complex and involves many criteria that need to be met as closely as possible (Willis, 1965). The simulator portability and cost are the two important constraints influencing its design and construction. The main advantage of rainfall simulator infiltrometer is that they do give some indication of the rate of infiltration of rainfall as opposed to the ponded-water conditions of ring infiltrometers. The disadvantage of rainfall simulator infiltrometers has been their cost and transportability. The designs of Tricker (1979) and Bhardwaj and Singh (1992), however, have attempted to overcome these limitations of the rainfall simulator infiltrometer for use as a field equipment.

Both Tricker (1979) and Bhardwaj and Singh (1992) designed the infiltrometer with the following principal components : (i) drop producing chamber, (ii) pressure head regulator, (iii) water reservoir, (iv) wind shield and support, and (v) infiltration cylinder and runoff collector. The latter model is an improvement of the former design in terms of field performance and portability. As a typical design example, various components of the rainfall simulator infiltrometer of Bhardwaj and Singh (1992) (figure 10) are briefly discussed in the following paragraphs.

Drop Producing Chamber

A drop forming mechanism which is heart of the rainfall simulator is designed to produce the water drops simulating natural rainfall. It is made of a circular perspex plate of 150 mm diameter and 10 mm thickness, through which 95 capilary holes each with a diameter of 0.9 mm are drilled.

Water Reservoir

A water reservoir of 5.5 litres capacity is used to store and supply water for the production of simulated rainfall, and is mounted just above the drop forming mechanism. It consists of a perspex cylinder with an internal diameter of 142 mm and a length of 300 mm, to which two perspex plates, one at the lower end and another at the upper end, of thickness 10 mm and 20 mm respectively, are cemented. A stopper is provided at the bottom end of the reservoir to regulate the flow of water into the drop producing chamber, while a rubber cork is fixed at the upper end. A glass pipe of internal diameter 5 mm passes through this rubber cork and connects the water reservoir with pressure head regulator.

Pressure Head Regulator

Pressure head regulator maintains a constant head of water over the drop forming mechanism so as to get a rain storm of desired intensity. It consists of a 300 mm long perspex pipe, with internal diameter of 50 mm and wall thickness of 5 mm. A stopper is provided at the bottom end to change the level of water in it. At the upper end, a rubber cork is fitted through which two glass tubes are made to pass. While one tube is open to the atmosphere, the other one connects the pressure head regulator with a water reservoir through a flexible polyethylene tube.

The head of water over the drop forming mechanism can either be controlled by varying the water level in the pressure head regulator through the stopper or by raising or lowering the position of the water reservoir, the clamping arrangement for which is provided in terms of holes drilled at various heights on the supports so as to fix the water resrevoir seat.

Wind Shield and Support

To prevent the distortion of the simulated rainfall by the wind, a wind shield is provided. It consists of a perspex pipe of 1.35 m and has an internal diameter that is the same as the drop producing chamber. The whole instrument is supported vertically, above the experimental plot by a wooden tripod. Tripod legs are braized on to a mild steel ring around the wind shield.

Infiltration Cylinder and Runoff Collector

The infiltration cylinder consists of two concentric mild steel cylinders with a diameter of 150 mm and 250 mm, respectively. It delineates the experimental plot under the simulated rainfall. A runoff trough is provided on the upper end of the inner cylinder to collect the runoff from the plot through flexible polyethylene tube.

The authors have conducted field tests to evaluate the infiltartion, runoff and soil erosion using both the double-ring and rainfall simulator infiltrometers under various rainfall intensities and soil cover conditions.

3.6 CONSTANT HEAD PERMEAMETER

It consist of a specimen container with an overhead water tank so as to maintain a constant head (Boers, et. al, 1992). An overflow outlet is provided with the overhead tank so as to help in maintaining a constant head (figure 11). The specimen container (containing soil) is placed on a container to collect water that has seeped through the soil. This water is collected in the jar for measurements and other tests. The constant hydraulic gradient "i" causing the flow is the head "h" (i.e. difference in the water levels of the overhead and bottom tanks) divided by the length "L" of the soil sample.

If Q is the total quantity of flow of water in time "t", from Darcy's law :

Rate of flow = $q = Q/t = KiA$

$K = Q/t \; 1/iA = Q/t \; L/h \; 1/A$ where

A=total cross sectional area of the sample and
K= Darcy's coefficient of permeability
Thus knowing the hydraulic conductivity, infiltration capacity can be calculated.

3.7 TIME DOMAIN REFLECTOMETRY (TDR) METHOD

Water content vs depth profiles during or following infiltration in the field have been conventionally determined using gravimetric sampling method. Because of the destructive nature of the sampling, spatial variability is introduced when time varied sampling is required. Field measurement of infiltration is considerably improved if repeated measurements are made at the same location. This is possible with the modern equipment, e.g. neutron probe. Another technique which has been successfully attempted is the Time Domain Reflectometry (TDR) technique.

The TDR technique is a recent method by which volumetric water content is estimated indirectly (Jury et. al, 1991). The method consists of the measurement of the permittivity or dielectric constant of the soil and subsequent calibration of this property with the volumetric water content. Measurement of the dielectric constant consists of placing a sensor (e.g., prong with two arms) forming two parallel waveguides into the soil and sending a step pulse of electromagnetic radiation along the guides. This pulse is reflected at the end of the prong and returned to the source, where its travel time and velocity can be estimated with an oscilloscope. The permittivity of the material (the soil) between the waveguides causes the velocity of the pulse to deviate in a known manner from the velocity of light in vacuum. Hence, the permittivity can be estimated from the travel time, and the water content can be calculated by a regression equation from the permittivity. The TDR sensors can be placed either horizontally or vertically.

Topp et. al (1983) used TDR to study selected aspects of infiltration in the field. They employed vertical and horizontal and transmission lines for detecting wetting fronts (figure 12), for following their progression with time, and for determination of water content vs depth profiles.

3.8 RECORDING SYSTEMS FOR RING INFILTROMETERS

Maximum infiltration rates are measured in the field by applying water to the soil surface either by ponding or as natural or artificial rain at rates sufficient to cause some runoff. The infiltration rate is very high in the beginning of water application, but diminish with time to much lower, nearly constant values.

3.8.1 Automated Regulating and Recording System

Various types of infiltrometer have been used to study the infiltration behavior. All ring infiltrometer measurements involve measuring water levels at various times. This is usually done with hook gauges or nail points at fixed heights, and sometimes with raingauge type recorders on the water supply tank. The automated system developed by Matula and Dirksen (1989) regulates and records the water supply. This eliminates the human error in the reading of water levels and also saves time. The schematic diagram of double ring infiltrometer set up with regulating and recording system is shown in figure 13a.

Construction and Working

This automated regulating and recording system has three main components, namely (i) a water level sensing device, (ii) a water supply device and (iii) a time registration with an electronic stopwatch.

Water level sensing device

A schematic detail of the water level sensing device is shown in figure 13b. When there is enough water on the soil surface in the inner ring (of the double ring infiltrometer) the plastic rod (9), which is attached to the polystyrene float (11), prevents light emitted by the light emitting diode (LED, 13) to reach the photosensitive transistor (4). The device can be set such that at the desired thinnest water layer on the soil surface, just enough light from the LED reaches the photo transistor to change its resistance and trigger the electronic circuit as shown in figure 13c. As a result, the time is recorded and a water supply cycle is started. When water is added to the inner ring, the float is pushed upward and the plastic tube again blocks the light from the LED, making the system ready to register another such event. Thus the lowest water level on the soil surface is sensed. The highest water level depends on the volume of water that is delivered by the water supply device.

Water Supply Device

The water supply device is schematically shown in figure 13d. When the electronic circuit is triggered by the photosensitive transistor of the water level sensing device, it activates the electromagnet (2). As a result, the upper end of the tube (13) is sealed (9), the lower end is opened (15) and the microswitch (1) is closed. This allows the water present in the vessel (12) to flow into the inner ring (dashed arrows) while the upper small compartment (5) is sealed off. The size of the opening (15) and its height above the soil surface should be adjusted such that, together with the protection provided by the perforated disk, the soil surface is not damaged by the flowing water. Water keeps running out of the vessel until the adjustable float (20) with the permanent magnet (19) drops below reed contacts (18), so that these open. This deactivates the electromagnet (2), which allows the spring (4) to push the core of the magnet upward. This, in turn, closes the seal (15) and opens the seal (9) and microswitch (1). Because the seal (9) is open again, the water in the small upper compartment (5) can flow into the vessel (12). When the float (8) has dropped to the level at which the reed contacts (6) are closed, the electrical valve (3) is activated and the water from the supply drum (fig. 13d) can flow through the upper compartment into the tube (13) and through the cut-out ports (14) into the vessel (12) (solid arrows). When the water reaches the level at which the magnet (7) in the float (8) again opens the reed contacts (6), the electrical valve (3) is deactivated and the water supply from the drum is cut-off. At this point the system is ready to receive a signal from the water level sensing device to deliver water to the inner ring and start a new cycle.

Thus, the water vessel (12) is always filled to the same level controlled by the float (8). The amount of water delivered each time to the inner ring is controlled by the height of the float (20) that can be adjusted with the gradation (16) and set screw (17). The simultaneous opening of one end and closing of the other end of the tube (13) prevents water running directly from the supply drum onto the soil surface in the inner ring. By registering the time of each cycle, the infiltration rate can be determined accurately in discrete steps. The number of steps can be tailored to the infiltrability of the soil by adjusting the float (20). It should be set such that the water depth of the soil surface varies as little as possible, while on the other hand the time between two events is large enough that the vessel (20) can be refilled.

Time Registration

The time of initiation of each water supply cycle can be stored in an on-line personal computer and the results processed immediately. The system can be made inexpensive by using a semi-automatic system, where a simple pocket calculator with quartz clock and electronic stop watch can be used. The starting time of each cycle is displayed while the real time clock keeps running. The events are announced by a buzzer, alerting the operator that time can be recorded manually.

3.8.2 Microprocessor Based Recording System (NIH, Roorkee)

It is a double ring (flooding type) infiltrometer with the inner ring of diameter 22.5 cm to 35.5 cm and the outer ring of diameter 37.5 to 50 cm. It works on the constant head principle with a specially designed constant head device. A microprocessor (Intel's 8085) has been incorporated in the measurement section so that the water level readings, alongwith time, can be stored in a memory module.

3.9 WATERSHED HYDROGRAPH AND BASIN METHODS

Infiltration may be determined from precipitation and streamflow records over a runoff plot or a watershed. Such an anlysis includes several variables such as varying rainfall characteristics, slope, length of overland flow, soil and vegetation differences, depression storage and surface detention occuring naturally. If the area is forested, canopy interception must be evaluated and any variation in soil type must be accounted for as well.

Using this method, infiltration rates of small agricultural watersheds of 3ha have been measured together with subsurface flow and surface storage from rainfall and runoff data (Ghildyal and Tripathi, 1987). On the basis of such studies, the three broad phases of hydrology- rainfall infiltration and hydraulics of overland flow as they affect the surface runoff- have been investigated.

In the hydrograph methods, the infiltration rate is determined from the records of the rainfall and runoff from the catchment area, neglecting evaporation. Theoretically, with a given infiltration rate, an increase in rainfall intensity will result in an increase in runoff. Therefore, a comparison of the detailed study of rainfall and runoff with time would give the infiltration rate. Since each period of intense rainfall in a given storm will produce a peak on the runoff hydrograph, the infiltration rate is determined by subtracting the amount of surface runoff under each peak from the amount of the rainfall.

The concept is outlined in figure 14 (taken from Black, 1991) where a curve of infiltration capacity is superimposed upon a histogram of a hypothetical rainstorm. Both the line and bars are in inches per hour, so it is possible to determine, knowing the length of time by which each bar of rainfall intensity exceeds the infiltration curve value, just how much rainfall will not infiltrate the soil.

The hydrographs methods are of special importance for agricultural watersheds which have a small catchment area.

However, in the poresence of a water table or where the ground water component of stream flow is large, it is difficult to separate the surface and ground water contributions to total hydrographs. Other sources of error include evapotranspiration, surface storage and interception effects. These methods have been applied for large catchment areas with some modifications. However, the validity of these methods tends to vary inversely with the size of the catchment area because of the time lag between rainfall and runoff, variations in soil type, antecedent meteorological conditions, and the variability in rainfall intensity and amount.

4.0 CONCLUSION

Quantification of infiltration and infiltration capacities has been the subject of a large number of studies, with most of the successful measurements being made on disturbed, nonforested lands. Kirkby (1978) summarized a large number of infiltration studies with relatively modern infiltrometer equipment. Amerman (1983) critically discussed the infiltration measurement and reviewed the two important measurement techniques, i.e., flooding type and sprinkling type infiltrometers.

Ring infiltrometers are commonly used for *in-situ* determination of soil hydraulic properties, i.e. the water content-pressure head relationship, water retention curve, the relation between water content and hydraulic conductivity, measurement of infiltration capacity, determination of spatial variability of soil properties. Rain simulators, on the other hand, are widely used to study soil erosion, soil crusting, and for measurement of infiltration and runoff.

The ring infiltrometers, especially the double ring types, are simple to use and involve little sampling error. The rain simulators are more complex, involve more assumptions, particularly on rainfall application, and have greater probability of sampling error (Julander and Jackson, 1983). However, the latter type are more capable of simulating the natural process and thus have intuitive and popular appeal. The comparative studies of the two types of instruments have shown that the range of measurements corresponding to the ring infiltrometer (double ring type) is wider than that resulting from the rain simulator, especially for the higher water contents (Touma and Albergel, 1992).

With advancements in technology, other types of infiltrometers and infiltration measurement techniques are also becoming popular. Some of these instruments/techniques are considered to be very promising, because of their operational features.

If water flow occurs in more than one direction, it is necessary to check for anisotropy. Although soil hydraulic properties are known to be affected by temperature, very little attention has been given to this fact. Jaynes (1990), for example, observed infiltration rates in the field that varied by 30% of the mean rate over a 24 hour period. The changes were related to the temperature at the soil surface.

In the last, it should be mentioned that to the best of the authors' knowledge, no Indian standards exist for infiltrometer and infiltration measurement techniques.

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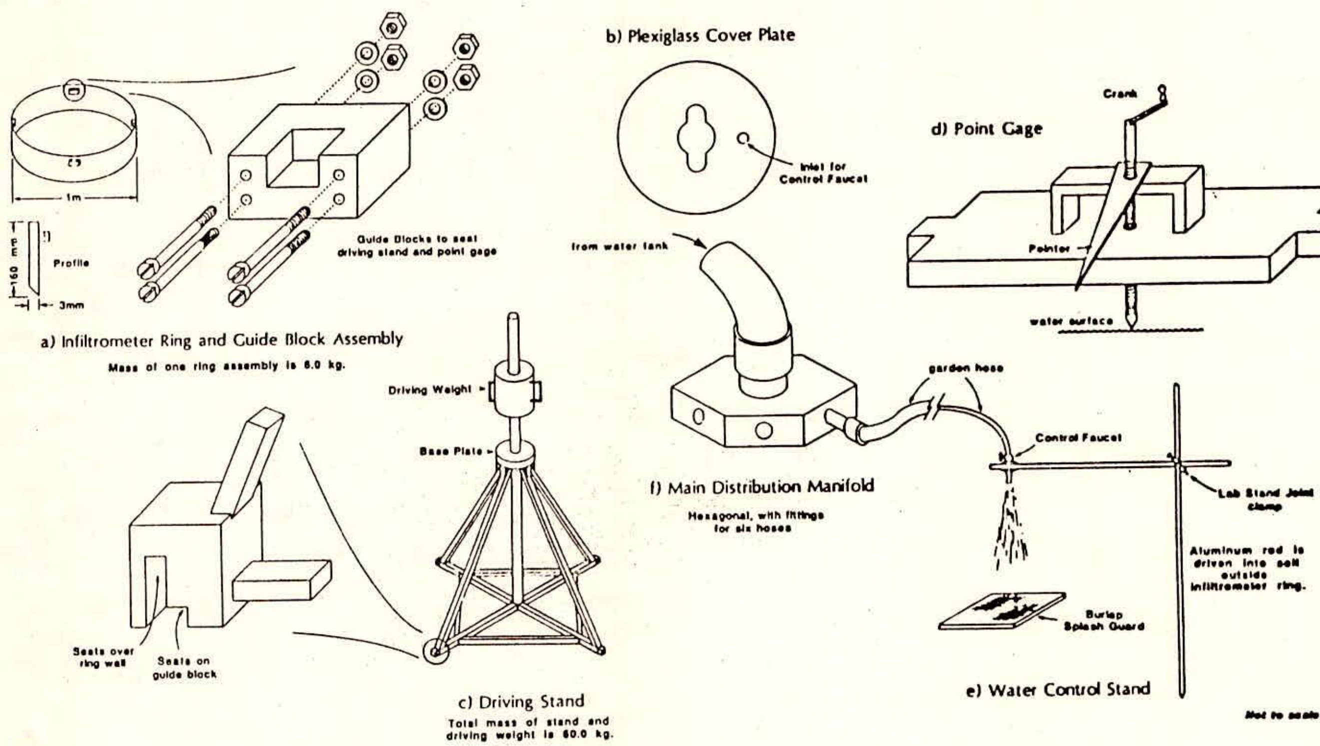

Fig.2a Schematic of single-ring infiltrometer used by Loague (1990)

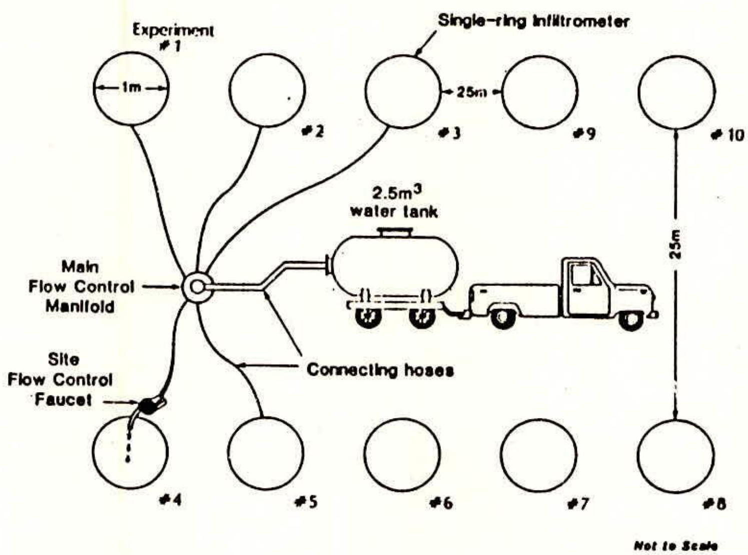

Fig.2b Experimental grid layout for simultaneous steady-state infiltration measurements

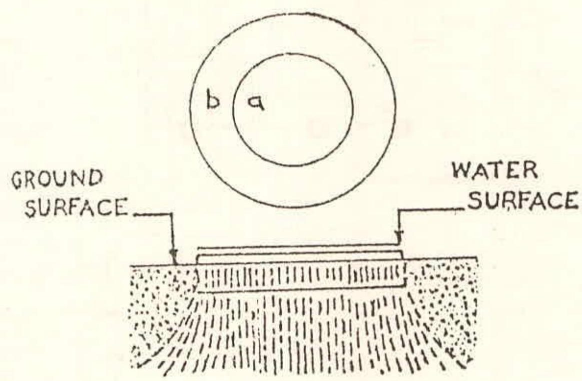

Fig.3 Double-ring infiltrometer

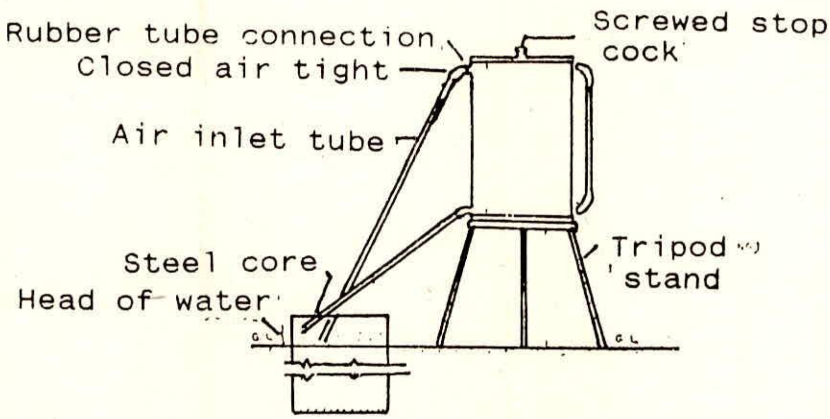

Fig.4 Self-dispensing infiltrometer

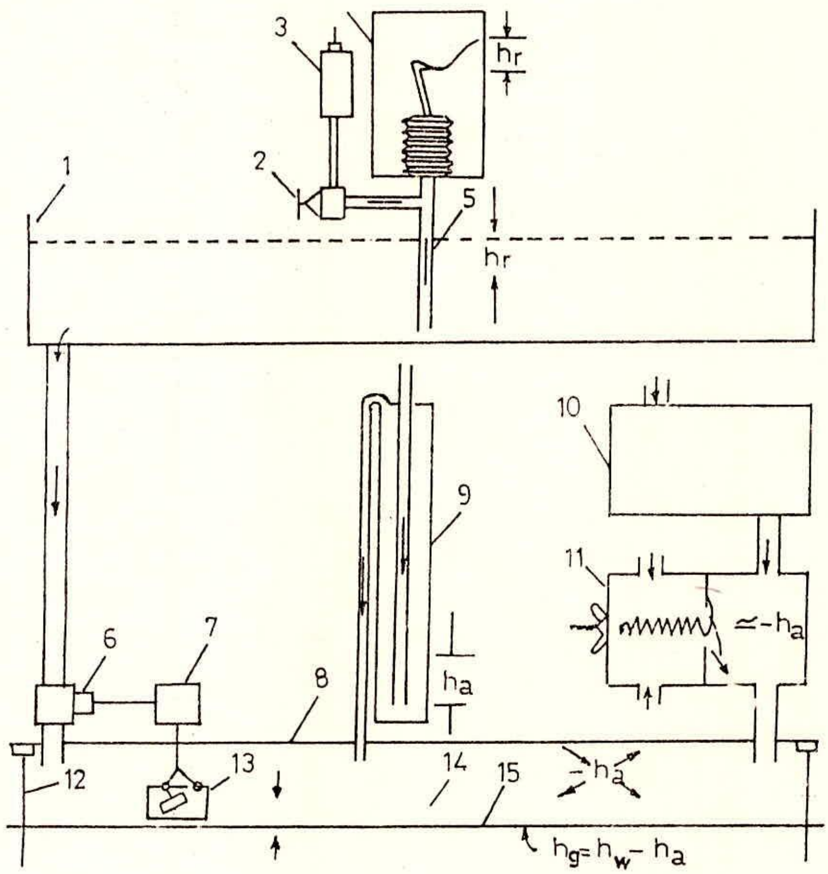

Fig. 5 Single-ring closed top infiltrometer

1 & 2 WATER MANOMETERS
3 NEEDLE VALVE
4 AIR LINE
5 SOIL SURFACE ACCESS RESERVOIR
6 MANOMETER WATER WELL
7 CLOSED-TOP INFILTROMETER RING
8 AIR PRESSURE ACCESS RESERVOIR
9 AIR PRESSURE REGULATOR (AIR BUBBLING TYPE)
10 AIR SUPPLY SYSTEM
11 SOIL SURFACE ACCESS TUBE
12 PONDED WATER SURFACE
13 SOIL SURFACE
14 SOIL PASTE SEAL
15 SEAL RETAINING RING

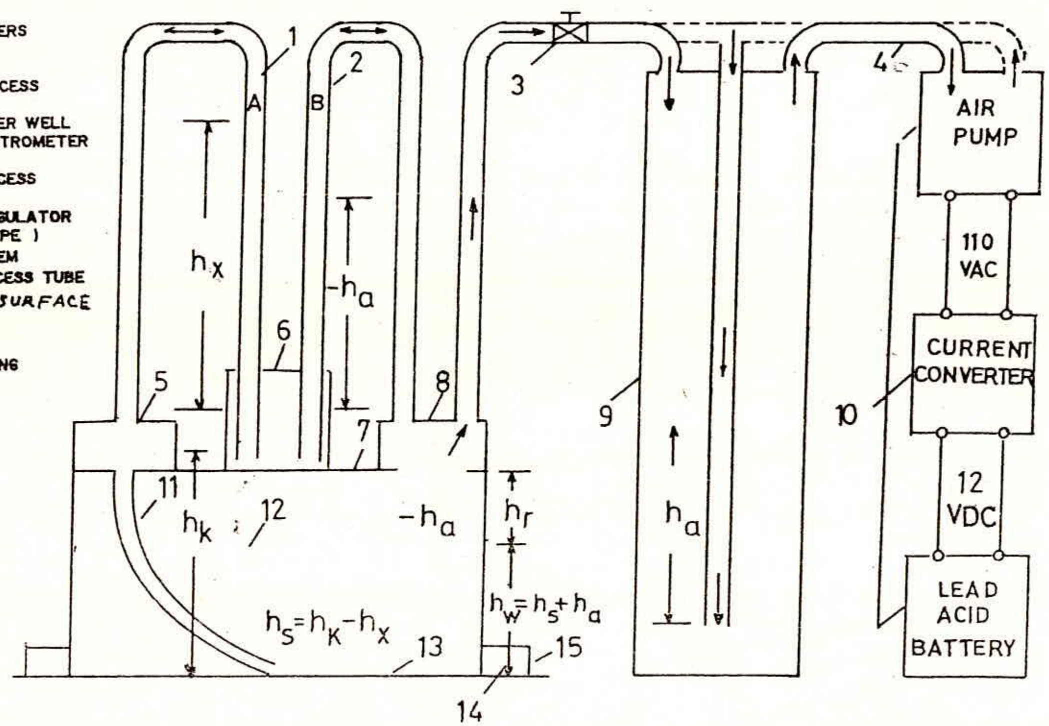

FIG. 6 SINGLE-SQUARE CLOSED-TOP INFILTROMETER

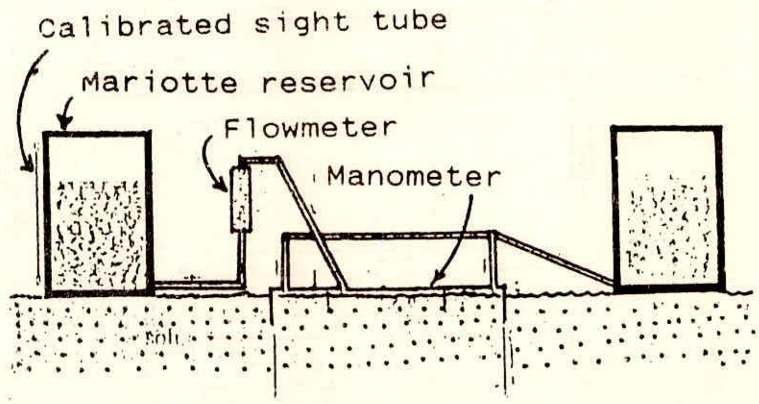

Fig.7 Double-cap infiltrometer

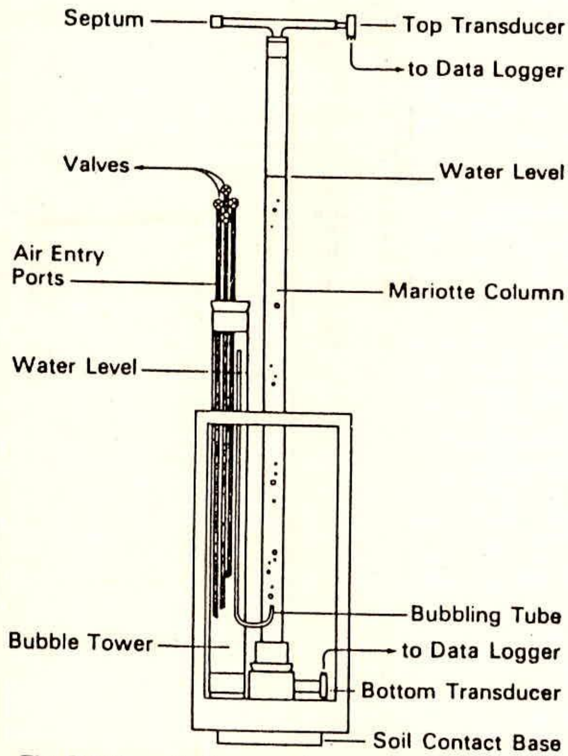

Fig. 8 Schematic diagram of tension infiltrometer.

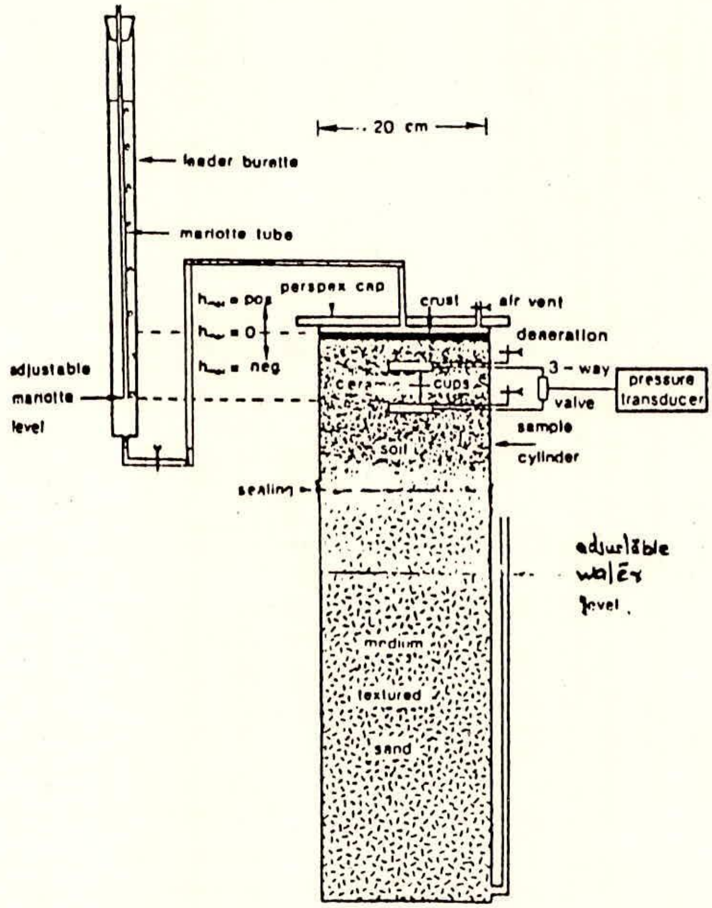

Fig.9 Schematic diagram of suction crust infiltrometer

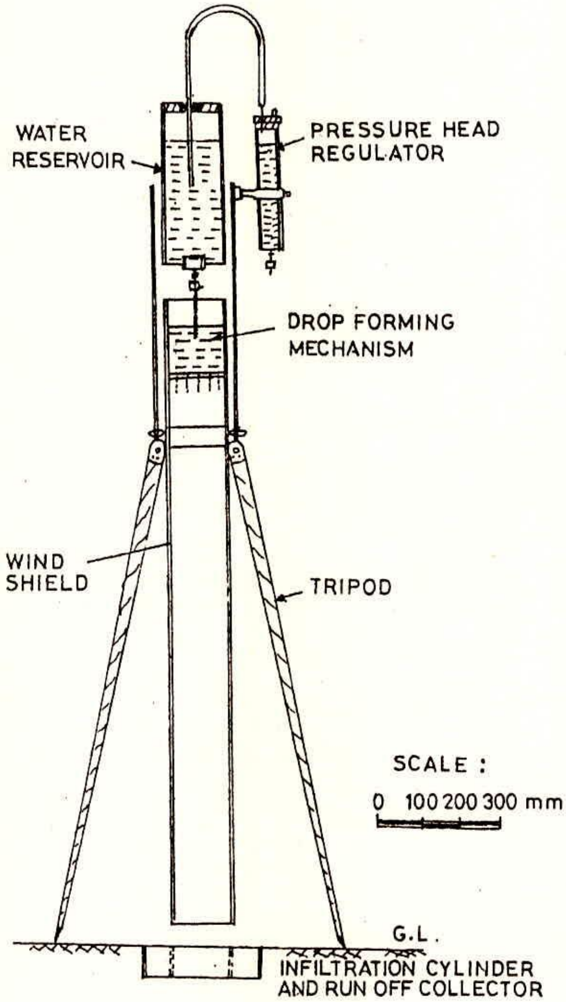

Fig. 10 Portable rainfall simulator infiltrometer

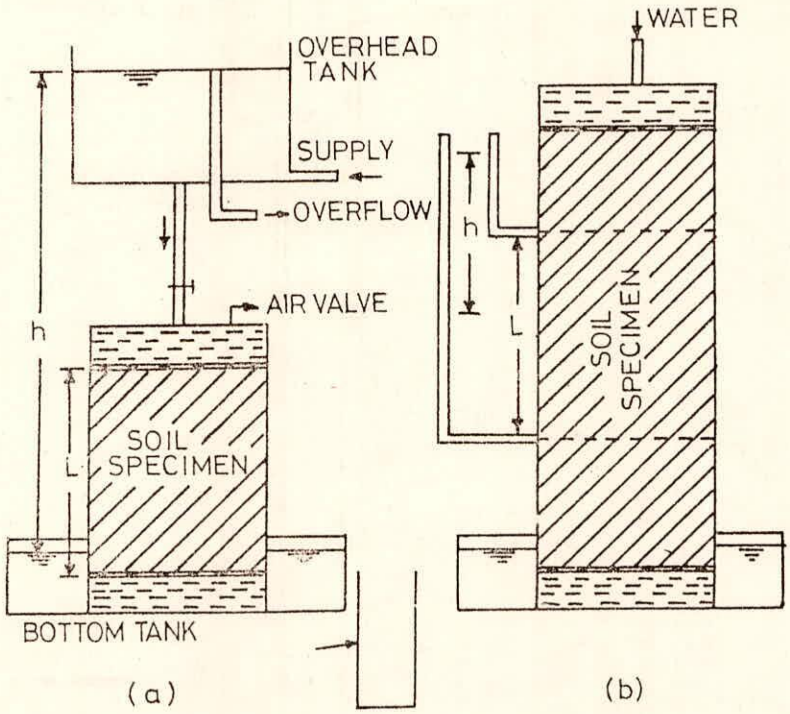

FIG.11 CONSTANT HEAD PERMEAMETER

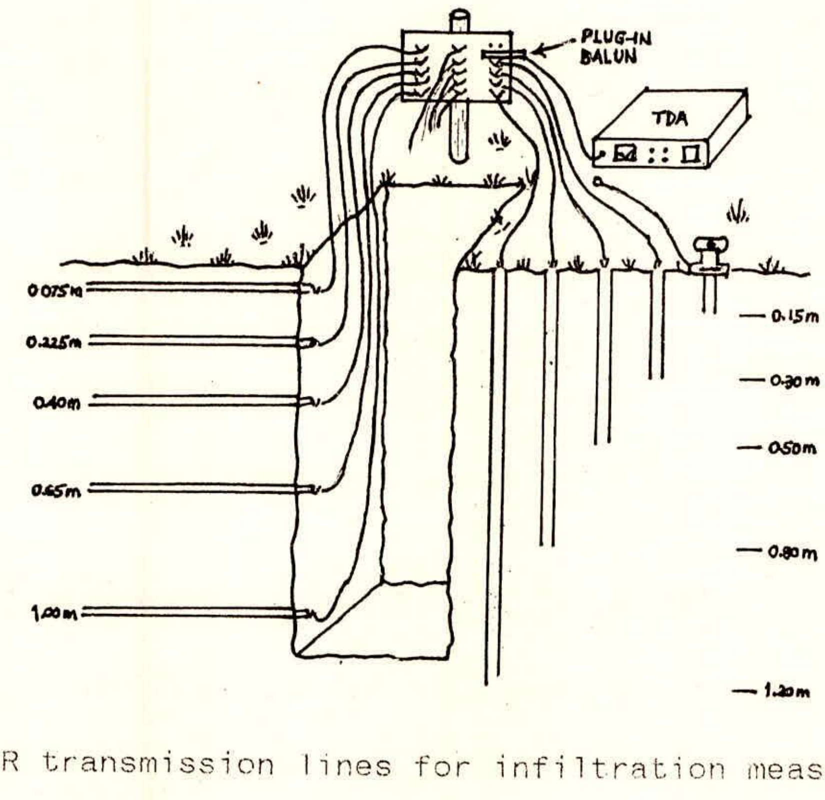

Fig.12 TDR transmission lines for infiltration measurements

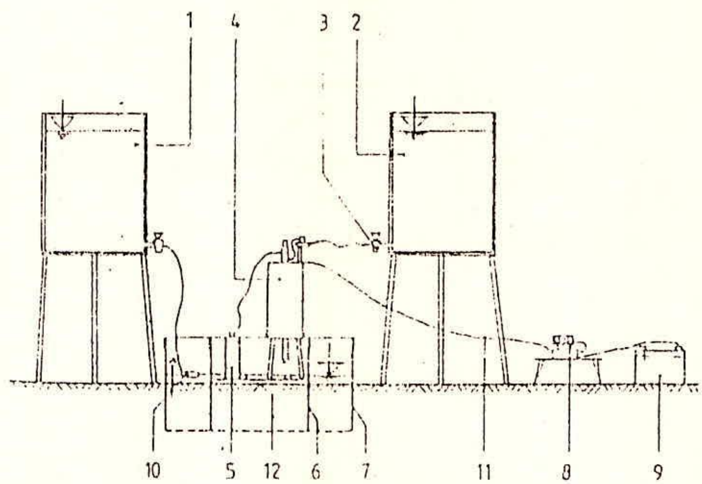

Fig. 13a Schematic diagram of regulating & recording double-ring infiltrometer

1. Water drum for guard ring
2. Water drum for inner ring
3. Valve.
4. Water supply device
5. Water level sensing device
6. Inner ring
7. Guard ring
8. Electronic stop watch with battery pack (5 V) and auxiliary circuitry (or computer)
9. Car battery (12 V)
10. Carburetor float and valve.
11. Electrical cords
12. Perforated disk.

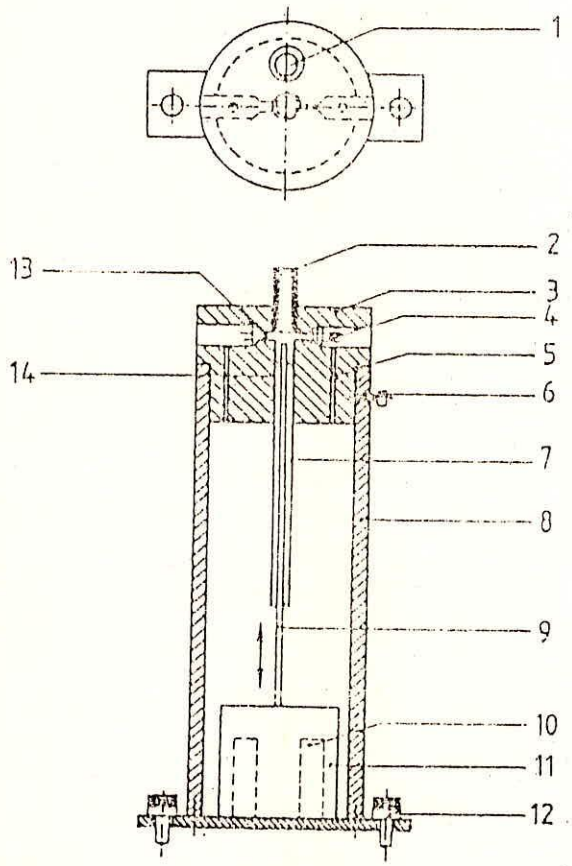

Fig.13b Cross-section & top view of water level sensing device

1. Socket for electrical connections
2. Black cover
3. Plexiglass measuring head
4. Photosensitive transistor
5. Holes for electrical wires
6. Set-screw
7. Glass holding tube
8. Plexiglass tube, diam. = 60 mm
9. Plastic rod
10. Water inlets
11. Polystyrene float (lacquered)
12. Leveling screws
13. Light-emitting diode (LED)
14. Inside black coating

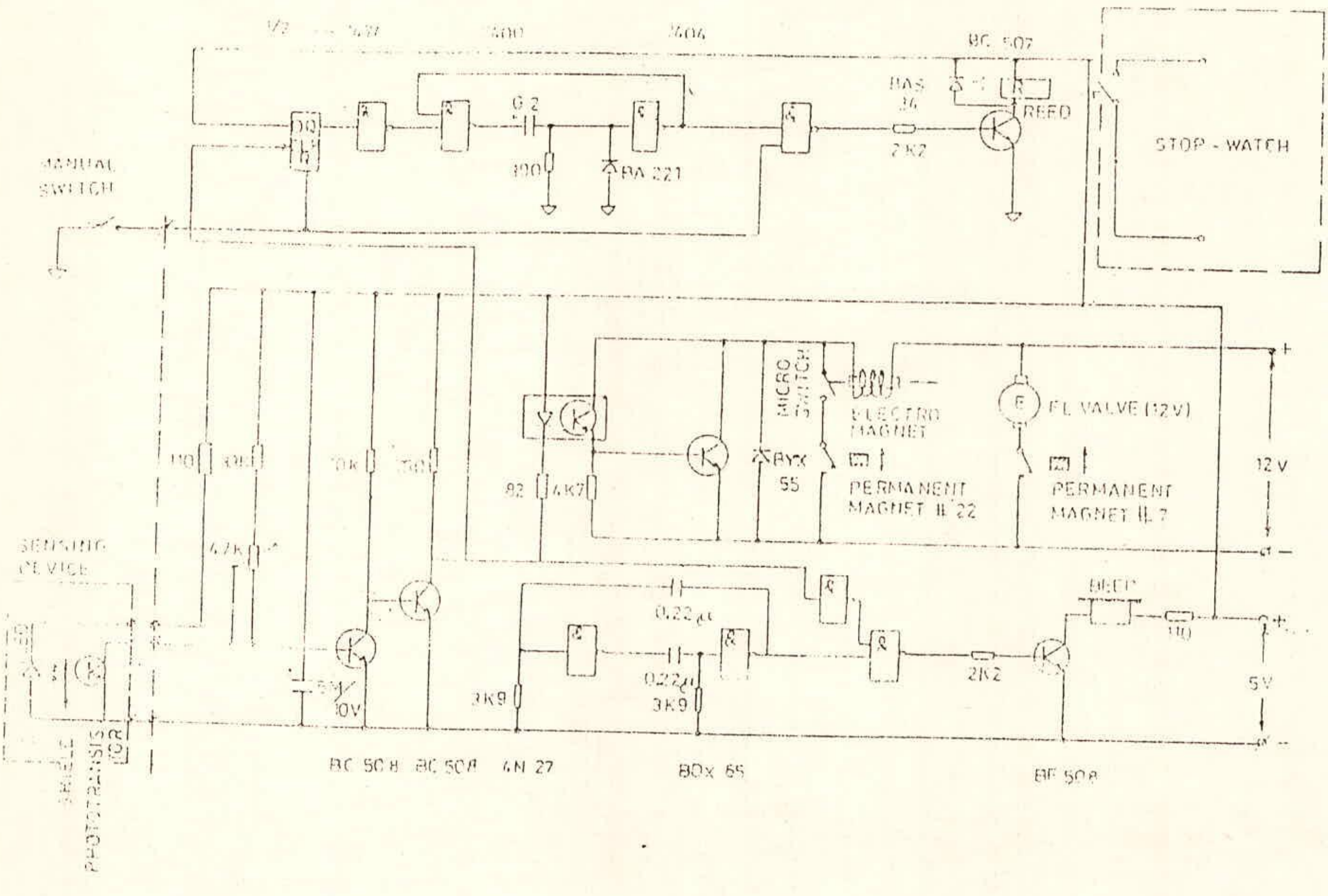

Fig.13c Electronic circuit controlling the water supply cycle

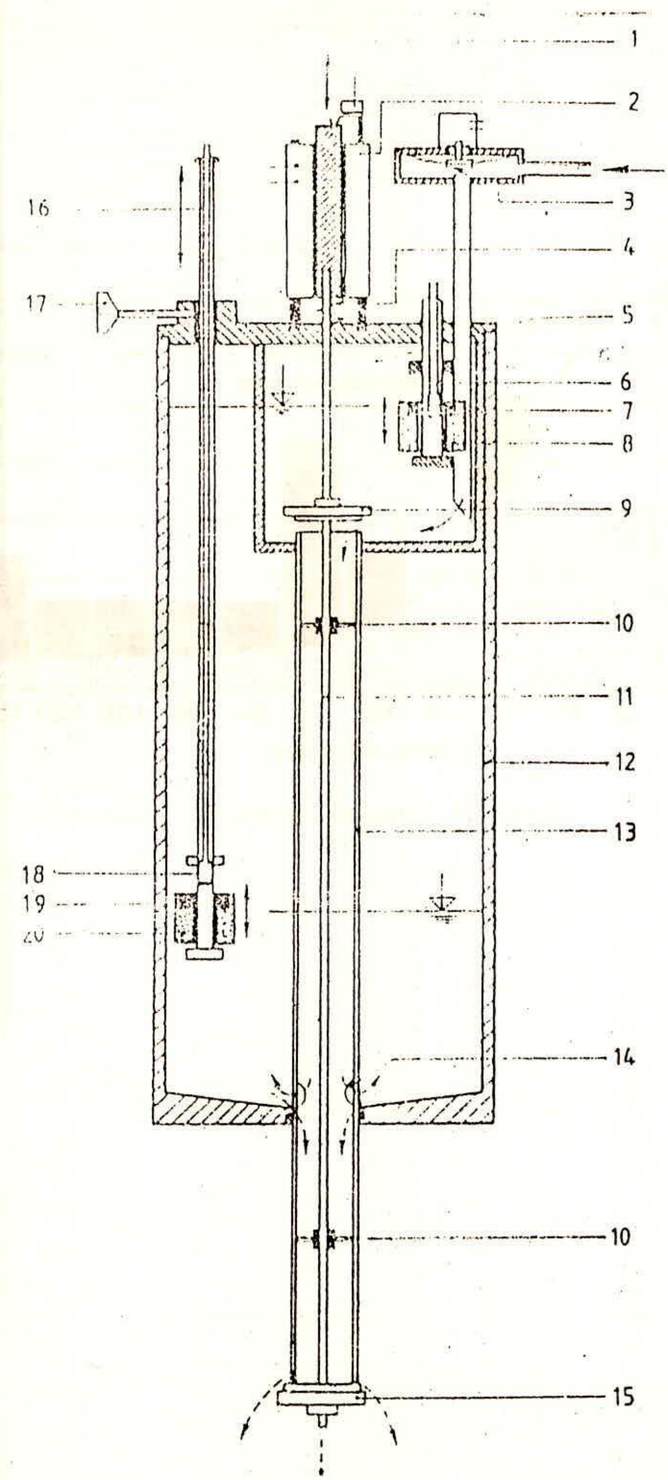

Fig.13d Cross-section of water supply device

1. Microswitch
2. Electromagnet
3. Electrical valve (water input)
4. Mechanical spring
5. Small compartment
6. Reed contacts
7. Permanent magnet ring
8. Polystyrene float
9. Upper rubber-plexiglass seal
10. Spacer
11. Rod connecting seals to electromagnet
12. Plexiglass vessel, diam. = 130 mm
13. Plexiglass tube, diam. = 30 mm
14. Cut out ports
15. Lower rubber-plexiglass seal
16. Indicator of lowest water level (adjustable)
17. Set screw
18. Reed contacts
19. Permanent magnet ring
20. Polystyrene float

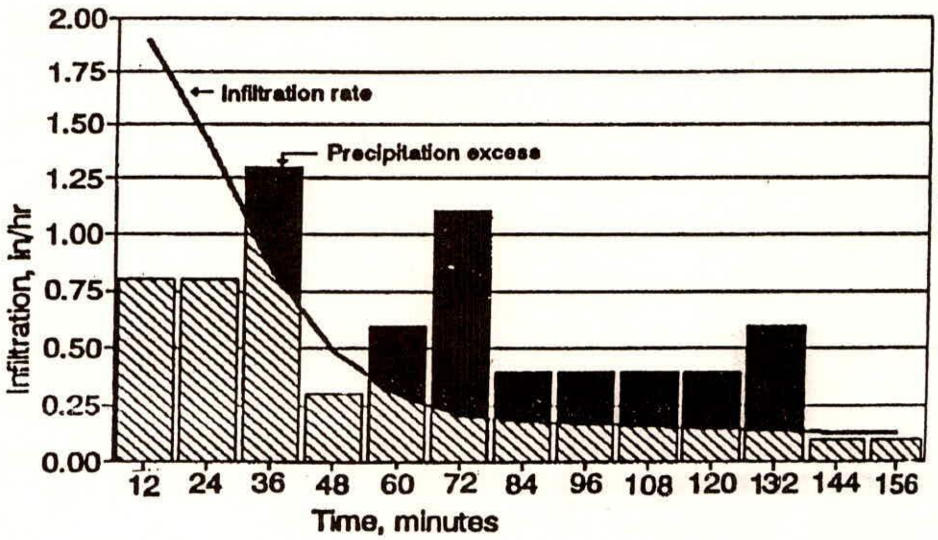

Figure 14 Infiltration rate and precipitation excess

DIRECTOR	:	S.M.SETH
STUDY GROUP	:	V C GOYAL B P ROY