STUDY OF MOISTURE DISTRIBUTION PATTERN UNDER TRICKLE IRRIGATION SYSTEM

BY

Jagabandhu Panda

A THESIS SUBMITTED TO
THE ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, BHUBANESWAR
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)
IN

SOIL AND WATER CONSERVATION ENGINEERING

DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING
College of Agricultural Engineering and Technology
Orissa University of Agriculture and Technology
BHUBANESWAR - 751003

JUNE, 1997

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CERTIFICATE

This is to certify that the thesis entitled "**STUDY OF MOISTURE DISTRIBUTION PATTERN UNDER TRICKLE IRRIGATION SYSTEM**" submitted in partial fulfilment of degree of Master of Technology (Agricultural Engineering) in Soil and Water Conservation Engineering of the Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of bonafide research work carried out by Sri Jagabandhu Panda under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The help and information as have been availed of in course of this research work have been duly acknowledged by him.

Date : 23/06/97

23/6/97

S. D. SHARMA

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Bhubaneswar
Dated, the 23rd June, 1997.

Jagabandhu Panda
(JAGABANDHU PANDA)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
CAET	College of Agricultural Engineering and Technology
cm	Centimetre
cc	Cubic Centimetre
Dr.	Doctor
Drain.	Drainage
EC	Electrical Conductivity
ed.	Edition
Eqn.	Equation
Fig.	Figure
gm.	Gram
GI	Galvanised Iron
hr	hour
Irrig.	Irrigation
Jour.	Journal
Kohm	Kilo ohm
Lph	Litre per hour
m	Metre
min	minute
MS	Mild Steel
q	Water application rate
t	time
VGM	Van-Genuchten Model

CHAPTER - I

INTRODUCTION

CHAPTER - I

INTRODUCTION

Irrigation is one of the influencial input factor which directly and extensively controls the output in crop production process. The total crop production of the country has increased from 50 million tonne to 176 million tonne (Rao G.V.,1994). The irrigation scenario of the country shows that the irrigated area has also increased during the period from 22.6 m.ha to 84.6 m.ha (Sivnappan,1994). These two statistics reveal the effect of change in irrigation scnerio on crop production. The most important source of irrigation in nature is rain fall. Rainfall being non uniformly distributed and erratic in nature in out country, the availability of required quantity of water to crops in proper time is a matter of concern. However with irrigation facilities it is possible to over come this problem and the maximum benifit can be derived from other inputs like improved seeds proper fertiliser dose and use of insecticides and pesticides.

Irrigated agriculture has been developed extensively for arid regions where natural precipitation is inadequate in most of the time of a year for production of many crops. However less emphasis has been given to irrigation facilities in relatively high rainfall areas, whereas these regions also suffer from dry spells due to which either no crop can be raised or crop yields are seriously hampered for want of required amount of moisture. Thus need of irrigated agriculture arises for arid and semiarid conditions and also during dry spells in subhumid and humid regions to save crop from moisture stress.

There is limited water resource available for irrigation from surface and ground water sources. It has been estimated that food requirement of the country will be about 235 million tonne by the end of 2000 A.D and 400 million tonne by 2025 A.D. (Sivnappana, 1994). The introduction of green revolution has modified the concept of irrigation. Along with the growing population the advent of green revolution has not only enhanced the importance of irrigation but also emphasised the need to use limited warer resources with maximum effectiveness and output. Irrigation has stabilised the food resourse of our country. Famines have been greatly reduced through the increased crop production and provision has been made for the support of a greatly increased population. In India irrigated agriculture involves revolutionary changes by way of providing technical know how in areas where artificial water supply is new to farmers and drastic steps have to be taken by the authorities concerned to enable the farmer to take full advantage of irrigation facilities. Most of the irrigation facilities are through canal irrigation system where farmers over irrigate their fields which are located close to the canal and suffer from heavy moisture stress which are away from the canal or are at tail end of the distributary. This over irrigation has not only caused reduction in irrigated area but also has made the fertile area unproductive in form of warer logged area. This is why rate of production in the canal irrigated area have become stable. This necessiates to bring change in the farmers mind for adopting alternative method of irrigation for increasing crop production at a faster rate to meet future demand.

Out of a number of methods of irrigation use of trickling or drip irrigation as method of irrigating large fields has become quite common practice in agriculture all over the world .The method is now one of the fastest growing new technologies in agriculture. The acrage under the trickle irrigation through out the world is steadily increasing. It has increased to the tune of 1,784,846, ha with highest acerage of 6,06,000 ha in U.S.A and only 20 ha in Icuador. In our coutry it is estimated that approximately 70,859 ha is under trickle irrigation system. Crop wise utilisation of trickle irrigation has been estimated as 42.2% for tea crop ,13.2% for vines, 12.5% for vegitables and the least for field crops , flowers and other unspecified crops (Anonymous, 1994). Going to state wise distribution it is highest in the state of Maharastra covering 32,924 ha followed by Andhra, Karnatak and others. The area under this method of irrigation in the state of Orissa is so meager that it does not appear in the list (Anonymous, 1994). Research on trickle irrigation is being carried out in almost all state / central agriculture universities/research stations of the country. Results are very much encouraging. It shows a very high degree of saving of water which is almost 50 to 60% of traditional water requirement and increase in crop production to the tune of 13.5% to 27% (Anonymous, 1994).

Trickle irrigation is the frequent slow application of water either directly on to the land surface or in to the roor zone of the crop. It is based on the fundamental concept of irrigating only the root zone of the crop and maintaining the water content of the root zone at or near optimum level.The trickle irrigation system consists of emitters which distribute the water for irrigation. These are actually attached to laterals which are connected to submains and main lines.

This method of water application to the soil have advanced from simple flood irrigation to a scientifically controlled sprinkler and trickle irrigation. Each of the conventional method of irrigation has certain advantages and limitations when considered on the technical and economical aspect. The trickle irrigation has developed specifically for economic use of water and profitable intensive agriculture. Some of the potential advantages of trickle irrigation system are as follows.

1. The traditional irrigation methods i.e. furrow, flood, and sprinkler irrigation consists of a relatively short period of water application followed by a long period of simultaneous redistribution, evaporation and extraction of soil moisture by plant, thus soil moisture potential varies from saturation to dry zone where as in the case of trickle irrigation frequncy of water application and duration of application increases. As a result of which average soil moisture potential is increased and is restricted to a narrow range hence eleminating high fluctuation in soil moisture which affects plant growth and crop yield. This increased soil water potential at very frequent and continuous water application is a consequence of both high average matric potential and low soil solution concentration resulting from the fact that the salinity of the soil solution approaches that of the irrigation water.
2. It minimises the salinity hazard to the plants by displacing the salt beyond the main efficient root zone and maintaing a relatively high soil moisture content due to high frequncy of irrigation. It helps in avoiding leaf burning and damage due to salt acclumulation on the surface of the leaves which are in contact with the irrigation water this is so particularly in sprinkler irrigation.
3. An additional feature of trickle irrigation is the possibility of restricting water supply to those parts of the soil where the activity of the root system with respect to water and nutrients is most efficient. Selective

wetting of the soil surface has additional benifits such as reducing evaporation due to comparatively low wetted surface area. The partial wetting also restricts the growth of weeds to the wetted region and thus reduces the cost of weed control by decreasing the need for weeding beyond the wetted region.

4. Trickle irrigation offers flexibility in fertilization a benifit unique to this system. Since fertiliser can easily be applied along with irrigation water, frequent or cotinuous application of nutrients at low concentration is feasible and seems to be very good practice. Optimising the nutritional balance of the root zone is possible by supplying the nutrients directly to the most effective part of the root zone and more options are available in the timing of application than with any other distribution system.
5. Under trickle irrigation loss of water due to run off even in low permeable and crusted soil is negligible. Much water saving may be achieved by restricting the water supply to the extent of the most effecient root zone.

The above claimed advantages of the trickle irrigation system can be justified by research results of various research stations. Exprimental studies reported by CWC(Anonymous, 1994) and presented In table 1.1 and 1.2 justifies the advantage of this over other on the basis of economic use of water, increase in crop production and reduction in cost of irrigation.

Table 1.1 Saving of water and increase in yield as compared to surface irrigation.

Sl.No	Crop	% Saving of water	% increase in yield
1	Cotton	53.0	27.0
2	Lady's finger	39.5	16.1
3	Tamato	27.0	5.0
4	Brinjal	55.8	17.5
5	Gourd	52.1	13.5
6	Ridge gourd	58.9	17.0
7	Sugar cane	59.8	5.0
8	cabbage	59.5	23.4

Table 1.2 Saving in power, water, labour and annual cost of maintenance (value per acre per year) as compared to conventional method of irrigation.

Sl No	Saving	Drip irrigation		Sprinkler irrigation	
		Mettalic	Plastic	Mettalic	Plastic
1	Power(KWH)	286	458	85	150
2	Water(%)	50	53	19.5	23
3	Labour(%)	65	65	42	42
4	Annual maintenance as % of cost of system	7.5	5	5	2

In trickle irrigation system, when three dimensional flow occurs ,the main design problem is to select the proper combination of emitter spacing and discharge for a given crop and soil.

One of the most important considerations in the design of the trickle systems is the volume of soil wetted by a single emitter. This must be known in order to determine the total number of emitters required to wet a large enough volume of soil to ensure that the plant water needs are met. In cases where there are no salinity problems the wetted volume of the soil should be kept within the limit of the effecient root zone. The volume of soil wetted from a point source is primarily a function of the soil texture, application rate and time of application of water. So it is essential to determine the proper combination of emiter spacing and discharge, irrigation frequency and time of application for a given set of soil moisture characteristic, crop root distribution, soil moisture distribution prior to each irrigation as well as the pattern of water up take by the roots. Determination of the proper emitter spacing and discharge under given external conditions requires knowldge of soil hydraulic properties together with crop response to the size and form of wetted soil volume and water distribution and fluctuation within this volume.In trickle irrigation soil serves less as a reservoir for water than for conventional irrigation becuse the water that is withdrawn from the root zone is continually replenished. Thus soil type alone is not highly important as a dertermining factor in establishing irrigation scheduling. However, soil type and application rate of water influence the pattern of water movement in the soil. Efficient operation and management of a trickle irrigation system requires a full understanding of above factors.

The extent and time histories of the wetting patterns are important considerations in determining the wetted boundaries of the irrigated soil and for establishing irrigation scheduling. In trickle irrigation, horizontal soil water movement is most important and a two dimensional moisture movement patteren in the soil profile must be considered.

Several research workers (Philip,1971, Wooding, 1968, Brandt et al. 1971, Bresler et al.,1971, Ben-Asher,1988) have presented models to determine the flow from the point sources which are often complicated and requires extensive soil data which render their use impossible for design process. In general, design procedures are based on tables which supply approximated wetted radii for generalised texture , various application rates and volumes. This often leads to trickle irrigation systems either under or over designed. So there is a need to fit the existing guidelines and procedures for specific soil ~ water conditions for efficient design of the system. Keeping the facts stated above in view, the present study has been under taken with the following specific objectives:

1. Determination of soil characteristics and devlopment of soil moisture and hydraulic conductivity reationship of the selected soil.

2. Development of a numerical simulation model for determining the soil-water distribution under trickle emitters at variable discharges.

3. Devlopment of a laboratory model for the study of soil water distribution under a point sources.

4. Validation of the numerical model with that of labortary model.

CHAPTER - II

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

The revolutionary development of trickle irrigation system is a result of a large number of studies conducted by scientiests, engineers on its different aspects. The combined efforts of scientiests, engineers and manufacturers have proved it as a most efficient technology in the field of irrigation. This chapter presents different models developed by research workers for imulating fluid flow in unsaturated porous media and outlines various methods for predicting soil physical characteristics from basic soil water properties. The feasibility and capability of the modelling systems to field conditions have also been discussed.

2.1 History and Development

During 1930's the peach growers of Australia were using 5 cm diameter G.I. pipes to irrigate the orchards, making triangular holes on the pipes by chiselling out the metals near each tree. The uniformity were assessed by visual observation and adjustments were done by turning the pipe and holes towards the plant. This system is thought to be the first step in drip irrigation technology without being defining the system as drip irrigation system (Anonymous, 1988).

During 1940, an Israeli engineer Symcha Blass noticed vigorous growth of a tree near a leaking faucet, in comparison to other trees in the neighbourhood. This example of leaking faucet encouraged him to find out a new device of irrigation system. Later he patented a low pressure system (Anonymous, 1988).

The basic ideas of drip irrigadion had been utilised in the years of 1960's by West German farmers. They laid clay pipes with open joints about 0.8m below the ground surface to utilise the system for irrigation as well as drainage as water table used to fluctuate during the year. This effort doubled the yield (Annonymous, 1988).

During 1960s the drip / trickle system was developed for field crops in Israel, Australia and America. Later it was extensively used as one of the irrigation system for different crops in various countries. The modern drip irrigation system differs from that of the early stage system by utilising much lower flow rates of the order 9 to 18 lph on mature trees. Smaller dia pipes were brought into use bringing a positive change in the economy of the systme. By 1974 over 64000 ha. throughout the world have been irrigated by drip irrigation system (Annonymous, 1988).

This system was introduced in India in early seventies. Significant developments came up during 1980s. Only a few states like Tamilnadu, Karnatak, Maharastra, Gujrat and Andhra Pradesh had adopted this modern method of drip irrigation. But now-a-days almost all the states have adopted this system.

2.2 Soil Water Movement and Distribution in Soil

Goldberg and Shmueli,1970 observed that the rate of horizontal advance of moisture movement in the soil mass and the matric potential at diferent distances from the point source depend upon both the soil type and trickle discharge rate. These two functions being interrelated, the width of the wetted zone along the trickle irrigation line is also a function of the time, rate of water application and the soil type.

Raats,1970 analysed steady infiltration from buried point source and surface point source.The partial differential equation for the matric flux potential and the Stokes stream function associated with symmetric flows are also derived. Here he assumed that the hydraulic conductivity is an exponential function of the pressure head. Explicit expression for the matric flux potential, the Stoke's stream function, the flux ,the pressure head and the total head are obtained. He also compared the solutions for buried point sources, surface point sources and gravity free flows .

Goldberg et al., 1971 studied the effect of trickle irrigation interval on soil moisture and salt distribution. In the experiment conducted in a vineyard keeping row to row distance 3m they observed that the main active soil layer supplying water to the roots was restricted to a strip 2m wide and 1.2m deep approximately. They further observed that it is possible to increase the lateral spread of wetting front by increasing the discharge rate of the emitters. They also concluded that higher the infiltration capacity of soil, lower will be the lateral movement of moisture front and thus needed a closer spacing of the emitters for optimal irrigation.

Brandt et al.,1971 suggested mathematical models to analyze multidimensional transient infiltration from a trickle source for a stable, isotropic and homogeneous porous medium. They considered two mathematical models.

(i) A plane flow model involving the Cartesion co-ordinates X and Z
(ii) A cylindrical flow model described by the Cylindrical co-ordinates r and z.

The diffusion type water flow equation in unsaturated soil was solved numerically by an approach that combines the non- iterative ADI difference technique with Newton's iterative method. The diffusion type water flow equation which has been used by them is as follows:

$$\frac{\delta\theta}{\delta t}=\frac{\delta}{\delta x}\left[D(\theta)\frac{\delta\theta}{\delta x}\right]+\frac{\delta}{\delta y}\left[D(\theta)\frac{\delta\theta}{\delta y}\right]+\frac{\delta}{\delta z}\left[D(\theta)\frac{\delta\theta}{\delta z}\right]-\frac{\delta k}{\delta z} \qquad 2.1$$

Where,

θ = soil water content ($L^3 L^{-3}$),

$D(\theta)$ = soil water diffusivity ($L^2 T^{-1}$),

and $K = K(\theta)$ = hydraulic conductivity of the soil (LT^{-1})

It has been assumed by them that , the both soil water diffusivity and hydraulic conductivity functions are dependent on water contents (θ) alone. X and Y are the horizontal co-ordinates and Z is the vertical co-ordinate which is considered to be positive downward.

Bresler et al., 1971 have compared the theory of transient infiltration from a trickle source developed by Brandt et al. 1971. with the experimental results. The effect of trickle discharge rates on the water content distribution have been studied. They found out the functional relationship between water diffusivity and water content by computer technique and arrived at a more accurate result than the conventional method of determination of water diffusivity.

Philip, 1971 established a general theorem that enables the solution of the quasi-linearised steady infiltration equation for a distribution of surface sources to be found immediately from the corresponding solution for buried point and line sources. He considered the flow of water through the soil as a diffusion process in a uniformily convective flow and sedimentation under gravity and brownian motion. The quasi linearised steady infiltration equation was genralised to apply tp hetorogeneous soils with conductivity depending exponentially on both moisture potential and depth.His postulation of the hydraulic conductivity as a function of both potential (ψ) and depth (Z) was given by

$$K(\psi, Z) = K_s \exp\ (\psi + \beta Z) \qquad 2.2$$

Where ,

K_s is the saturated hydraulic conductivity. For homogeneous soil the above equation can be reduced to the form as:

$$K(\psi) = K_s \exp(\psi) \qquad 2.3$$

Further equation dealing with the steady flow in heterogenous unsaturated media has also been given by Philips, 1971 as:

$$\frac{\delta K}{\delta Z} = \nabla.(K \nabla \psi) \qquad 2.4$$

Roth, 1971 conducted experiment on desert soil and observed that volume of soil wetted was more a function of water applied than the time of water application .Of course he had not considered the moisture content of the soil profile with respect to water advance.

Rowlin,1973 has given the justification of the moisture flow under steady state condition for the trickle emitters in field condition due to its frequency of irrigating the field for a relatively longer period of time.

Warrick,1974 analysed water flow from a point source using linearised form of the moisture folw equation. He studied the time dependance of the infiltration by numerical analysis and found out amenable solution for the advance of the wetting front during infiltration. He analysed the flow pattern resulted from a two point source having overlaping geometry of the flow domain under steady state condition .

Keller and Karmelli, 1974 observed that the percentage of wetted area compared to the whole irrigated area depends on emitter discharge, spacing and soil type.They have also presented a table which is use full as a guide for estimating the percentage of wetted area for various soil textures, emitter discharges and spacings.

Ahmed et al., 1976 studied the effect of soil type and water application rate from a drip line source on the two dimesional water distribution within the soil profile. He observed in loamy sand soil that horizontal movement of moisture front during water application is influenced by gravity and declines with respect to time. With further elapse of time the horizontal advance tend to approch a limit. After termination of water application the horizontal advance is very small compared to the vertical advance. In silt loam soils he observed auniform water advance in both the directions. According to him the water movement is dominated by the capillary action of the pores. For the same volume of water applied, the horizontal advance is directly proportional and vertical advance is inversely proportional to the water application rate. The shape of the wetting front confirms to a semi ellipse.

Hachum and Alfaro, 1976 made a laboratory study and found that for a given volume of irrigation water as the, water application rate increases, depth of the wetted zone decreases while horizontal spread of wetting increases.Also increase in water application rate, increases the width of wetted zone near the emitters.

Khepar et al., 1983 investigated the effect of rate of discharge ,volume of water applied and initial moisture content of soil on moisture distribution in soil profile following drip irrigation. In loamy sand for levelled surface they observed that:

(I) At higher application rate the moisture content of soil in different layers was less than that at lower application rates.

(ii) High application rate associated with high initial moisture content of soil can allow greater soil coverage ,allowing wider emitter spacing .

(iii) With the increase in water application volume the horizontal advance of the wetting front increases.

(iv) After 24 hours of turning off water application the soil moisture content undergoes redistribution through the wetted volume and attains equlibrium wetting front advances both horizontally and verticlally.

Philip, 1984 found the solution in closed form for the travel times of marked particles from burried and surface infiltration sources. His study is based on the quasi-linear analysis of steady three dimensional unsaturated flow. The mathematical postulation given by him can be applied to all linear convection diffusion processes from continuous point sources in the appropriate infinite and semiinfinite regions. The limitation in use of this model in soil water context is that the travel velocities are based on a mean volumetric moisture content.

Teghavi et al., 1984 investigated the transient movement of water in an unsaturated porous medium using the zero order continuous linear finite element method. The two dimensional non linear partial differential equation is transformed logarithmically to smooth down the abrupt changes in the soil water characteristic relations. They used the Newton-Raphson technique to iterate towards the exact solution of the original non-linear equations along with a modified implict finite difference scheme to approximate the time derivative. This model is capable to simulate water movement through very dry soil environments which causes a steep moisture front. Also this model can be applied in irregularly shaped flow regions.

Clotheir et al., 1985 observed that the distribution of water from a drip emitter is dominated by soil characteristics. Water flow pathways in soil mass can act to subvert the uniform distribution of water. In such cases microjets should be used as the emitters.

Schwartzmass and Zur, 1985 developed a model for estimating the dimensions of the wetted soil under a point source and reported that the wetted soil volume depends on the hydraulic conductivity of the soil, the emitter discharge and on the total amount of water in the soil.The following empirical equations were developed to estimate the wetted depth and width.

$$Z^1 = K_1 (V_w)^{0.63} \left(\frac{C_s}{q} \right)^{0.45} \qquad 2.5$$

$$W = K_2 (V_w)^{0.22} \left(\frac{C_s}{q} \right)^{-0.17} \qquad 2.6$$

and $$W = K_3 (Z^1)^{0.35} (q)^{0.33} (C_s)^{-0.33} \qquad 2.7$$

Where ,

Z^1 = vertical distance to wetting front (m)

W = wetted width or diameter of water pattern (m)

K_1= empirical coefficient ≈29.2.

V_w = volume of water applied (lit)

C_s = saturated hydraulic conductivity of the soil (m/sec)

q = point source emitter discharge (lit/hr)

K_2 = empirical coeff.≈ 0.0094.

Ben-Asher, 1986 developed an effective hemispherical model to study infiltration from a point trickle source in the presence of water extraction. The position of the wetting front was derived analytically. He sugggested that in the short time limit the wetting front follows a simple $t^{1/3}$ dependence where t is the time of advance of the wetting front. The rate of advance of wetting front depends on a single soil parameter closely related to the staturared water content. At the larger times the effect of water extraction modify the solution to an exponential approach to a limiting radius, which is determined by the balance between the competing discharge and extraction processes. The equation derived to find the wetting front position at any time under no water extraction condition was given by :

$$R(t) = \left[\frac{3Qt}{\Delta\theta}\right]^{1/3} \qquad 2.8$$

Where,

R(t) = effective radius of a wet hemisphere(L)

Q = discharge rate of the emitters (LT^{-1})

$\Delta\theta$ = difference between average moisture content and the initial moisture content which can be approximated half the value of saturated water content.

and t = time of operation of the trickle source.

Kaul and Michael, 1986 conducted experiments at water technology center IARI,New Delhi to investigate the status of moisture in different soil horizons at different radial distances from the point source. They concluded that :

(i) Soil moisture content in the wetted zone resulting from the point source of water application rapidly increases in the soil layers close to the source of water application i.e about 15cms depth and 20 cm dia.

(ii) The moisture content in the zone cited above attains a value close to the saturation moisture content of the soil and continued at this level till the remaining part of the water application and for some time thereafter depending upon the water application rate and duration of application.

(iii) The soil moisture profile at any instant during water appliction was a function of water application rate,the ultimate profile being a function of total volume of water application.

(iv) The values of soil moisture content at different depths and at different lateral distances in the wetted zone can be considered while fixing the emitter discharge.

Tifera, 1987 conducted expriments taking various soils and observed power relationship between vertical and horizontal advance of wetting front and elapsed time.

Dash, 1989 and Mohanty ,1990 observed that for equal amount of water applied, power relationship exists between :

(i) Vertical and horizontal advance of wetting front I and elapsed time at any water application rate.

(ii) Vertical and horizontal advance of wetting front and water application rate at any elapsed time,

(iii) Wetting front profiles at any time confirms semi elliptical pattern.

Andreas et al., 1991 compared the models developed for soil water distribution under trickle emitters using hemispherical model developed by Ben-Asher,the finite element model,the mathematical model using linearised partial differential equation,as well as experimental procedure for verifying the above models and have found out close agreements between them.

Nayak ,1991 studied the two dimensional moisture front advance in soil taking two trapezoidal ridges having different cross sections but equal side slopes. He observed that initially the horizontal advance is higher than that of vertical advance for certain time which depends on cross sectional area of ridge section, water application rate and soil characteristics. Then the trend was reversed i.e the vertical advance become higher than horizontal advance.This trend is same for each water application rate. The advance in both the directions could be expressed by a power equation with variations in values of coefficients, with change of cross section and water application rate.

Omary et al., 1992 developed a three dimensional finite element model for studying the movement of water and pesticide from trickle irrigation. They used a cylindrical flow model having co-ordinates r, ϕ and z to simulate water and pesticide movement from a trickle irrigation emitter.They considered unsaturated,non-steady flow in multilayered soil.They used finite element technique to solve the non-linear differential aquations in conjuction with a finite difference scheme to solve the time dependent part of the equations. Linear shape function were used to approximate the different parameters in the differential equations.

Sen et al., 1992 developed a simple numerical methodology to solve Warrick's analytical model for surface trickle point source. They attempted to validate numerically Warrick's theory for wide range of soil moisture conditions by dividing the hydraulic conductivity-moisture content relationship into small segments of 0.02cc/cc. They compared the outputs with the numerical outputs of Brandt et al.,1971 and also with the experimental data for four different soils.

Chu, 1994 suggested the Green-Ampt analysis of wetting patterns for surface emittrs.He developed a three dimensional Green-Ampt analysis and presented the infiltration capacity curve for a three dimensional infiltration model. This infiltration capacity curve represents the time distribution of wetting pattern, volume of a water source with unlimited inflow supply.The infiltration capacity curve is applied to describe the wetting pattern of a surface emitter with a constant discharge by matching the emitter discharge with the average rate of infiltration-capacity. He also derived algebraic solutions of the wetted radius and the maximum wetting pattern depth.

Kerkides et al., 1994 derived an analytical solution for vertical one dimensional flow for both ponded and constant flux boundary conditions in order to find out the moisture profile as a function of time and space continuam r and z, where r and z are the polar co-ordinates of the flow regime.

2.3 Determination of Soil Physical Properties

Determination of soil physical properties are essential to the solution of problems involving irrigation,drainage ,water conservation ,ground water discharge etc. Various investigators have developed extensive mathematical theories to describe soil water movement under different sets of initial and boundary conditions (Hillel, 1971,Kirkham and Powers,1972).

The two most important soil physical properties are matric suction ~water content relationship and hydraullic conductivity -water content relationship. A number of methods have been developed for measuring the unsaturated hydraulic conductivy in labortary and field condition.

2.3.1 Laboratory and field measurement of unsaturated hydraulic conductivity

Youngs, 1964 developed an infiltration method to determine the relationship between hydraulic conductivity and moisture content. Two methods of obtaining the necessary unsaturated condition of the porous column were employed. One maintains the porous material at a suction through a porous membrane, the other maintains the air pressure in dry porous material at a pressure greater than atmospheric with the surface kept saturated. Water was applied with the head maintained constant during the experiment by means of the mariotte flasks ,which measures the water taken up by the porous column. Then for both the methods, the volume of water uptake was plotted with respect to time as well as moisture front advance. Finally by conducting the experiment at different moisture contents, a relationship between hydraulic conductivity and water content was found out for both the methods.

Watson, 1966 developed an instantaneous profile method for the determination of unsaturated hydraulic conductivity. He conducted this experiment in the laboratory for a soil column by first saturating it and then allowing the water to drain out vertically downwards. Then the soil water suction and moisture content was regularly monitored by using strain gauge pressure transducers and neutron probe moisture meter. Using the equation of flow of water in vertical direction, the flux profiles at different times and elevations were found out from the neutron moisture meter data. Similarly the values of hydraulic heads at different elevations and times were also found out from the strain gauge transducer data. By using Darcy's law the relationship between hydraulic conductivity and water content was found out from the above curves. Later Hillel et al., 1972 used this method in field condition.

Hillel and Gardner, 1970 measured unsaturated hydraulic conductivity by infiltration through an impending layer. The experiment involves a series of infiltration trials through capping plates of different hydraulic resistance. Here the effect of this resistance was to induce the development of a suction at the surface of the infiltrating column. An actual measurement of the capillary conductivity was obtained by allowing the process to proceed to the steady stage, when flux becomes equal to the conductivity and the use of progressively impending place gave progressively smaller hydraulic conductivity values corresponding to lower water contents of the transmission zone. Later Bouma et al., 1971 used this in field condition.

2.3.2 Determination of hydraulic conductivity using models

Reliable estimates of the unsaturated hydraulic conductivity are especially difficult to obtain, partly because of its extensive variability in the field and partly bacause measuring this parameter is quite time consuming and expensive. For this very reason several investigators have developed models for calculating unsaturated hydraulic conductivity.

Marshall, 1958 developed model based on pore size distribution with the following assumptions.

(i) The rate of flow is controlled by the cross sectional area of the connecting pores.

(ii) The cross sectional area of a neck is that of the smaller pores.

He found the expression for hydraulic conductivity as follows

$$K(\psi) = \left[\frac{2\gamma}{\rho_v g}\right]^2 \frac{\theta^2 - n^{-2}}{8} [\psi^{-2}_1 + 3\psi^{-2}_2 + 5\psi^{-2}_3 + 7\psi^{-2}_4 + .. + (2n-1)\,\psi^{-2}_n] \qquad 2.9$$

Where,

n = number of pores.

θ = volumetric water content

$\psi_1, \psi_2, \psi_3 \ldots\ldots \psi_n$ are values of suction heads in different pores.

Millington and Quirk, 1961 developed a model similar to that of Marshall model ,1958. The difference being in the power of θ, which in this case is 4/3 and n is equal to the total number of interacting pore classes at saturation.By using suitable matching factor, these models have been found to yield accurate values of hydraulic conductivity of soil.

Green and Corey, 1971 developed a computational method based on pore interaction model of Marshall and compared it favourably with modified methods of Millington and Qurik and of marshall for prediction of hydraulic conductivity versus water content relationship on number of soils. All methods required matching one point onthe calculated hydraulic conductivity curve to an experimentally measured hydraulic conductivity value.

Van-Genuchten, 1980, developed another model to find out $K \sim \theta$ relationship from $\psi \sim \theta$ relationship. He assumed the θ, ψ relationship like

$$\Theta = \left[\frac{1}{1+(\beta\Psi)^n}\right]^m \qquad 2.10a$$

Where,

β, m, n are undetermined parameters.

ψ is the suction pressure.

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad 2.10b$$

Where,

θ_s = saturated moisture content

θ_r = residual moisture content

θ = volumatric moisture content

From this based on Mualem's theory, 1976, he derived the relationship for $K(\Theta)$ as follows.

$$K_r(\Theta) = \Theta\,[1 - (1 - \Theta^{1/m})^{m}]^2 \qquad 2.11$$

Where $K_r(\Theta)$ = relative hydraulic conductivity.

Shani et al., 1987 proposed a method using drippers to estimate the soil hydraulic properties, based on assumed relationships of the hydraulic conductivity and matric head. The method was based on the observation that, when water is applied at a constant rate to a point on the soil surface, a ponded zone is created that approaches a constant area in a short time. Once the borders of the ponded zone were steady, saturated hydraulic conductivity and the matrix flux function were evaluated from a regression of flux vs reciprocal of ponded radius. The other soil hydraulic parameters were derived according to the hydraulic relations assumed. A comparision of hydraulic parameters measured and estimated by two other methods for these soils showed good agreement with each other.

The review presents a picture about the various works done in the field of moisture movement under trickle irrigation and determination of the soil physical properties. Crops extract moisture from the wetted bulb of the soil caused by emitter. Hence it is required to get more and more information about the moisture movement in the soil by the emitters. This soil moisture distribution model are to be used for designing the drip irrigation system, for proper emitter spacing and optimising the water use level of plants. The application of the modeled data of moisture movement for design depends on the availability of the soil properties data and also the reliability of these datas with that of the field/experiment values. Simultaneously the model should not be associated with complicated mathematical functions for which the calculations will be difficult. At last the sucess of a mathematical model for prediction of moisture movement and distribution depends on

(i) Proper application and conversion of physical conditions to mathematical problems

(ii) Availability of reliable input parameters i.e. soil physical properties, discharge rate etc.

(iii) Simple calculations and systematic output of results which can be used for design of the system where the field data are not available.

Keeping the above points in mind the subsequent studies are made and reported in the next chapters.

CHAPTER - III

THEORITICAL CONSIDERATION

CHAPTER - III

THEORETICAL COSIDERATION

This chapter deals with the theoretical and analytical model development of flow through unsaturated porous media taking place from trickle emitter.

3.1 Darcy's Law

The flow of water through porous medium was studied experimentally by Henry Darcy (1856): According to him the quantity of water passing a unit cross section of soil is proportional to the gradient of hydraulic head. In mathematical symbols Darcy's law is

$$Q = K\, I\, A \qquad 3.1$$

Where,

Q = volume of water passing through the soil column per unit time ($L^3 T^{-1}$)

I = hydraulic gradient (dimensionless)

$= \frac{\Delta H}{\Delta L}$ = hydraulic head difference per unit length of the soil water space.

A = cross sectional area of the soil column (L^2)

K = proportionality constant or known as hydraulic conductivity, which is defined as the flux of water per unit gradient of hydraulic potential (LT^{-1})

$$q = -K \frac{\Delta H}{\Delta L} \qquad 3.2$$

Where, q = volume of water passing through unit cross sectional area of the soil column in unit time and is termed as flux (LT^{-1}).

3.2 Factors Affecting the Hydraulic Conductivity of Unsaturated Soil

The factors which affect the hydraulic conductivity of unsaturated soil are those related to the properties of soil and soil-water content.

In general as water content of the soil is reduced, the air enters the soil pores. Such air filled pores are no longer effective channels for the flow of water. Hence with the reduction in the water content, the effective porosity is reduced accompanied by rapid lowering of the hydraulic conductivity of the soil. Also as the soil suction increases, the macro pores are emptied first, which greatly reduce the effective cross sectional area of the flow. As a result the macro pores which are better conductors of water go out of action with an increase of suction. The water has to now move through micro pores which offer considerable resistance to its passage and consequently reduces its conductivity.

3.3 Flow Equations for Unsaturated Soil

From the above discussions it is clear that Darcy's low is insufficient to describe water flow in an unsaturated soil due to a very rapid reduction in hydraulic conductivity. Also the total cross sectional area available for the flow as the soil-water content decreases from saturation. Therefore for unsaturated flow systems, Darcy's law has been extended by assuming that the conductivity is now a function of soil suction, i.e. K= K (h).

Considering that the Darcy's law is valid during unsaturated flow the Darcy's equation can be witten as;

$$q = -K(h)\ \nabla\psi_T \qquad 3.3a$$

and $$\psi_T = h - z + \pi \qquad 3.3b$$

Where

q = flux density (LT^{-1}).

$K(h)$ = hydraulic conductivity (LT^{-1}) which is a function of water content(θ) or matric pressure head (h)

$\Delta\psi_T$ = potential gradiant of the total potential ψ_T

z = gravitational pressure head (L)

h = matric pressure head (L)

π = osmotic pressure head which is very small and hence neglected

Hence $\psi_T = h - z$ 3.3c

3.4 Equation of Continuity

The equation expressing the continuity of flow of fluid in the medium and combined with Darcy's law, is know as the equation of continuity. The equation is simply a statement of the law of conservation of matter. For water flow in the soil this equation can be developed by considering the water balance over a stationary elemental volume of soil through which the flow is taking place. In general, the equation is written as

Rate of water accumulation in a soil element = Rate of water entering into the soil element - Rate of water leaving the soil element

Considering a small volume element of soil (Fig.3.1) in the form of a para llelepiped of edges Δx, Δy and Δz parallel respectively to its axes x, y, and z through which water is flowing in all the cartesian co-ordinate direction. Let the companents of velocity of flow (flux) in the directions of the axes be q_x, q_y and q_z respectively.

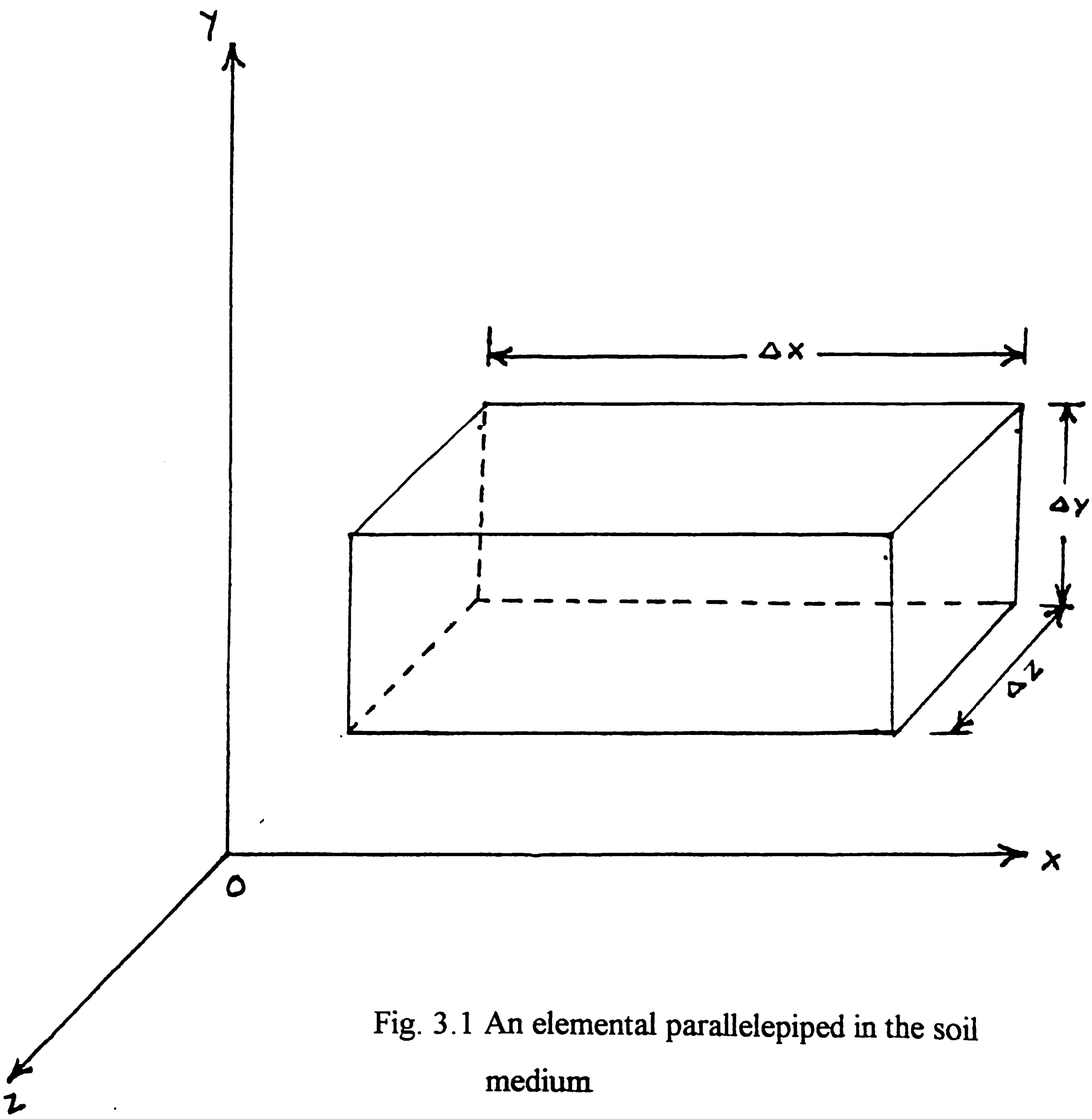


Fig. 3.1 An elemental parallelepiped in the soil medium

The inflow rate through the face $\Delta y \Delta z$ at x $= q_x \Delta y \Delta z$

The outflow rate through the face $\Delta y \Delta z$ at x $+\Delta x$ $= q_{x+\Delta x} \Delta y \Delta z$

The inflow rate through the face $\Delta x \Delta z$ at y $= q_y \Delta x \Delta z$

The outflow rate through the face $\Delta x \Delta z$ at y $+\Delta y$ $= q_{y+\Delta y} \Delta y \Delta z$

The inflow rate through the face Δx Δz at z $= q_z \Delta x \Delta z$

The outflow rate through the face $\Delta x \Delta y$ at z $+\Delta z$ $= q_{z+\Delta z} \Delta y \Delta y$

If the inflow rate into the volume element is greater than the rate of outflow, the volume element must be accumulating water at a rate given by,

Rate of water Accumulation	=	Rate of inflow from each face	-	Rate of outflow from each face.

$$\Delta S = -(\Delta q_x \ \Delta y \Delta z + \Delta q_y \Delta x \Delta z + \Delta q_z \Delta x \Delta y) \qquad 3.4$$

An alternative expression for this rate of accumulation can also be obtained in terms of the rate of increase of water content in the volume element $\Delta x \Delta y \Delta z$. If θ be the volume of water per unit volume of soil and t be the time, the rate of accumulation of water in the volume element

$$\Delta s = \frac{\delta \theta}{\delta t} \Delta x \Delta y \Delta z \qquad 3.5$$

equating eqn 3.4 and 3.5 we get ;

$$\frac{\delta\theta}{\delta t} = -\left[\frac{\delta qx}{\delta x} + \frac{\delta qy}{\delta y} + \frac{\delta qz}{\delta z}\right] = -\nabla.q \qquad 3.6$$

Eqn 3.6 is referred to as the equation of continuity of water balance equation over the stationary volume element.

Substituting eqn 3.3 and eqn 3.3b in eqn 3.6 we get

$$\frac{\delta\theta}{\delta t} = -\nabla.[-K(h)\nabla(h-z)]$$

$$= \nabla.[K(h)\nabla h - K(h)\nabla z] \qquad 3.7$$

But $\nabla z = \hat{K}$ i.e. unit vector along z direction

So, $$\frac{\delta\theta}{\delta t} = \nabla.[K(h)\nabla h - K(h)K$$

$$= \nabla.[K(h)\nabla h] - \frac{\delta K(h)}{\delta z} \qquad 3.8$$

This eqn 3.8 is non-linear moisture flow equation.

3.5 Solution of the Non-Linear Moisture Flow Equation.

The general non-linear differential equation 3.8 can be solved only by numerical techniques on a large scale computers. Even then the storage capacity needed for a four dimensional grid (x, y, z, t), large computational times and resulting accuracy problems can present drawbacks. So an alternative approach can be adopted for the solution of the above eqn.. This approach is the linearization of the non-linearized equation. This can be obtained by defining a matric flux potential after Gardner (1958) as

$$\phi = \int_{-\infty}^{h} K(h)\, dh = K/\alpha \qquad 3.9a$$

Where,

h is the pressure head (L)

K is the hydraulic conductivity K(h) (LT^{-1}) of the form

$$K(h) = K_o \exp(\alpha h) \qquad 3.9b$$

Where, α is a coefficient (L^{-1}) commonly within the range 0.002 to 0.02 cm^{-1}. (Philip 1969, Braester 1973)

K_o (LT^{-1}) is normally saturated hydraulic conductivity or can be determined from bestfitting of K and h values.

From the above eqn 3.9a we can derive

$$\frac{d\phi}{dh} = K(h) \qquad 3.10$$

Putting K from eqn 3.10 in eqn 3.8

$$\frac{\delta\theta}{\delta t} = \nabla.\left[\frac{d\phi}{dh}\left(\frac{\delta h}{\delta x}\hat{i} + \frac{\delta h}{\delta y}\hat{j} + \frac{\delta h}{\delta z}\hat{k}\right)\right] - \frac{\delta K(h)}{\delta z}$$

$$= \nabla.\left[\frac{\delta\phi}{\delta x}\hat{i} + \frac{\delta\phi}{\delta y}\hat{j} + \frac{\delta\phi}{\delta z}\hat{k}\right] - \frac{\delta K(h)}{\delta z}$$

$$= \nabla.[\nabla\phi] - \frac{\delta K(h)}{\delta z}$$

$$= \nabla^2 S - \frac{\delta K(h)}{\delta z} \qquad 3.11$$

where,

$\hat{i}, \hat{j}, \hat{k}$ are unit vectors along x, y, z directions respectively.

Differentiating the flux potential with K(h) we can get

$$\frac{\delta\phi}{\delta K(h)} = \frac{1}{\alpha} \text{i.e.} \delta K(h) = \alpha\delta\phi \qquad 3.12$$

Putting the value of δK(h) from eqn 3.12 in eqn 3.11 we can get

$$\frac{\delta\theta}{\delta t} = \nabla^2\phi - \alpha\left(\frac{\delta\phi}{\delta z}\right) \qquad 3.13$$

Where,

t = time

θ = volumetric moisture content

∇^2 = the laplacian operator with respect to ordinary space

z = vertical co-ordinate taken to be positive down wards.

We can write eqn 3.13 as

$$\frac{\delta\theta}{\delta\phi}.\frac{\delta\phi}{\delta t} = \nabla^2\phi - \alpha\frac{\delta\phi}{\delta z}$$

or $$\frac{\delta\phi}{\delta t} = \frac{\delta\phi}{\delta\theta}\left[\nabla^2\phi - \alpha\frac{\delta\phi}{\delta z}\right]$$ 3.14

Assuming $\frac{\delta\theta}{\delta\phi}$ is a constant, the eqn 3.14 is reduced to the linearized form with time and it can be stated as.

$$\frac{\delta\phi}{\delta t} = \left(\frac{K}{\alpha}\right)\nabla^2\phi - K\left(\frac{\delta\phi}{\delta z}\right)$$ 3.15

Where, $\frac{d\phi}{dt} = \frac{\alpha}{K}$ 3.16a

$$K = \frac{dK}{d\theta}$$ 3.16b

The solution of the eqn 3.15 can be obtained by introducing one initial and one boundary condition.

The initial condition is that the flux at any point at time t =0 is zero.

Mathematically speaking ϕ (r, z 0) = 0 3.17a

The boundary condition is that no flow occurs at the surface except at the origin. Mathematically.

$$-\frac{\delta\phi}{\delta z} + \alpha\phi = 0, z = 0, r \neq 0$$ 3.17b

Where r, z are the cylindrical co-ordinates with z positive downwards. Also ϕ and the derivatives of ϕ vanishes as z or r becomes large. At origin a singularity of strength "q" is assumed i.e. water is introduced at a rate of q per unit time ($L^3\,T^{-1}$). Thus q is taken as the trickle rate of the emitter.

The solution of eqn 3.15 subject to Eqn 3.17a when the source is buried in an infinite medium is by Carslaw and Jaeger 1959 :

$$\phi_B = \frac{q}{2\left(r^2+z^2\right)^{1/2}\pi^{3/2}}\exp\left(\frac{\alpha z}{2}\right)\int_{\alpha\left(\frac{r^2+z^2}{4Kt}\right)}^{\infty}\exp\left[-\xi^2-\frac{\alpha^2\left(r^2+z^2\right)}{16\xi^2}\right]d\xi \qquad 3.18$$

Where,

ξ is a dummy variable.

Defining dimensionless co-ordinates and time as

$$R = \frac{\alpha r}{2} \qquad 3.19a$$

$$Z = \frac{\alpha z}{2} \qquad 3.19b$$

$$T = \frac{\alpha K t}{4} \qquad 3.19\text{ c}$$

and a dimensionless matric flux potential Φ_B by

$$\Phi_B = \frac{8\pi\phi_B}{\alpha q} \qquad 3.20$$

after Philip 1971 Eqn. 3.18 reduces to

$$\Phi_B = \frac{2e^Z}{\pi\rho} \int_{\rho/2\sqrt{T}}^{\infty} \exp\left[-\xi^2 - \frac{\rho^2}{4\xi^2}\right] d\xi^2 \qquad 3.21$$

Where $\rho^2 = R^2 + Z^2$

By Abramowitz and Stegun, 1964 integration of eqn 3.21 gives

$$\Phi_B = \frac{e^Z}{2\rho}\left\{e^{\rho}\operatorname{erfc}\left(\frac{\rho}{2\sqrt{T}} + \sqrt{T}\right) + e^{-\rho}\operatorname{erfc}\left(\frac{\rho}{2\sqrt{T}} - \sqrt{T}\right)\right\} \qquad 3.22$$

Following steps analogous to Philip, 1971 the gradient will be

$$\frac{\delta\Phi_B}{\delta Z} = \Phi_B + \frac{Ze^Z}{2\rho}\left\{e^{\rho}\operatorname{erfc}\left(\frac{\rho}{2\sqrt{T}} + \sqrt{T}\right) + e^{-\rho}\operatorname{erfc}\left(\frac{\rho}{2\sqrt{T}} - \sqrt{T}\right)\right\} \qquad 3.23$$

Thus the quantity $\Phi_B - \frac{\delta\Phi_B}{\delta Z}$ varishes along Z = 0 $(R \neq 0)$, approaches zero as $\rho \rightarrow \infty$ and satisfies the differential eqn 3.15.

Philip (1972) suggested a solution for surface source if the solution corresponding to buried source is known. According to him let us assume for the moment that the solution for the point source is

$$\Phi_S = 2\left\{\Phi_B - e^{2Z}\int_{Z}^{\infty} e^{-2Z'}\left[\Phi_B\right]_{Z=Z'} dZ'\right\} \qquad 3.24$$

Where, Z' is a dummy integration variable.

It is noted that Φ_S will satisfy Eqation 3.17b or its equivalent

$\Phi_S - (1/2)\,(\delta\Phi_s/\delta z) = 0,\ Z = 0,\ R \neq 0$ 3.25

As eqn 3.15 and 3.17a are also satisfied and Φ_S goes to zero as Z or R becomes large, Eqn 3.24 is the correct solution.

Thus the final solution for surface point source can be stated as :

$$\Phi_S = 2\left\{\Phi_B - e^{2Z}\int_Z^{\infty} e^{-2Z^l}\left[\Phi_B^l\right]dZ^l\right\} \qquad 3.26a$$

Where, $\Phi_B^l = \left[\Phi_B\right]_{Z=Z^l}$ 3.26b

The integration part of the eqn is carried out following the Gauss-Leguerre quadrature method for arbitrary lower limit of integration.

Putting $Z^l = Z + X/2$ in eqn 3.26a we may write

$$\int_Z^{\infty} e^{-2Z^l}\left[\Phi_B^l\right]dZ^l$$

$$= e^{-2Z}\int_0^{\infty} e^{-X}\left[\Phi_B\right]_{Z^l=Z+X/2}\frac{dX}{2}$$

$$= 1/2\ e^{-2Z}\sum_{i=0}^{n} w_i\left[\Phi_B^l\right]_{Z^l=Z+X/2} \qquad 3.27$$

The weighted summation in eqn (3.27) is solved numerically by Gauss-Leguerre 15- point formula i.e. n =14 with the weighted value (w_i) and sompling point (x_i) given.

3.6 Determination of Unsaturated Hydraulic Conductivity

From the previous discussions it is known that the hydraulic conductivity is a function of volumatric moisture content and suction head. The value of hydraulic conductivity of the medium depends on the degree of saturation of the medium. The unsaturated hydraulic conductivity is an input parameter for obtaining the solution for moisture flux and hence the volumatric moisture content. Therefore it is required to determine the unsaturated hydralic conductivity.

3.6.1 Relative hydraulic conductivity

Relative hydraulic conductivity is defined as the ratio of the hydraulic conductivity any moisture content to that of at saturation i.e.

$$K_r = \frac{K(\theta)}{K_s} \qquad 3.28$$

Mualem, 1976 derived the equation for predicting the relative hydraulic (K_r) from the knowledge of soil-water retention curve, is given by

$$K_r = \Theta^{1/2}\left[\frac{\int_0^{\Theta}\frac{1}{\psi(x)}dx}{\int_0^{1}\frac{1}{\psi(x)}dx}\right]^2 \qquad 3.29$$

Where,

$$\Theta = \frac{\theta-\theta_r}{\theta_s-\theta_r} \qquad 3.30$$

θ_s = Saturated moisture content

θ_r = Residual moisture content

Again the value of Θ in terms of ψ is given by the following equation,

$$\Theta = \left[\frac{1}{1+(\beta\psi)^n}\right]^m \qquad 3.31$$

A typical θ vs ψ curve based on eqn 3.31 is shown in fig 3.2. It should be noted that a nearly symmetrical "S" shaped nature of the curve reveals that the slope $d\theta/d\psi$ becomes zero, when θ approaches its both saturated and residual values. In order to determine the values of the parameters defined above, the value of ψ is assumed to be a unique and continuous function of the dimensionless moisture content Θ i.e. $\psi = \psi(\Theta)$

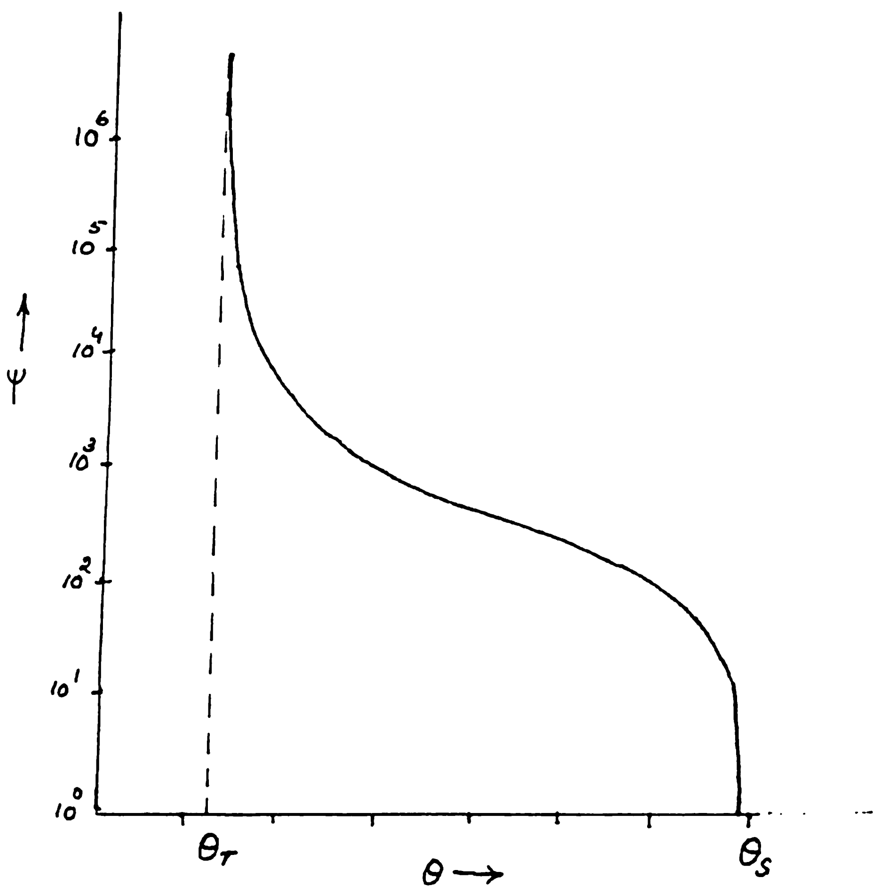


Fig. 3.2 Typical soil moisture retention curve

Solving the eqn 3.31 for $\psi = \psi(\Theta)$ and substituting the resulting expression into eqn 3.29 gives

$$K_r(\Theta) = \Theta^{1/2}\left[\frac{f(\Theta)}{f(1)}\right]^2 \qquad 3.32$$

Where $f(\Theta) = \int_0^{\Theta}\left[\frac{x^{1/m}}{1 - x^{1/m}}\right]^{1/n} dx \qquad 3.33$

Substituting $x = y^m$ into eqn 3.33 we get

$$f(\Theta) = m \int_0^{\Theta^{1/m}} y^{m-1+1/n}(1-y)^{-1/n} dy \qquad 3.34$$

Integrating the eqn 3.34 for m=1-1/n we get

$$f(\Theta) = 1 - (1 - \Theta^{1/m})^m \qquad 3.35$$

So f (1) = 1 & putting the value of f(Θ) and f(1) in eqn 3.32 the expression for $K_r(\Theta)$ will be

$$K_r(\Theta) = \Theta^{1/2}\left[1 - \left(1 - \Theta^{1/m}\right)^m\right]^2 \qquad 3.36$$

3.6.2. Estimation of the parameters β, m and n.

The soil water content as a function of the suction head can be expressed as,

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\beta\psi)^n\right]^m} \qquad 3.37$$

Differentiation of eqn 3.37 with respect to ψ leads to

$$\frac{d\theta}{d\psi} = \frac{-\beta m(\theta_s - \theta_r)}{1 - m} \Theta^{1/m} (1 - \Theta^{1/m})^m \qquad 3.38$$

From the eqn 3.31 the value of β can be solved as;

$$\beta = \frac{1}{\psi}\left[\Theta^{-1\ m} - 1\right]^{1/n} \qquad 3.39$$

Substituting eqn 3.39 into eqn 3.38 we get,

$$\frac{d\theta}{d(\log\psi)} = \frac{-m(\theta_s - \theta_r)}{1 - m} \Theta(1 - \Theta^{1/m}) \qquad 3.40$$

Taking SL be the absolute value of the slope of Θ with respect to log ψ, i.e.

$$SL = \left[\frac{d\Theta}{d(\log\psi)}\right] \qquad 3.41$$

or equivalently,

$$SL=\frac{1}{(\theta_s-\theta_r)}\left[\frac{d\theta}{d(\log\psi)}\right]$$ 3.42

From eqn 3.40 and 3.42 we get;

$$SL = 2.303\ \frac{m}{1-m}\Theta\left(1-\Theta^{1/m}\right)$$ 3.43

The best location on the $\theta\sim\psi$ curve for evaluating the slope SL is the half way between θ_r and θ_s i.e. θ_p (intermediate moisture content) defined as;

$$\theta_p = \frac{\theta_s+\theta_r}{2}$$ 3.44

Let SL_p be the value of slope of intermediate moisture content θ_p, then

$$SL_p = 1.151\ \frac{m}{(m-1)}\Theta_p(1-\Theta_p{}^{1/m})$$ 3.45a

Where, $$\Theta_p = \frac{\theta_p-\theta_r}{\theta_s-\theta_r}$$ 3.45b

ψ_p = Suction head corresponding to θ_p

$$= \frac{1}{\beta}\left(2^{1/m} - 1\right)^{1-m} \qquad 3.45c$$

The value of m can be given by the following inversion formula as;

$$m = \begin{cases} 1 - \exp(-0.8SL_p) & (0 < SL_p \leq 1) \\ 1 - \dfrac{0.5755}{SL_p} + \dfrac{0.1}{SL^2_p} + \dfrac{0.025}{SL^3_p} & (SL_p > 1) \end{cases} \qquad 3.46$$

The values of β, m, n may be used to derive the hypothetical soil water retention curve. In Fig 3.2 the point `p' on the curve is located halfway between θ_r and θ_s and the corresponding value of θ_p can be determined.

In somecases no clearly defined or measured value for the residual moisture content will be available. In that case θ_r must be estimated at the permanent wilting point (ψ = 15 bar) or extrapolating the values towards lower water content values; where dθ/dψ i.e the gradients becomes zero.

CHAPTER - IV

MATERIALS AND METHODS

CHAPTER - IV

MATERIALS AND METHODS

This chapter deals with the experimental set up and methodolgy adopted in the course of research work .The study was conducted in the laboratory of the Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Bhubaneswar

4.1 Collection of Soil

The soil used in the experiment had been collected from the EB-2 block of the Central Farm of the O.U.A.T. The soil for experimental use were collected from four locations at three depths i.e 0-15 ,15-30 and 30-50cm. The soil collected from, different locations and depth were dried and mixed throughly .These were then crushed seived with a 2mm size seive and stored in the laboratory for experiment.

4.2 Determination of Physico-Chemical Characteristics of Soil

The above soil was tested for its bulkdensity, texture, electrical conductivity, pH , saturated hydraulic conductivity (k_s). Volumatric moisture content verses suction pressure relationship was developed by laboratory test and presented in chapter v.

4.2.1 Bulk density

Soil samples at different locations and depths were taken by core sampler and bulk density of each sample were determined and thus average bulk density was determined .

4.2.2 Textural analysis

The seived soil was analysed by hydrometer procedure. The classification of soil was determined according to the USDAsoil triangle.

4.2.3 Mesurement of EC and pH

Electrical conductivity (EC) and pH of the soil was measured by using standared procedure.

4.2.4 Saturated hydraulic conductivity

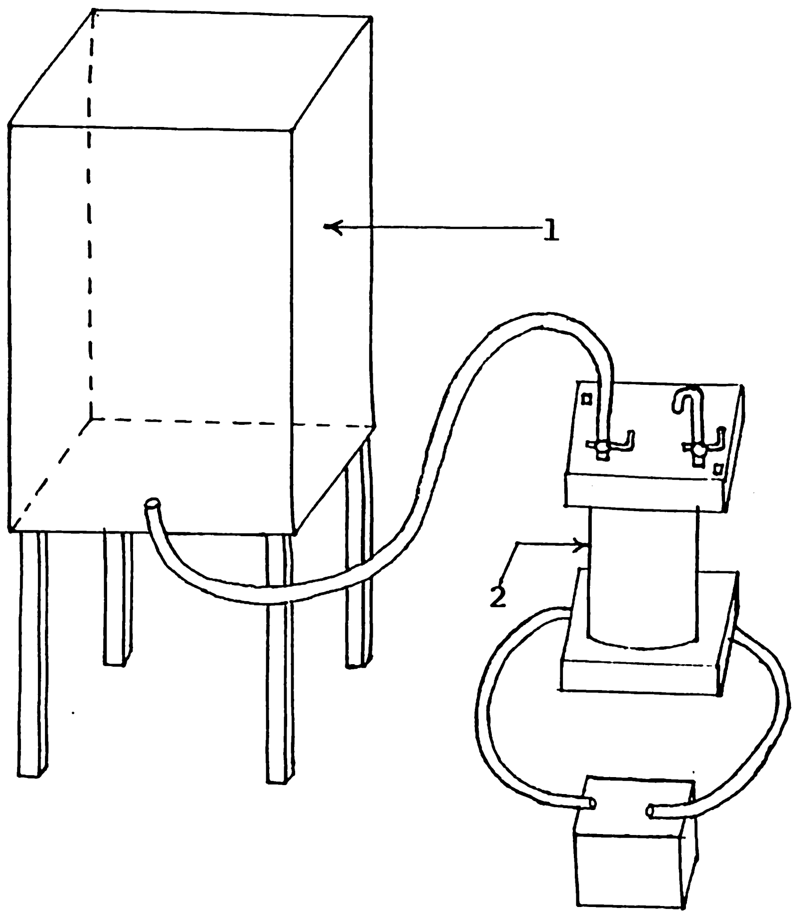
Saturated hydraulic conductivity of the soil was determined by constant head permeameter as shown in fig 4.1 and plate 4.1 .

4.2.5 Volumatric moisture content (θ) and suction pressure (ψ) relationship.

The relationship between moisture and suction pressure was determined from the moisture retention data of the soil . The method used for obtaining this data is to control the soil suction and allow the soil moisture transfer content to come to steady value by moisture through a porous wall. This control of suction is done in pressure membrane appratus.

4.2.5.1 Principle of moisture extraction

As soon as air pressure inside the chamber is raised above atmospheric pressure the higher pressure inside the chamber forces excess water through the microscopic pores of the cellulose membrane . The high pressure air however does not flow through the pores since they are filled with water and the surface tension of the water at the gas-liquid interface at each of the pores supported the pressure much the same as a flexible ruber



1. Tank maintaining constant head
2. Permeater

Fig. 4.1 Measurement of saturated hydraulic conductivity by constant head permeameter

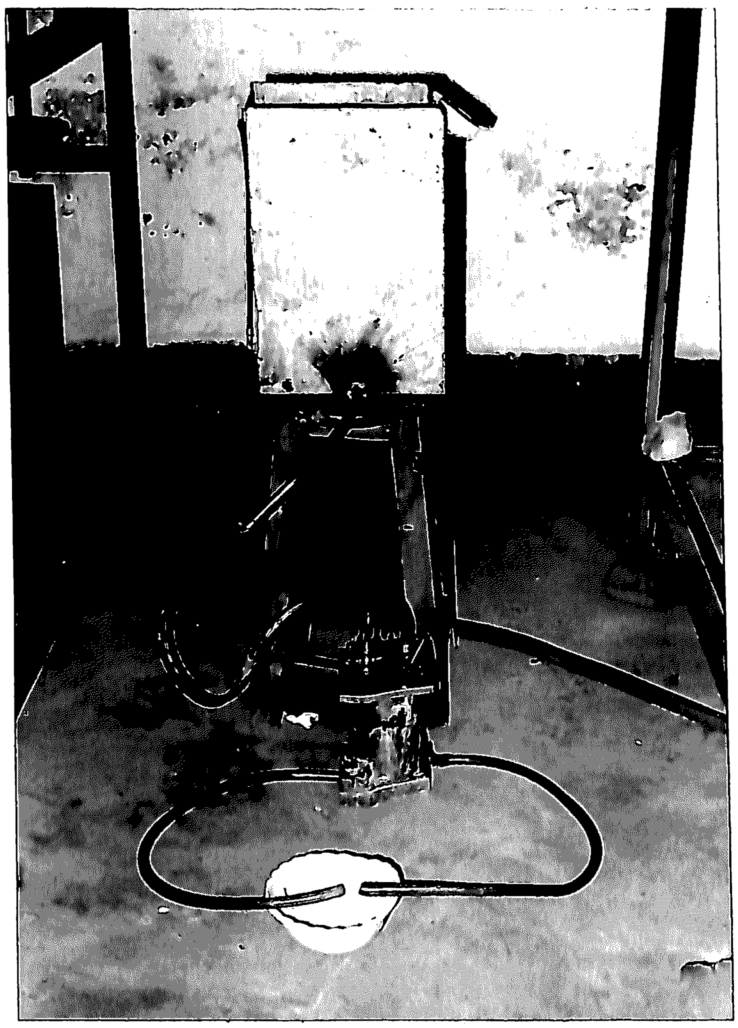


Plate No. 4.1 A view of the experimental steup of constant head permeameter diaphagram. When the air preesure is increased inside the extractor the radius of curvature of this interface decreases. However the water films will not break and let air pass throughout the whole pressure range of the extractor .At any given air pressure in the chamber, soil moisture will flow from around each of the soil particles and will out through the cellulose membrane until such time as the effective curvature of the water films throughout the soil are the same at the pores in the membrane. When this occures an equilibrium is reached and the flow of moisture ceases. When air pressure in the extractor is increased flow of soil moisture from the samples starts again and continues until a new equilibrium is attained. At aquillibrium there is an exact relationship between the air pressure in the extractor and the soil suction and hence the moisture content in the sample.

4.2.5.2 Procedures for running the pressure membrane extractor

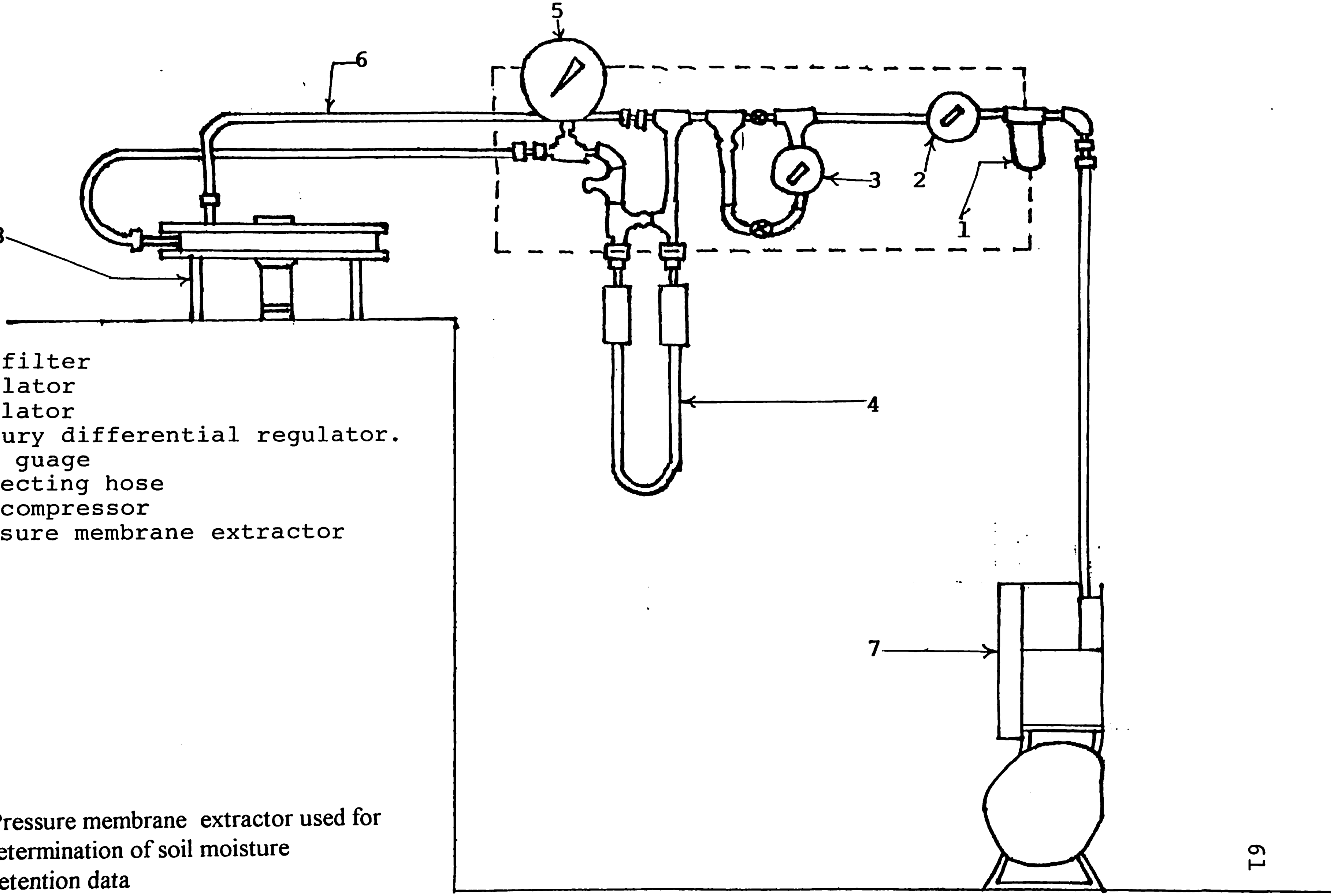
The extractor was readily dissambled for use by undoing the eight clamping bolts around the periphery of the unit. The nuts on the clamping bolts were undoed for several turns instead of removing these completely and then the bolts were sliped out of the slots. The bolts have special rectangular heads which fit into a constraining groove in the bottom of the lower plate. In replacing the clamping bolts care should be taken that there heads were properly fitted in to the groove. After the clamping bolts were removed the top plate was lifted off . The seal between the top plate and the outer cylinder was made by a rubber "O" ring which is fitted in a groove in the cylinder wall. A similar "O" ring was fitted to make a seal between the cylinder and the screen drain plate. The heads of these screws were fitted in to slots in the side of the cylinder wall. The wing nuts on the under side of the extractor plate were loosened to release the cylinder. The eccentric heads were then rotated out of the cylinder slot.

Sieved soil sample was taken and made saturated by keeping in water for 24 hours. A cellulose casing which had been throughly soaked in water was laid on the screen drain plate and centered. The "O" ring was now laid on the cellulose disc at the edge and the out cylinder was set on so that the "O" ring fitted in the groove around the wall of the cylinder. The two eccentric screws were turned to hold the cylinder in place and the wing nuts tightened. Saturated soil was kept in the concentric rings placed on the cellulose membrane. The 2nd "O" ring was laid in the top groove of the outer cylinder and the top plate was set on so that the top and bottom bolts slots lined up. The clamping bolts were inserted as indicated previously and tightened down.

The small out flow tube in the screen drain plate was connected by a tight fitting rubber sleeve to a piece of small diameter tubing which was extended laterally and connected to the tip of a buret. Gas diffusing through the membrane passed continuously in small out flow tube and kept the extracted liquid transported to the buret.

Before the pressure was turned on the mercury differential regulator, bypass valve was opened full. Possible damage to the compression diaphargm and distrubances to the samples in the extractor was prevented by this. Also blowing of mercury to other parts of the system by a rush of air through the "U" tube was prevented. The pressure regulator was opened slowly after closing the exhaust valve and adjusted to the extraction pressure desired. Water started flowing from the extractor in to the buret which had been attached to the out flow tube. The level of the water in the buret was observed periodically. The expriment set up is shown in figure 4.2 plate 4,2.

Extraction pressure was changed to a higher value after 48 hours from the application of previous pressure assuming that the equilibrium had been attained within this time. At each equilibrium the out flow reading and the corresponding pressure was noted down. The extraction was run for pressure 0.3 bar ,0.5bar, 1bar, 3bar, 5bar, 7bar and 9bar. After 7bar there was no out flow for a increase in pressure. So further running beyond 9bar suction pressure was discontinued and the samples were transfered to moisture boxes. The residual moisture content of the samples were determind gravimatrically. The moisture retained at each suction pressure is then calculated. These datas were then plotted to get the moisture retention curve.



1. Air filter
2. Regulator
3. Regulator
4. Mercury differential regulator.
5. Test guage
6. Connecting hose
7. Air compressor
8. Pressure membrane extractor

Fig. 4.2 Pressure membrane extractor used for determination of soil moisture retention data

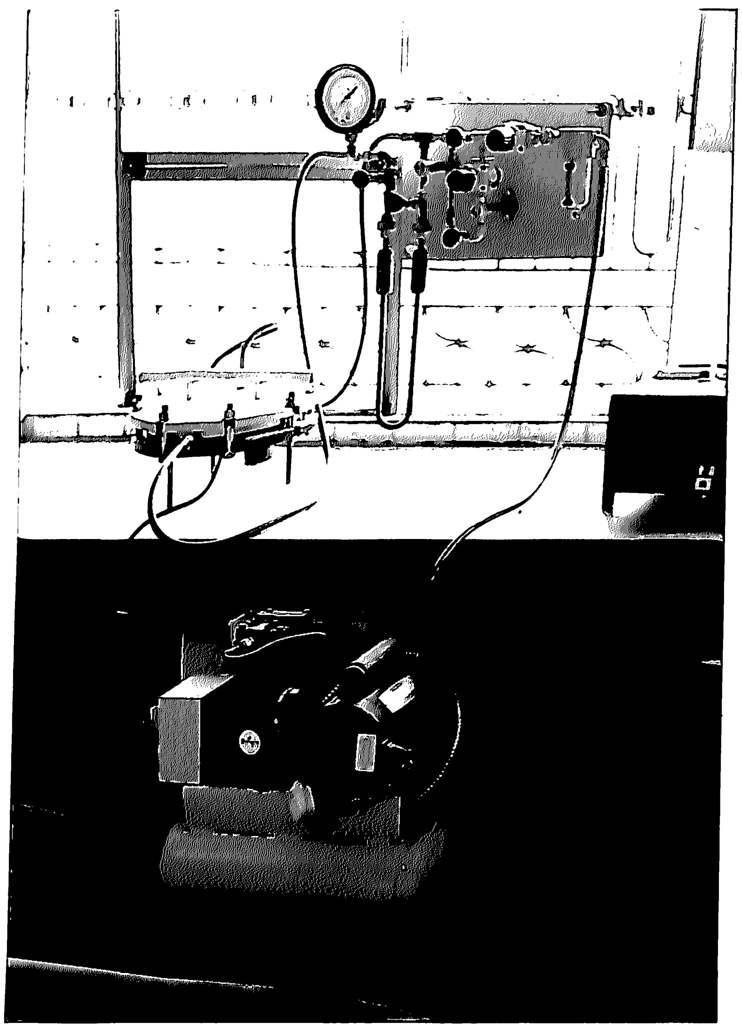


Plate No. 4.2 A view of the pressure membrane extractor

4.2.6 Procedure for determining the values of K(θ) and ψ(θ)

As described in chapter-III, section 3.6.1 the values of the unsaturated hydraulic conductivity was determind for the corresponding (θ) values using Ven-Genuchten model and ψ(θ) was interpolated. The followning procedure is adopted for calculations.

(i) The values of θ obtained experimentally using pressure plate technique was plotted against the corresponding values of soil moisture suction head (ψ).

(ii) The value of θ_p was determined from the values of θ_r and θ_s.

(iii) The value of ψ_p corresponding to the value of θ_p was interpolated from the retention data.

(iv) The value of SL_p corresponding to the value of θ_p was determined.

(v) The value of m was computed.

(vi) The relative hydraulic conductivity (K_r) was determined .

(vii) The unsaturated hydraulic conductivity (K (θ)) corresponding to a moisture content (θ) was determined.

(viii) The ψ (θ) corresponding to the moisture content (θ) is interpolated

(xi) The values of θ , K (θ), ψ (θ) were tabulated for further application.

4.3 Mathematical Model Development Using Warrick Model

Following steps were involved in determining moisture content at a point using Warrick model.

(I) The equation 3.9b had been used to linearise the non-hysteretic hydraulic conductivity function by fitting an exponential regression between K and ψ. Hence α and K_0 was determined.

(ii) The matric flux potential for thr corresponding $K(\theta)$ or θ value was obtained using equation 3.9a.

(iii) For each value of radius (r), vertical depth (z) and time of run (t) the corresponding dimensionless co-ordinates were determined.

(iv) The solution of equation 3.15 for a burried source for particular r,z,t,value was determined by equation 3.22 .

(v) The corresponding solution for a surface source was obtained from equation 3.24.

(vi) The integrated portion of the egn 3.24 was done by following Gauss-Leguerre Quadrature method for arbitrary lower limit of integration. The weighted summation is carried out neumerically by the Gauss -Leguerre 15 point formulation. The mathematical procedure is discussed in section 3.4 .The weighted value (w_i) and sampling point (x_i) are given in appendix (A).

(vii) The matric flux potential for the corresponding dimensionless matric flux potential was determined from equation 3,20 for a particular discharge rate q.

(viii) The θ value was then calculated by interpolation using Lagrange's method for the corresponding mattric flux potential (ϕ) value.

(ix) All the above calculations were made through iterations by segmenting $K \sim \theta$ relationship over small moisture increments $\Delta\theta$ = 0.02 cc/cc over which the $K \sim \theta$ relationship was assumed resonably linear. The iteration was started for each r.t.z, with the $dK/d\theta$ (k) in equation 3.19c, corresponding to the $\Delta\theta$ at the saturated moisture regime untill the calculated moisture content falls within the desired $\Delta\theta$ range.

4.4 Laboratory Setup for Measurement of Soil Moisture at Different Points

The experimental set up was arranged in the laboratory for determination of soil moisture at different locations (Fig 4.3, Plate 4.3) and the methodology adopted for takingt the observations are discussed in following paragraphs.

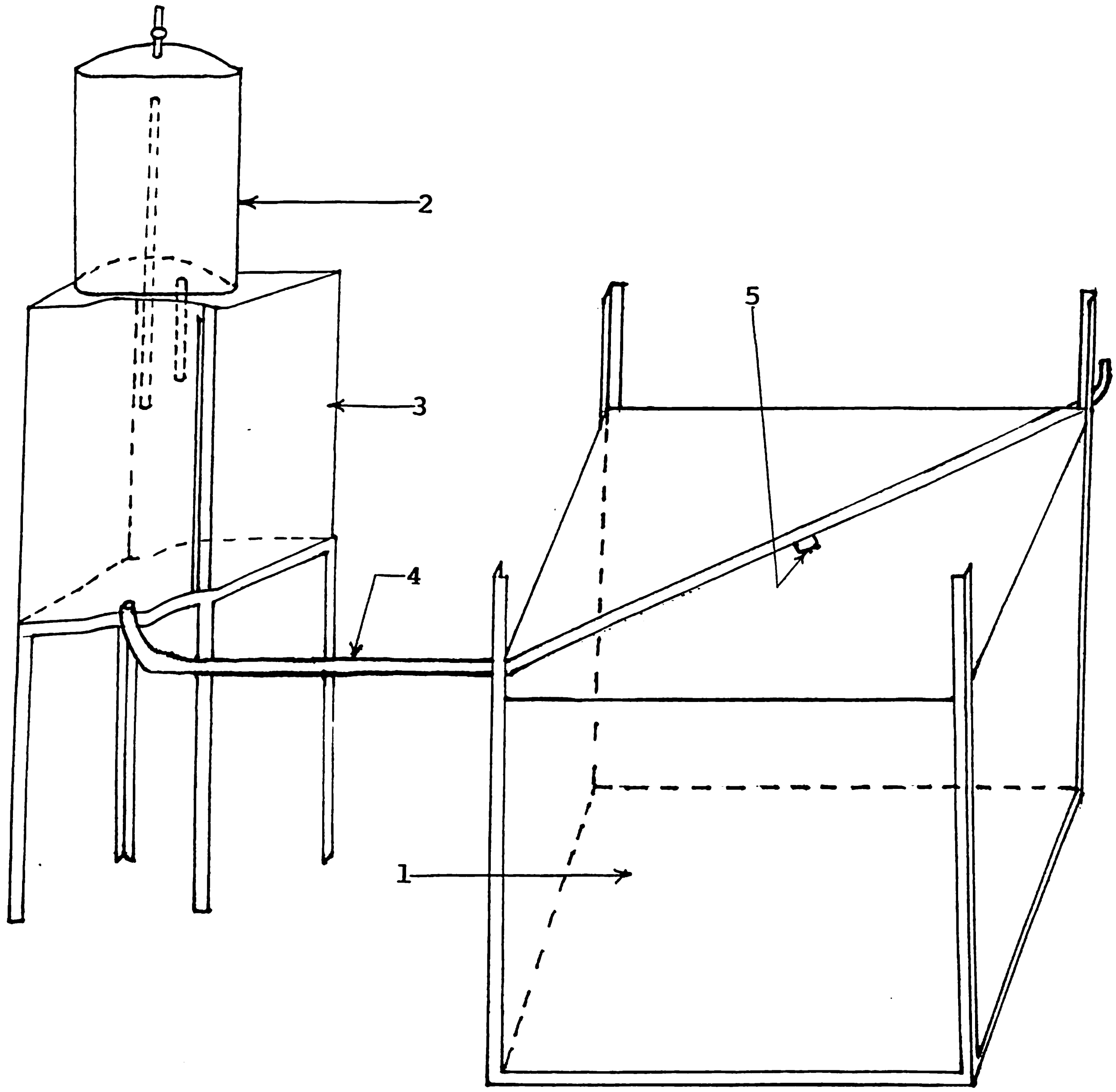


Fig.4.3 Laboratory model to study the moisture distribution in the soil volume.

1. Soil tank model
2. Constant head divice.
3. Water supply reservoir.
4. PVC pipe.
5. Emmitter

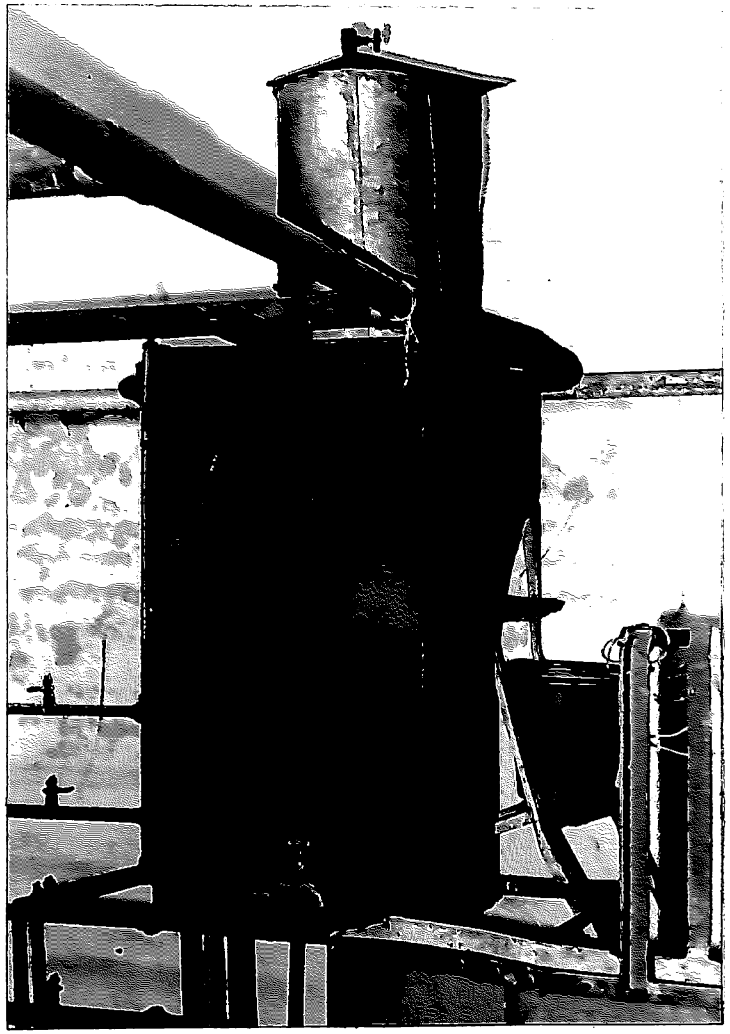


Plate No. 4.4 A view of the constant head water application system

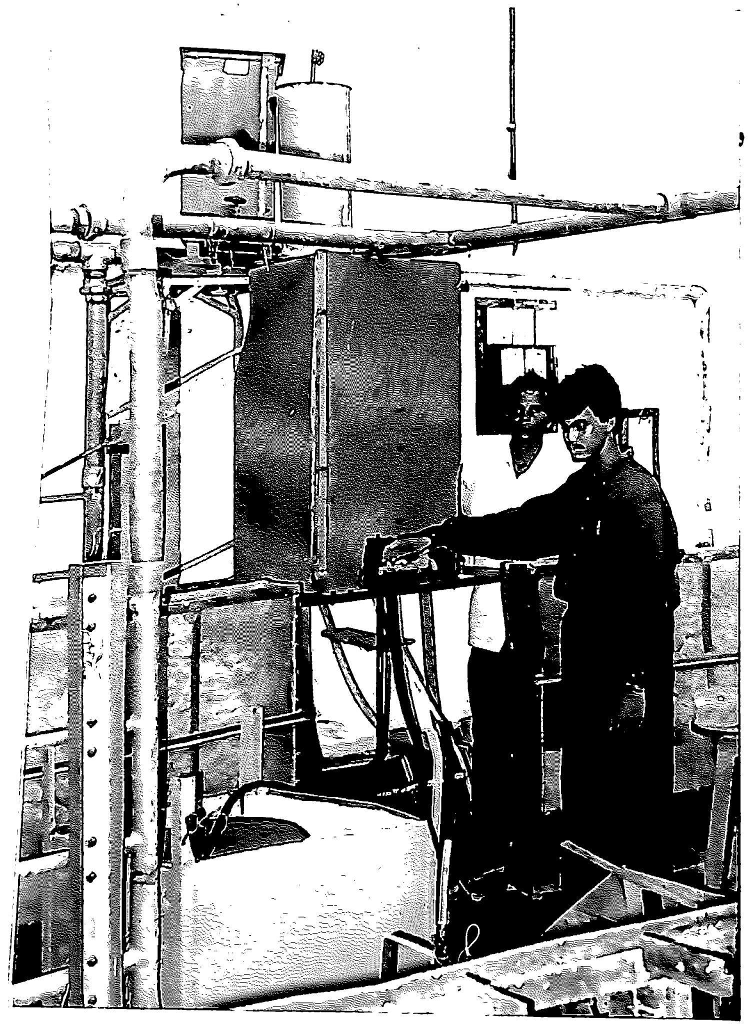


Plate No. 4.3 A view of the Laboratory setup used for study of moisture distribution pattern

4.4.1 Soil tank model

The soil tank model had inside dimension of 60cms in length, 60cms in width and 50 cms in height. This was fabricated out of 2mm thick M.S sheet and 25mm x 25 mm x 5mm size angle iron. At the four corners of the tank the angles were projected upwards for 20cms to support the pvc pipe containing the emitter at the middle of the tank .The top portion of the container was left uncovered.

4.4.2 Water application system

The water application system consisted of a water supply reservoir, pvc pipe fitted with emitter and a cylindrical device to maintain constant water level in the water supply reservoir while the experiment was in progress. The water supply reservoir had inside dimensions of 50cms in length, 50cms in width and 100cms in height. The reservoir was provided with a bib cock at the bottom to which a 19mm diameter pvc pipe was connected . To this pipe emiter was connected.

A devise was used to maintain constant water level in the reservoir while the experiment was in progress. This devise consisted of a 30cms diameter and 52 cm height cylinder closed at both ends.At one end (which

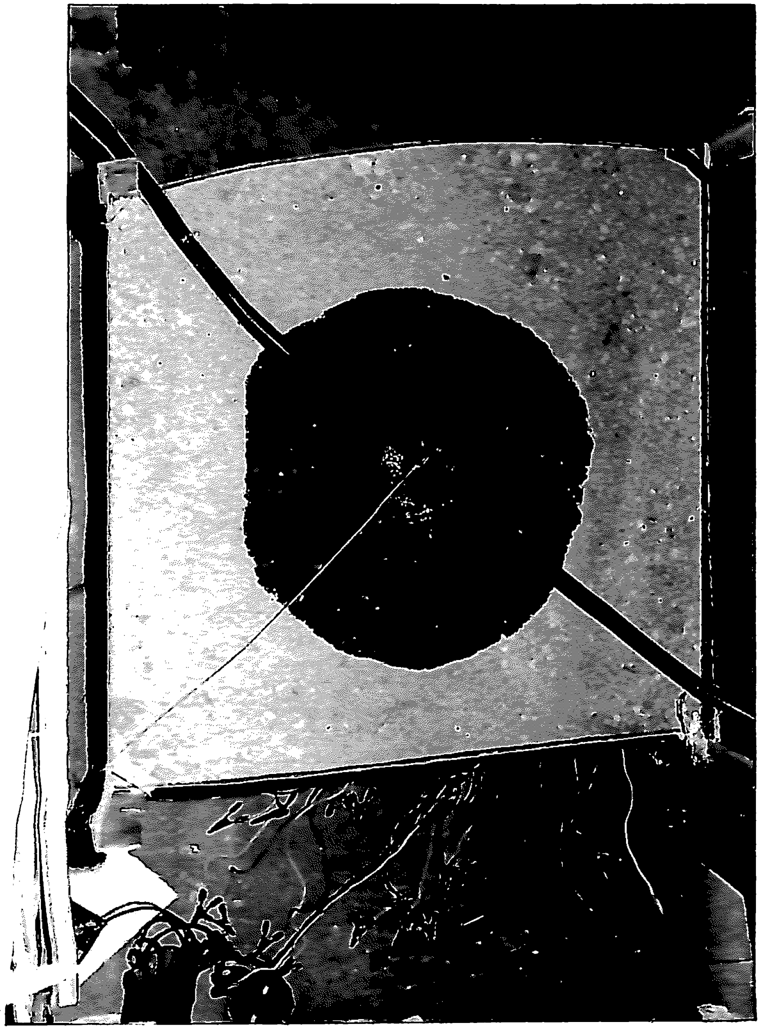


Plate No. 4.6 A view of the moisture front at the soil surface

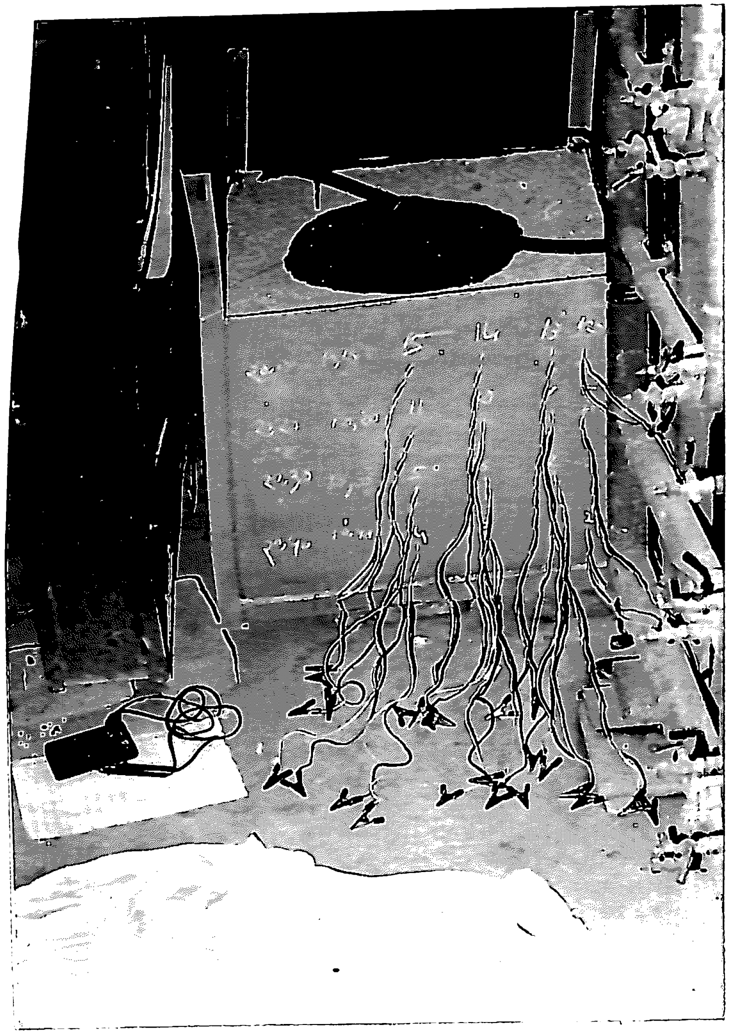


Plate No. 4.5 A view of the soil tank model was kept up) a 12mm diameter GI pipes was welded and a gate valve was fitted to the pipe. On the other end, two GI pipes provided with stop coks were also welded. One of the two pipes extended in to the cylinder leaving approximately 1cm gap from the top. This pipe served as air pipe and it was meant to creat atmospheric pressure inside the cylinder when lower end of the pipe was open to atmosphere. The other pipe was meant for release of water from the cylinder.

4.4.3 Measurement of soil moisture content at different locations

To measure soil moisture content at different locations with soil mass after a period of run, the electrical resistance sensors were used. These sensors work on the principle of conductance of electricity. When two electrodes are placed parallel to each other in porous non coducting medium and then electric current is passed the resistance to the flow of electricity is inversely proportional to the moisture content in the medium.So by measuring the resistance between the two plates the corresponding moisture content can be determined .

In this experiment gypsum blocks of size 4cmx3,5cmx2cm were used as moisture sensors to measure the moisture content of the soil volume. Fifteen numbers of gypsum blocks were placed inside the soil tank model in a 10cm square grid while filling up soil.Small holes were drilled on the back of the model for passage of conductors cconnected to gypsum blocks. The resistance between the two paralle plates was measured by multimeter and hence the volumatric moisture content is determined.

The resistance measurement vary with the soil type. Since the same reading may indicate different amounts of available moisture for different soil textures,the individual blocks were calibrated for the soil. The following procedures were adopted for calibrating the individual blocks.

In the labortary the calibration was carried out using a cubic container of wire screen (size 30x30x30cm) with one side open. All other inner sides were lined with a fine cloth and the container was filled with dry soil. The resistance blocks were embeded in dry soil of the container and the lead wires are kept outside. The soil was saturated for overnight. The container was kept outside to expose all sides for evaporation. As the soil dried the resistance readings were recorded periodically with a digital multimeter and also soil moisture content of the samples taken from the block depths were determined by gravimatric method. These moisture content and resistance datas were plotted and presented in chapter V. These curves were then used to determine the volumatric moisture content for a measured value of resistance.

4.5 Experimental Technique

Soil samples collected from the farm and stored in the laboratory was dried in open air for sufficient time. The soil was then filled in the soil tank model. Average bulck density was maintained in the container equal to that of field conditions.

Clean tap water was used in the experiment .Inthe begining water storage tank was filled up to a certain level. The cylinderical devise which was used to maintain constant head was installled on the top of the storage tank and filled with water through the gate valve keeping the air tube open. The gate valve was then closed and air tube was allowed to remain open. Due to gravitational force, water from the cylinder flowed to the tank and necessary air was supplied by the air pipe to maintain atmospheric pressure in the cylinder. As soon as water level in the tank touched the air pipe ,entry of air in to the cylinder was checked there by stopping further flow of water from the cylinder to the tank due to the creation of vaccum inside the cylinder.

Before applying water to the soil volume by emitter ,the discharge rate of this for the supplied head was determind. This was done by operating the emitter for 2hrs and collecting the volume of discharge through the emitter.

The emitter was kept at the center of the soil filled tank and water was applied to the soil volume. The emitters were run for three discharges. These were operated till the horizontal water front touched the vertical boundary of the container. Through out the experiment, gypsum block readings were taken at 30min intervals. These readings were then converted to moisture content values by using the calibration curve.

4.6 Validitation of the Theoritical Model

The measured moisture content at different radius and depth after a particular time of run of experiment was compared with that of the theoritical predicted values for the same radius depth and time. The relative agreement of each theoretical out put with the experimental data was studied quantitatively using relative error percentage(REP), defined as

$$REP = \frac{\text{Theoritical--Experimental}}{\text{Experimental}} \times 100$$

The REP was calculated at each time for different depths and radius from the point of water application.

CHAPTER - V

RESULTS AND DISCUSSION

CHAPTER-V

RESULTS AND DISCUSSION

This chapter is devoted to various results obtained during the course of the study and also a critical discussion of the results obtained.

The soil used for experiment was tested for its physico-chemical properties. This soil was used for study of moisture content distribution pattern as predicted from soil properties and discharge rate by using linearised model of Warrick. The model was tested by calculating relative error percentage at each point for time of application of water.

5.1 Soil Physico-Chemical Properties

The average bulk density of the soil used was found out to be 1.714gm/cc. From hydrometer analysis the percentage of various particles present in the soil was found out as :

Sand-69.34%

Silt- 15.56%

Clay- 15.10%

From the soil classification triangle, soil was found out to be sandy-loam.

The electrical conductivity (EC) and pH of the soil was measured to be 0.418 millimhos/cm and 5.325 respectively.

The saturated hydraulic conductivity of the soil was determined to be 5.93 cm/hr. The saturated moisture content was also determined and it was found out to be 0.354 cc/cc.

For determination of the relationship between hydraulic conductivity and moisture content, the soil moisture retention data for a corresponding suction pressure was determined by pressure outflow-method. These datas are shown in Table 5.1.

Table 5.1 Soil moisture retention data of the soil

Sl. no.	Suction pressure (bar)	Volumatric moisture content retained at the pressure (cc/cc)
1	9.0	0.017
2	7.0	0.017
3	5.0	0.022
4	3.0	0.045
5	1.0	0.082
6	0.5	0.120
7	0.3	0.251

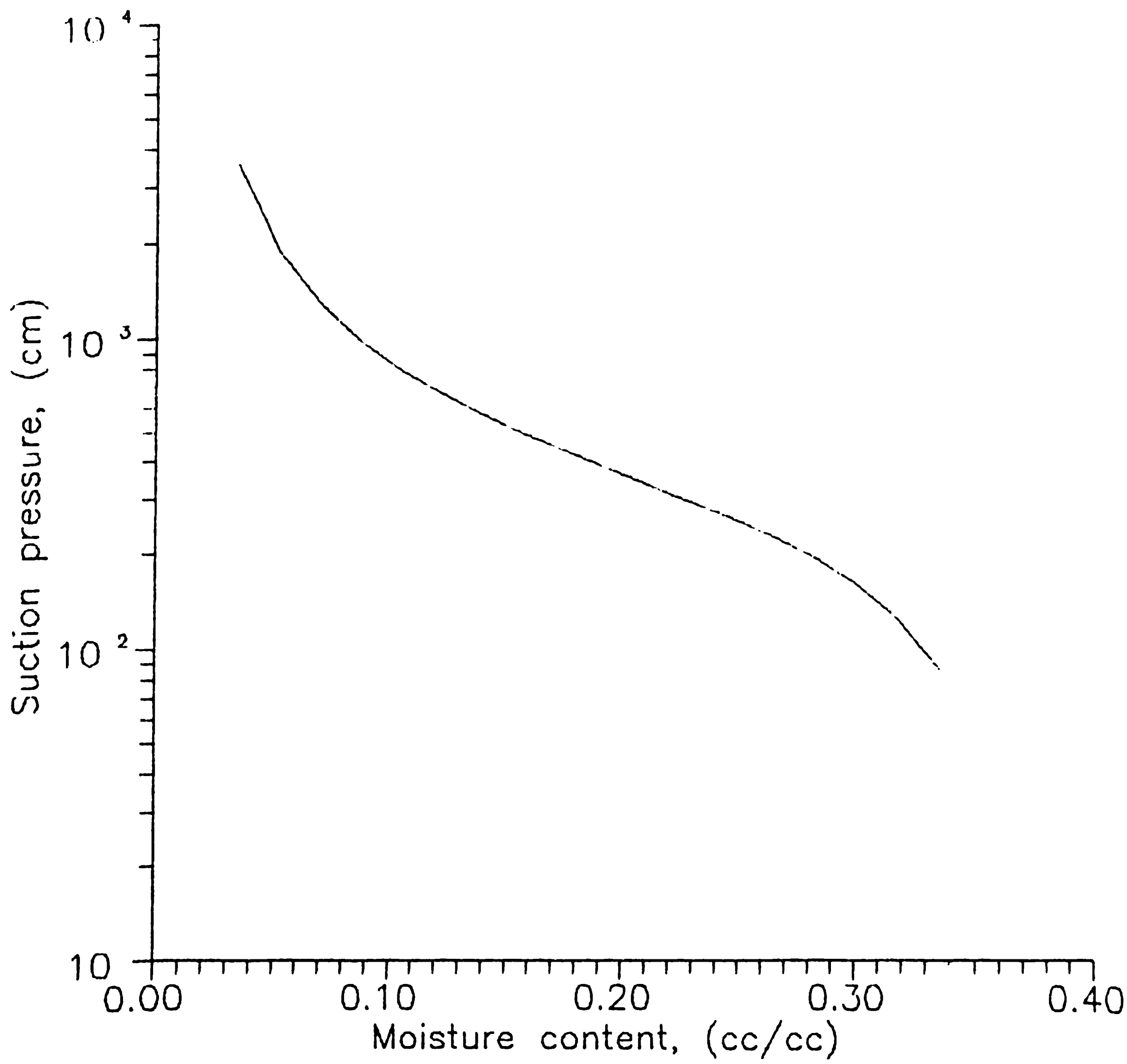


Fig. 5.1 Relationship between Moisture content and Suction pressure.

From the Table 5.1 it is seen that most of the moisture is drained out of soil at suction presure of 0.5 bar. Approximately 0.234cc/cc moisture is drained between the suction pressure of 0.0 to 0.5 bar. From 0.5 bar to 7 bar pressure, the amount of moisture drained is 0.103 cc/cc. After 7 bar pressure practically there is no outflow of moisture from the soil volume. Hence it is assumed that at pressure of 7 bar this soil attains its residual moisture content value i.e. 0.017cc/cc. This property of the soil is probably due to coarse texture of the soil. As the texture is coarse there is maximum number of macro pores which are drained at low pressure. The suction pressure and volumetric moisture content relationship is shown in Fig 5.1. Also from Fig 5.1 it is seen that after a pressure of 0.5 bar the rate of volume of water drained per unit increase in pressure decreased and it attains an approximately constant value at suction pressure of 5 bar.

The hydraulic conductivity for different moisture content values are determined by the VGM model. This model is programised to give the hydraulic conductivity for different moisture content values. The VGM model programme is given in Appendix-B.

For selected values of suction pressures, the corresponding values of moisture content, relative hydraulic conductivity and hydraulic conductivity as determined by the VGM model is produced in Table 5.2. Also the relationship

Table 5.2 Table showing the unsaturated hydraulic conductivity, relative hydraulic conductivity, volumetric moisture content and suction pressure.

Moisture content (θ) in cc/cc	Suction pressure log(ψ) in cm	Relative (Kr) hydraulic conductivity	Unsaturated hydraulic conductivity (K) in cm/hr
0.0347	3.546	7.87807e-07	4.671e-06
0.0524	3.269	1.59404 e-05	9.452e-05
0.0702	3.104	9.30326e-05	5.516e-04
0.0879	2.985	3.26925e-04	1.938e-03
0.1056	2.890	8.41245e-04	5.166e-03
0.1234	2.810	1.95159e-03	1.157e-02
0.1411	2.740	3.88227e-03	2.3020e-02
0.1588	2.676	7.08857e-03	4.203e-02
0.1766	2.616	1.21377e-02	7.197e-02
0.1943	2.559	1.97829e-02	1.173e01
0.2121	2.503	3.10298e-02	1.840e-01
0.2298	2.447	4.72386e-02	2.801e-01
0.2475	2.390	7.02928e-02	4.168e-01
0.2653	2.328	1.02896e-01	6.101e-01
0.2830	2.260	1.49139e-01	8.843e-01
0.3007	2.180	2.15754e-01	1.279e-01
0.3185	2.077	3.15430e-01	1.870e+00
0.3362	1.916	4.79454e-01	2.843e+00

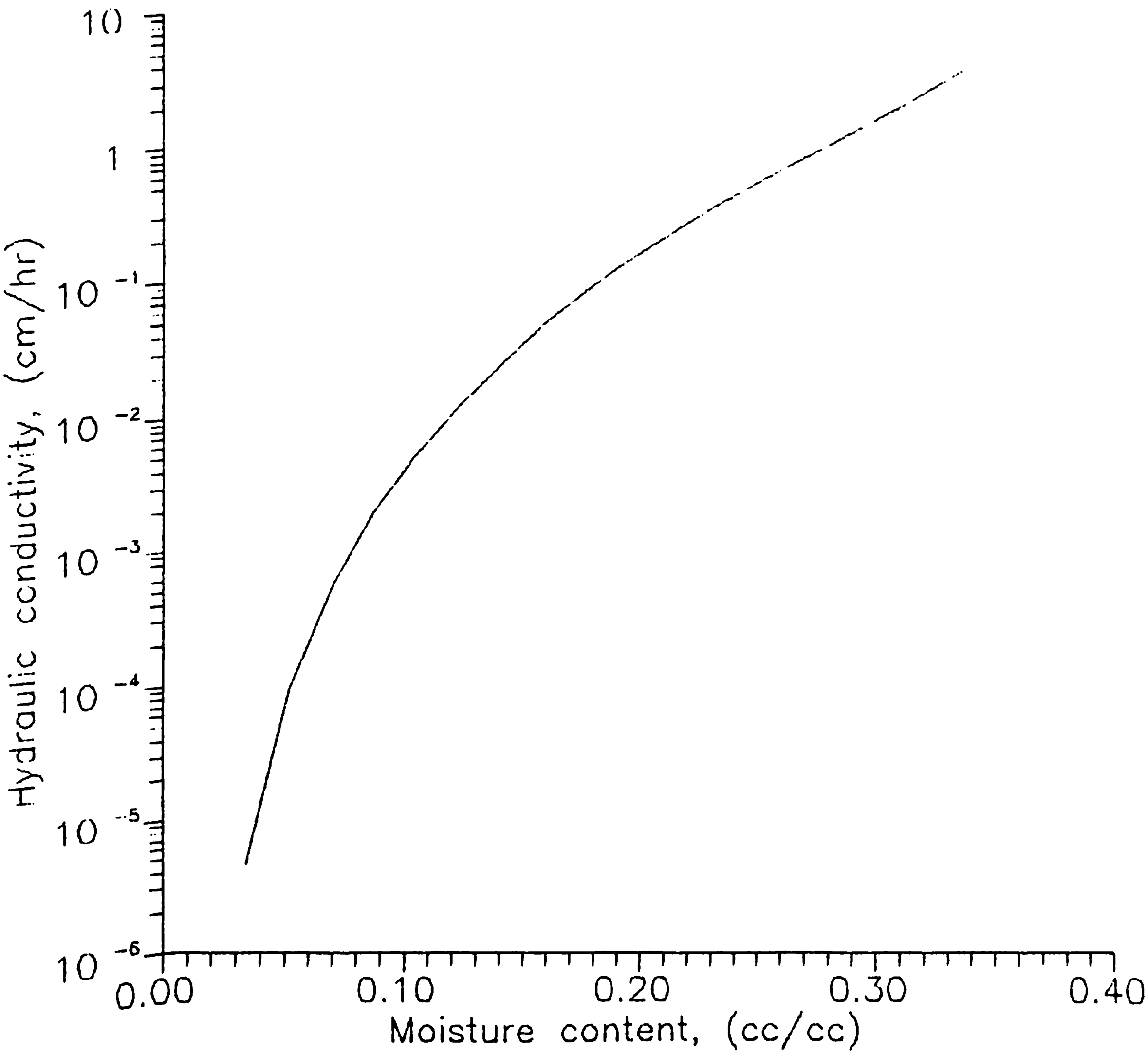


Fig. 5.2 Relationship between Moisture content and Hydraulic conductivity.

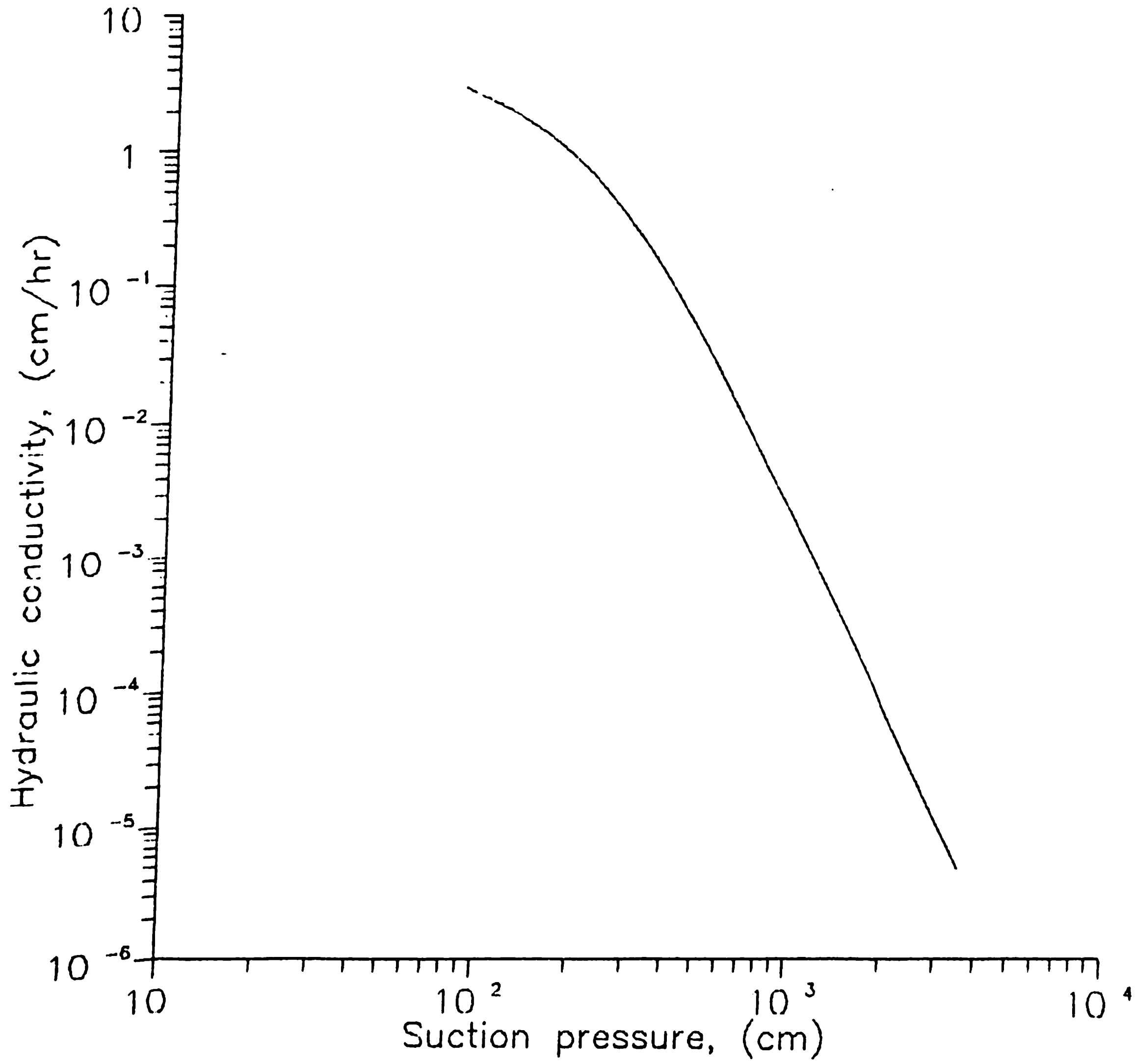


Fig. 5.3 Relationship between Suction pressure and Hydraulic conductivity.

between moisture content & hydraulic conductivity and suction pressure & hydraulic conductivity are shown in Fig 5.2 and Fig 5.3 respectively.

From Fig 5.2 it is seen that for the moisture content upto 0.2cc/cc, the rate of change of hydraulic conductivity is more. But for moisture content above 0.2 cc/cc, the rate of change of hydraulic conductivity is less. At lower moisture content values the rate of decrease of the hydraulic conductivity is faster than that at higher moisture content values. Also as the moisture content approaches towards the saturated value, the conductivity approaches a constant value with very less rate of change with respect to moisture content.

Similarly from Fig 5.3 it is seen that the rate of change of conductivity is faster at higher suction pressures. As the suction pressure decreases the conductivity increases at a faster rate. But this trend is seen upto a suction pressure between 300 to 400 cm of water. After that point the rate is very slow as is seen in flater portion of the curve.

5.2 Linearisation of the Hydraulic Conductivity Function

To linearise the non-hysteretic hydraulic conductivity function for fitting an exponential regression between K and ψ, eqn 3.9a discussed in chapter-III and data from Table 5.2 have been used. The regression equation between K and ψ is given in eqn 5.1.

$$K(\psi) = 1.84 \exp(0.004\psi) \qquad 5.1$$

where ψ is suction head assumed to be positive.

From the eqn 5.1 the value of $\propto$ is found out to be 0.004. As the value of $\propto$ has to lie between 0.2 to 0.002, (Philip. 1969, Braester. 1973) the regression fit of equation 5.1 is justified. The Ko value from the equation was found out to be 1.84.

5.3 Calibration of Moisture Sensing Blocks

The calibration of the moisture blocks were carried out as described in chapter-IV. The volumetric moisture content and the corresponding resistance readings are provided in Table 5.3. The regression analysis is made to develop the relation between moisture content of the soil and corresponding resistance readings of the sensors. All the sensors showed power relations between moisture content and resistance readings. The best fit equations are also shown in the Table 5.3. The best fit curves for different sensor blocks are given in Fig 5.4 (a) to 5.4(n).

Table 5.3 Resistance of the moisture sensing blocks in K-ohm for corresponding moisture contents.

Moisture Content cc / cc — Block Number	0.354	0.349	0.344	0.275	0.251	0.221	0.185	0.174	0.166	Best fit equations for the corresponding blocks
1	103.1	105.6	162.2	170.4	183.4	207.0	218.0	234.0	254.0	Mc=(R** -0.85868)* 20.7867
3	99.2	102.5	121.1	123.6	141.0	147.8	163.9	172.1	182.5	Mc= 187.36*(R**-1.34881)
4	81.3	82.1	83.4	84.1	85.2	87.5	91.3	99.6	130.5	Mc=306.31*(R**-1.58004)
5	82.6	85.2	103.1	107.4	112.2	114.0	125.4	165.5	375.0	Mc=3.170*(R**-0.52784)
6	65.2	68.1	70.0	72.8	78.8	81.1	87.0	92.5	103.5	Mc=1131.78*(R**-1.92873)
7	82.4	102.7	129.8	130.0	148.8	162.8	168.1	195.2	306.0	Mc=9.31494*(R**-0.725817)
8	100.5	104.2	110.5	122.6	131.8	143.6	149.5	164.9	230.0	Mc=52.0723*(R**-1.09005)
9	143.2	146.8	163.2	170.1	195.2	230.6	301.0	353.0	400.0	Mc=15.5619*(R**-0.769151)
10	51.9	53.2	65.4	69.6	84.0	89.1	91.3	131.0	202.0	Mc=4.2451*(R**-0.640116)
11	68.5	69.2	72.9	76.4	86.1	90.0	104.4	115.3	152.4	Mc=29.9742*(R**-1.06696)
12	128.8	132.5	159.8	175.6	280.0	374.0	393.0	418.0	519.0	Mc=5.18253*(R**-.549733)
13	97.0	99.8	119.2	123.5	133.4	138.7	149.6	164.1	362.0	Mc=5.54966*(R**-.627718)
14	60.1	62.1	76.5	80.8	91.5	95.0	104.8	113.5	135.0	Mc=32.4288*(R**-1.08858)
15	96.4	98.2	116.7	120.1	129.0	137.2	143.2	149.1	188.5	Mc=175.817*(R**-1.35258)

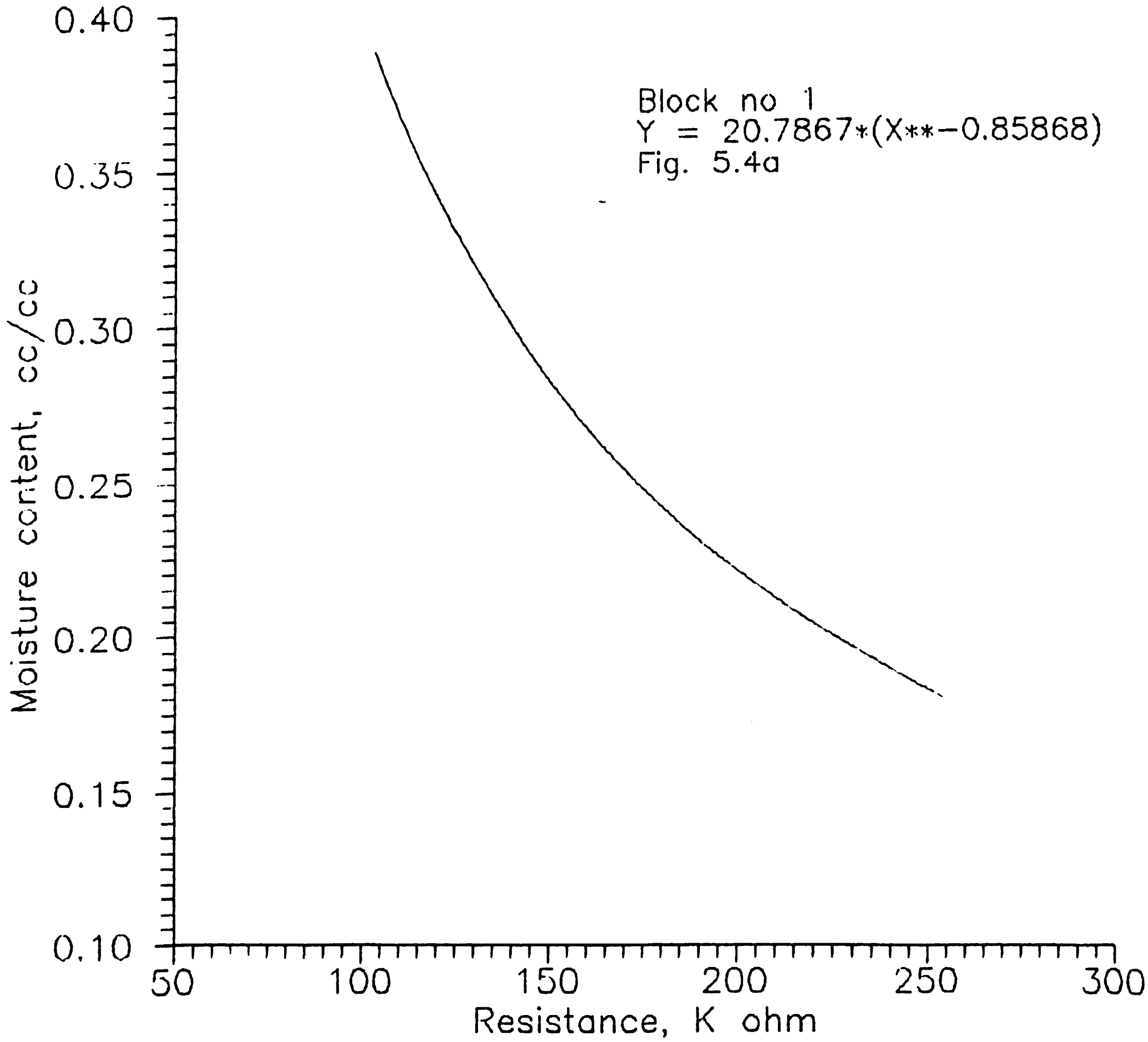
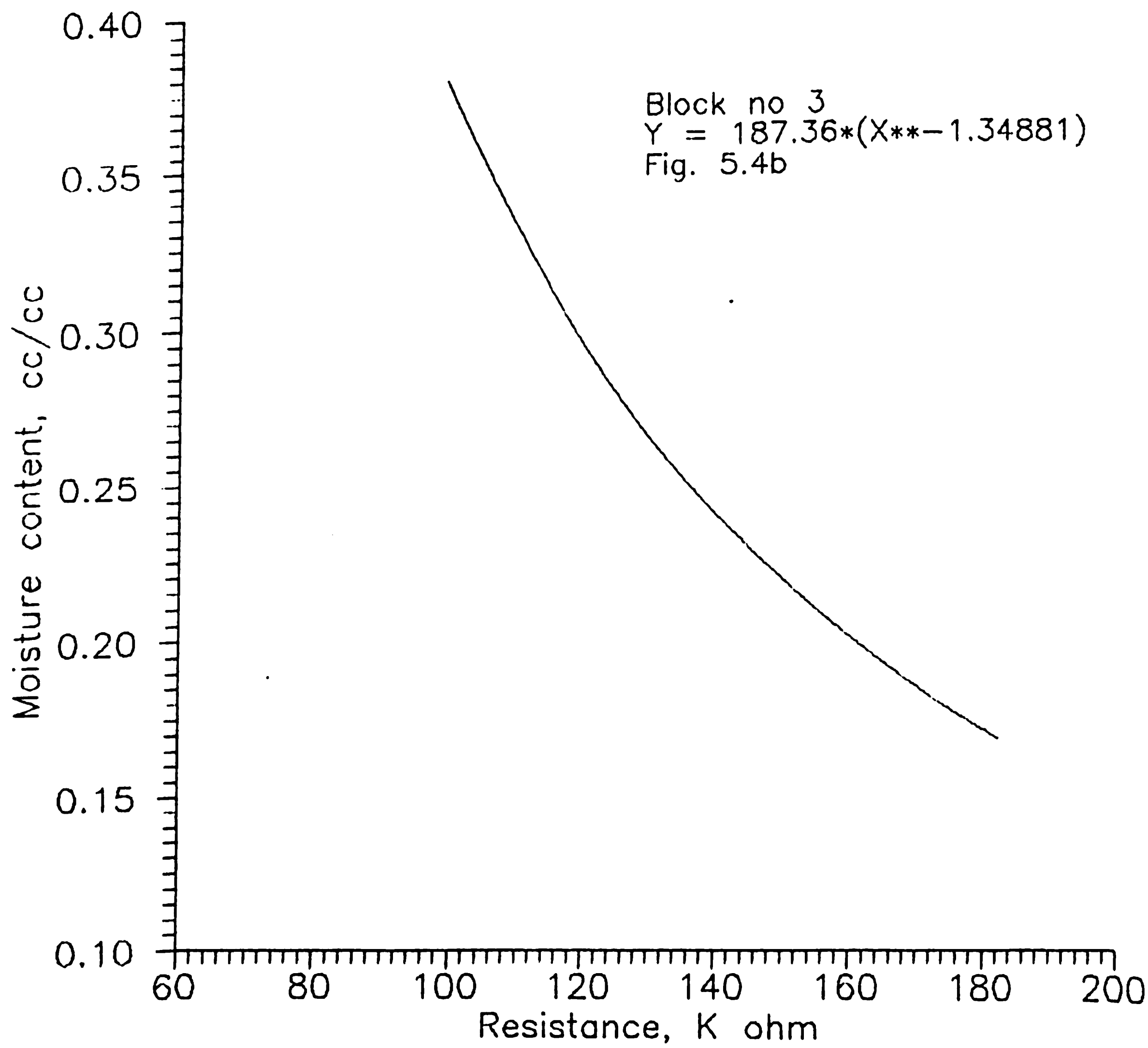
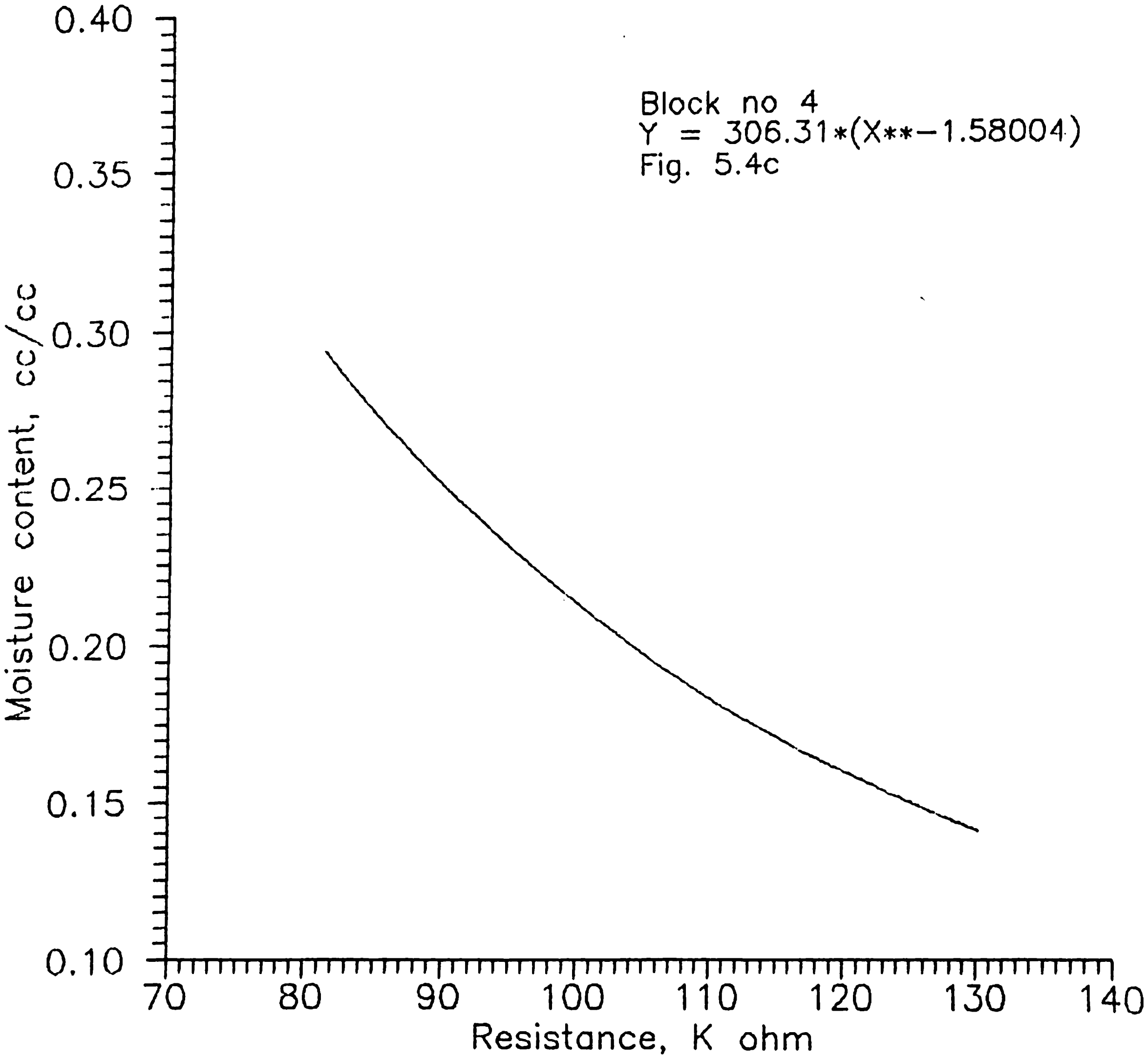
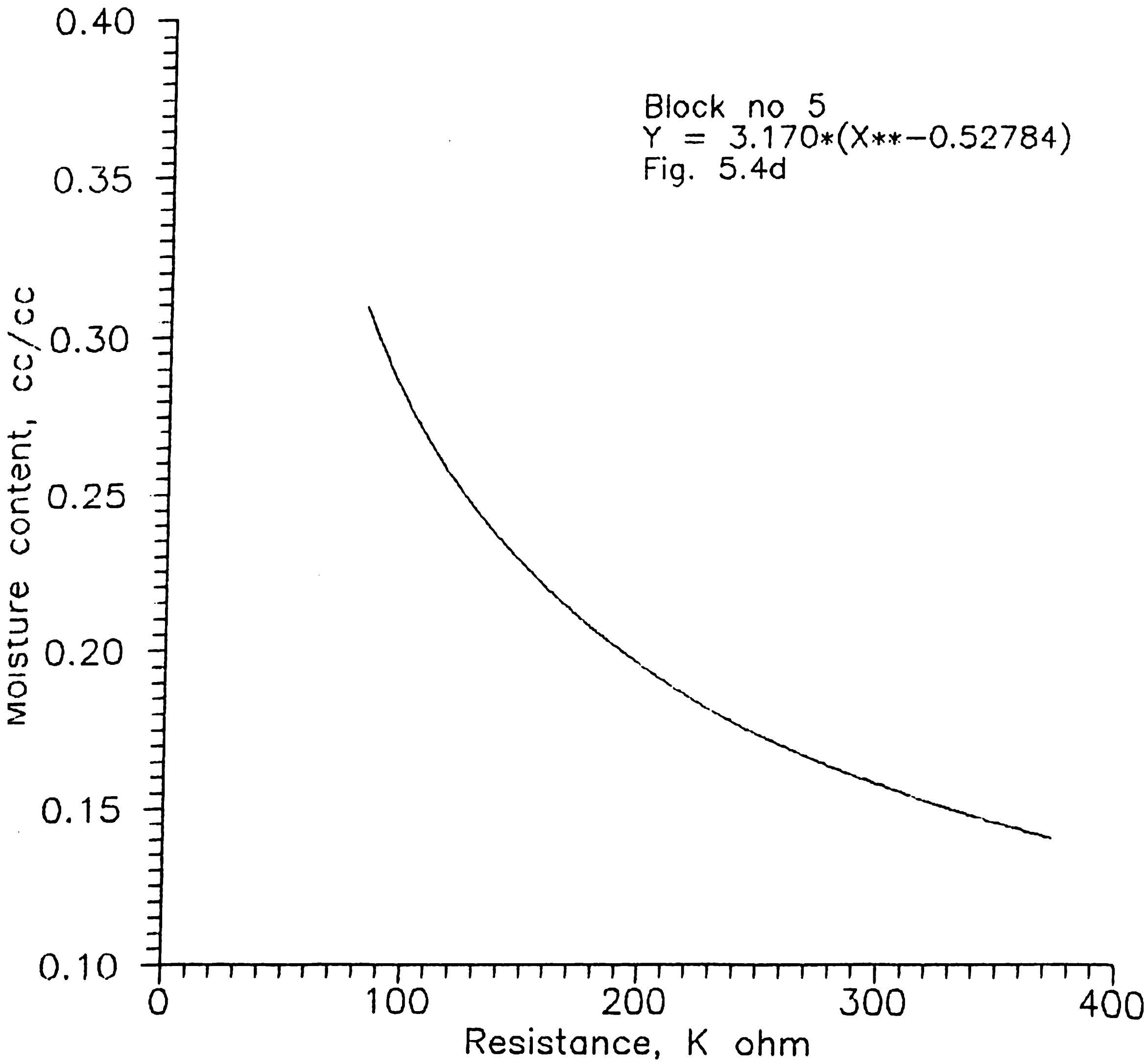


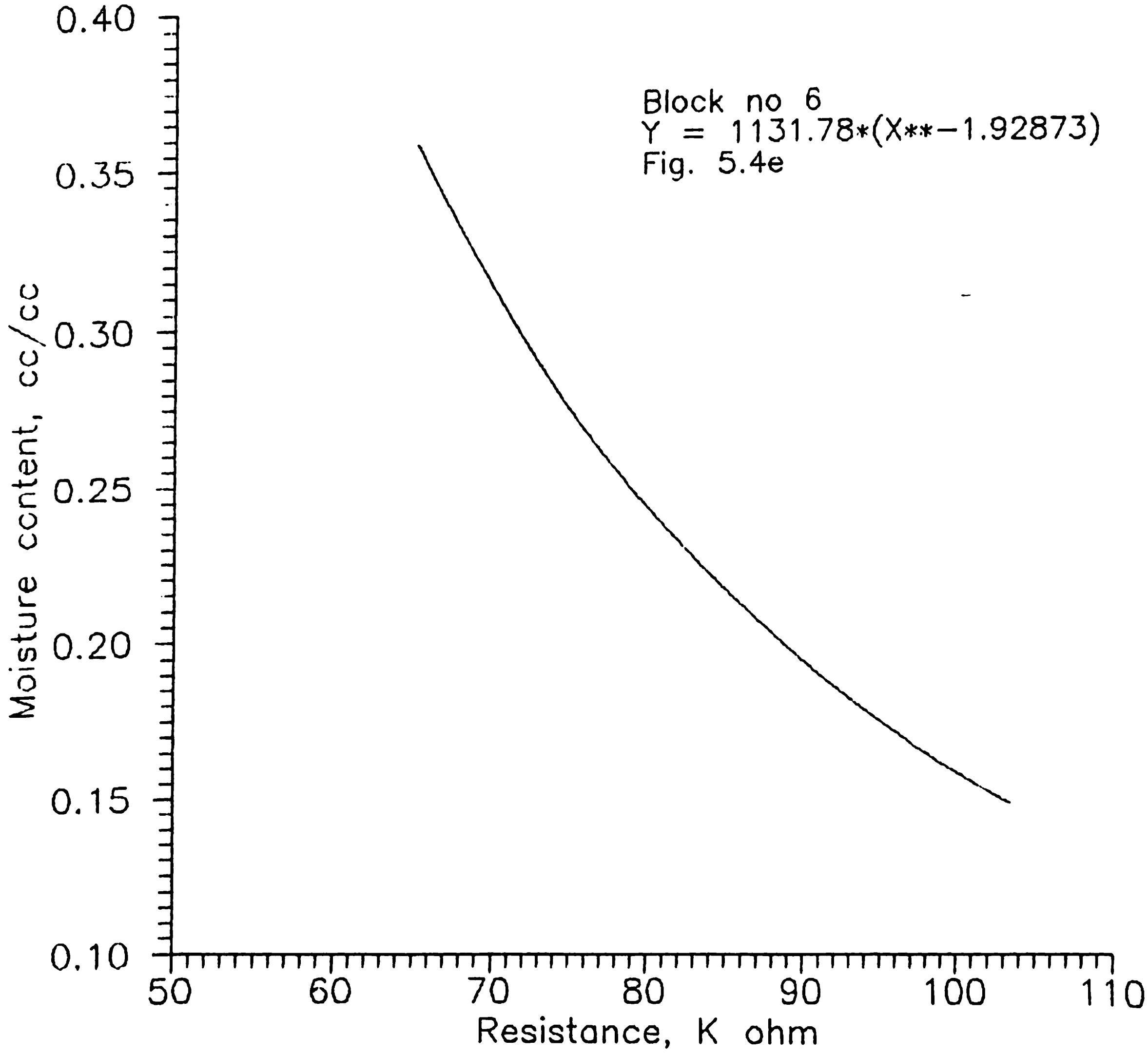
Fig. 5.4 a to n Relationship between moisture content and resistance reading of the moisture sensors



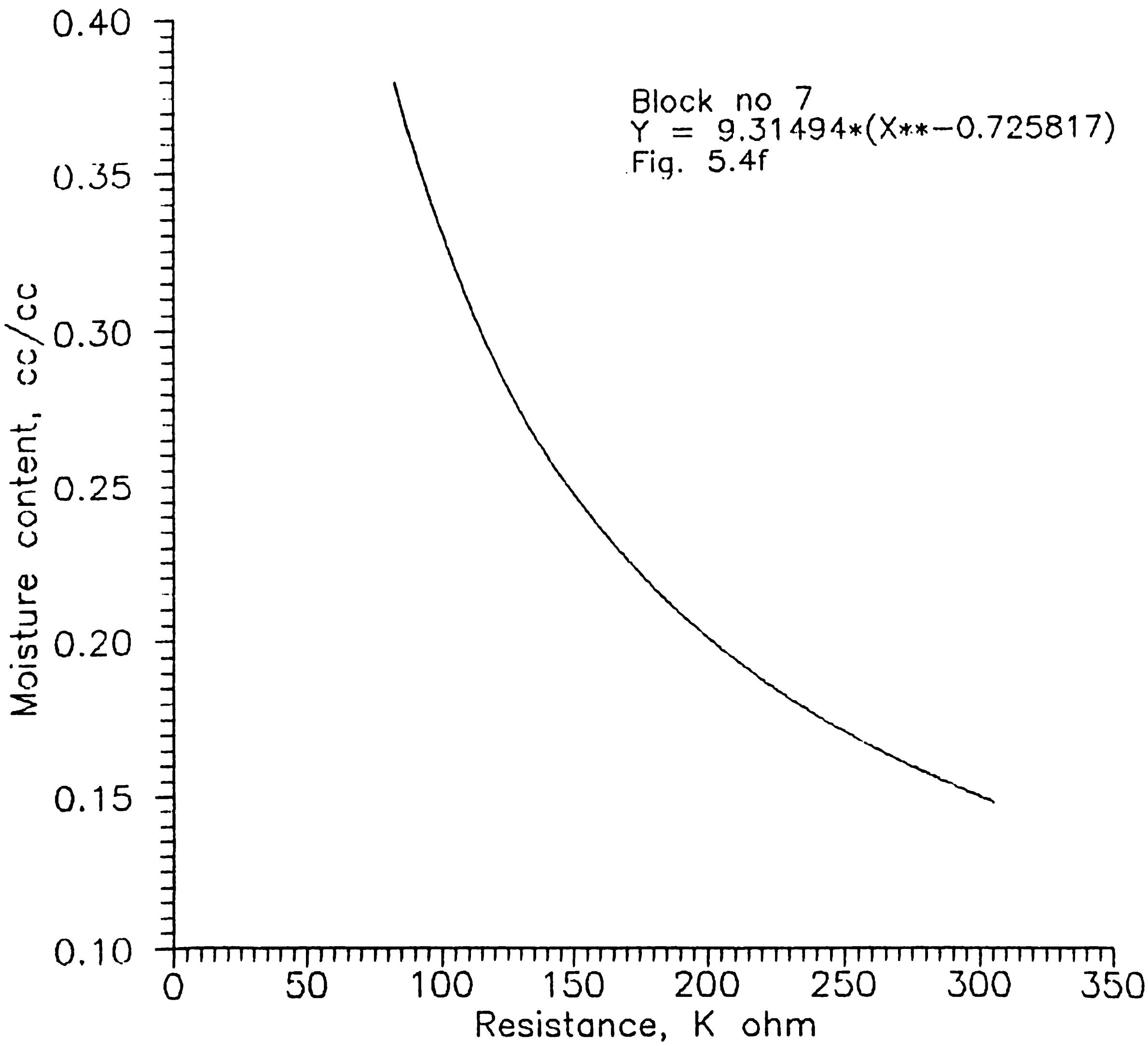
Block no 3
Y = 187.36*(X**-1.34881)
Fig. 5.4b
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
60
80
100
120
140
160
180
200
Resistance, K ohm

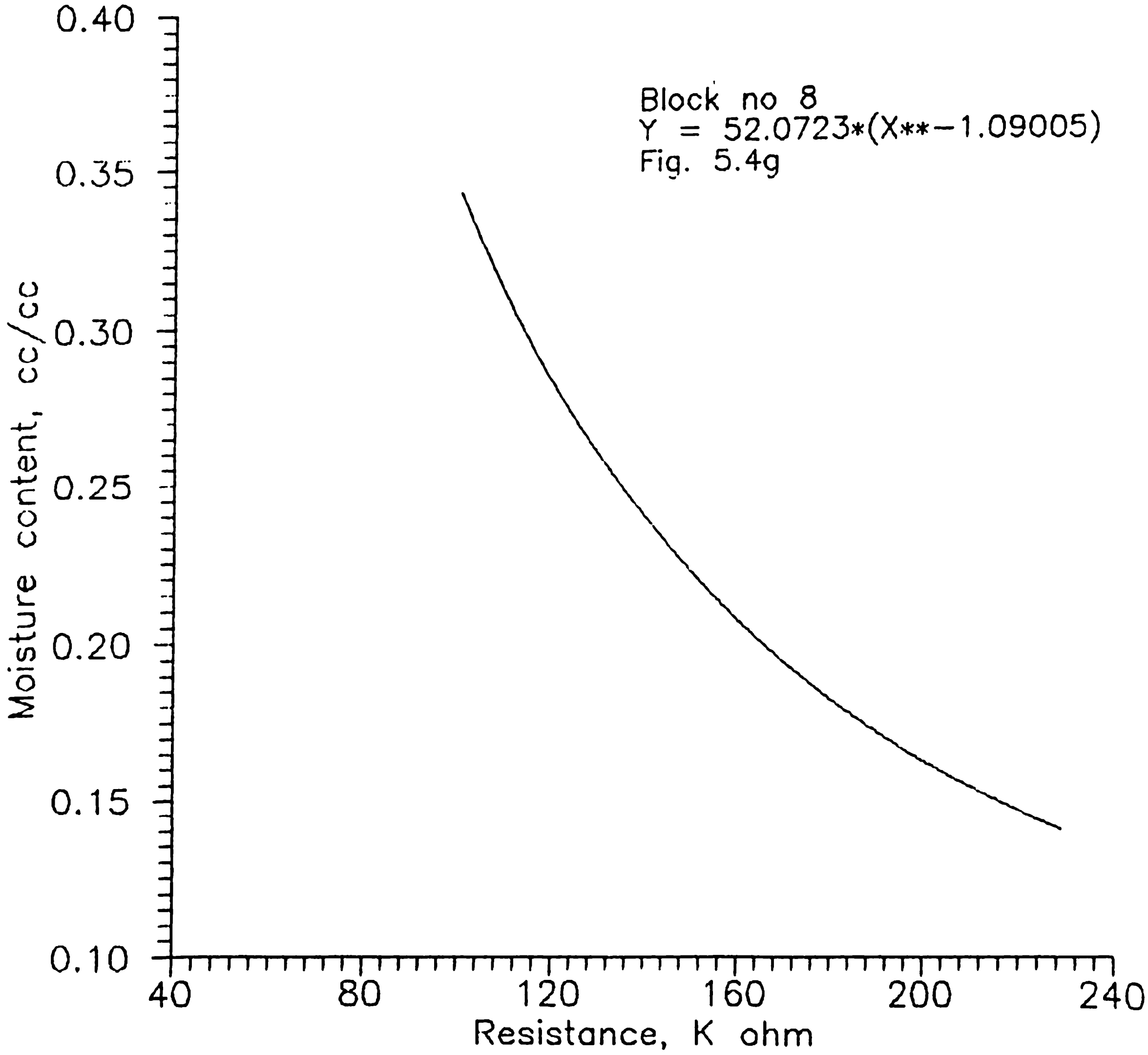

Block no 4
Y = 306.31*(X**-1.58004)
Fig. 5.4c
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
70
80
90
100
110
120
130
140
Resistance, K ohm

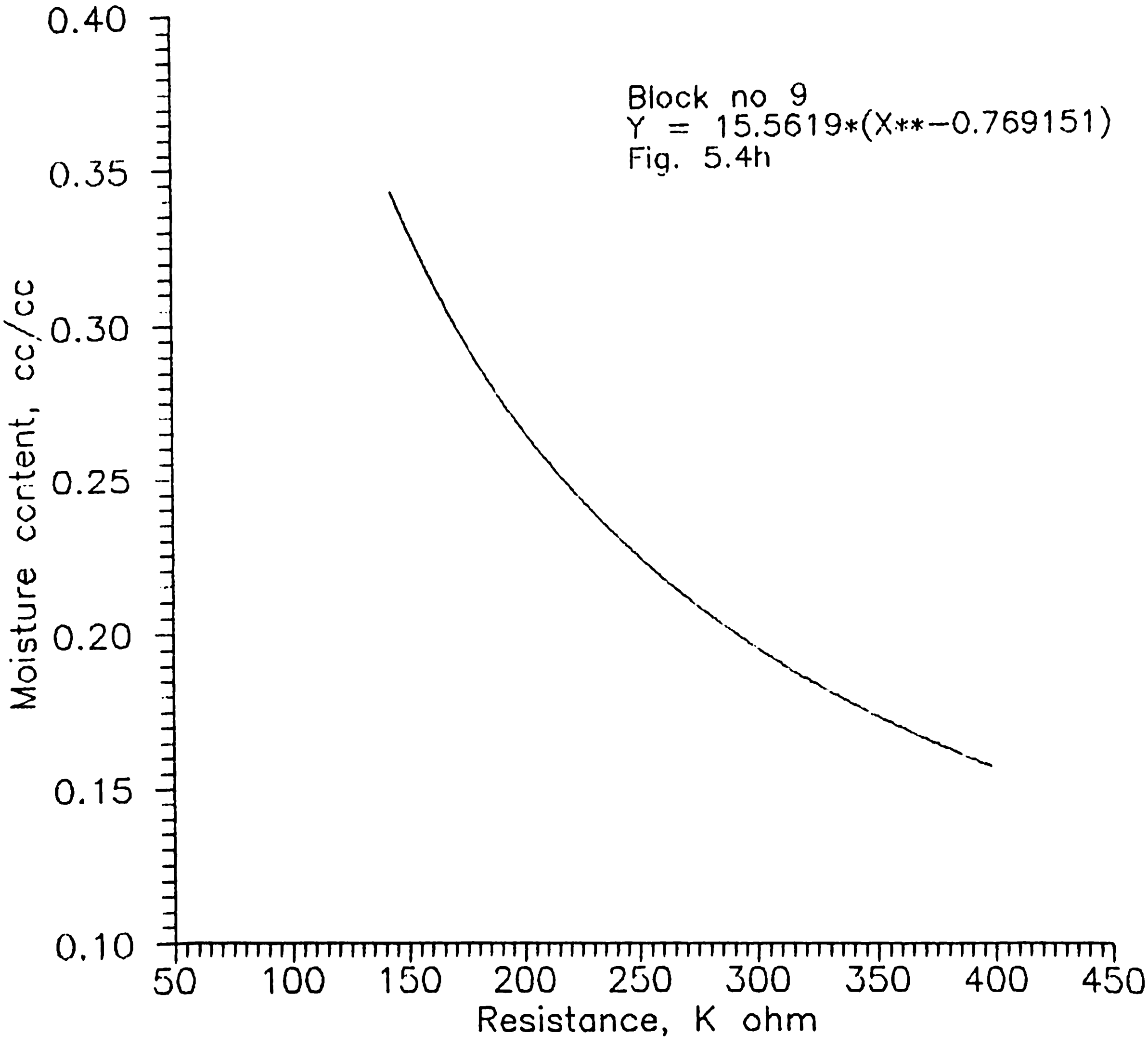

Block no 5
Y = 3.170*(X**-0.52784)
Fig. 5.4d
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0
100
200
300
400
Resistance, K ohm

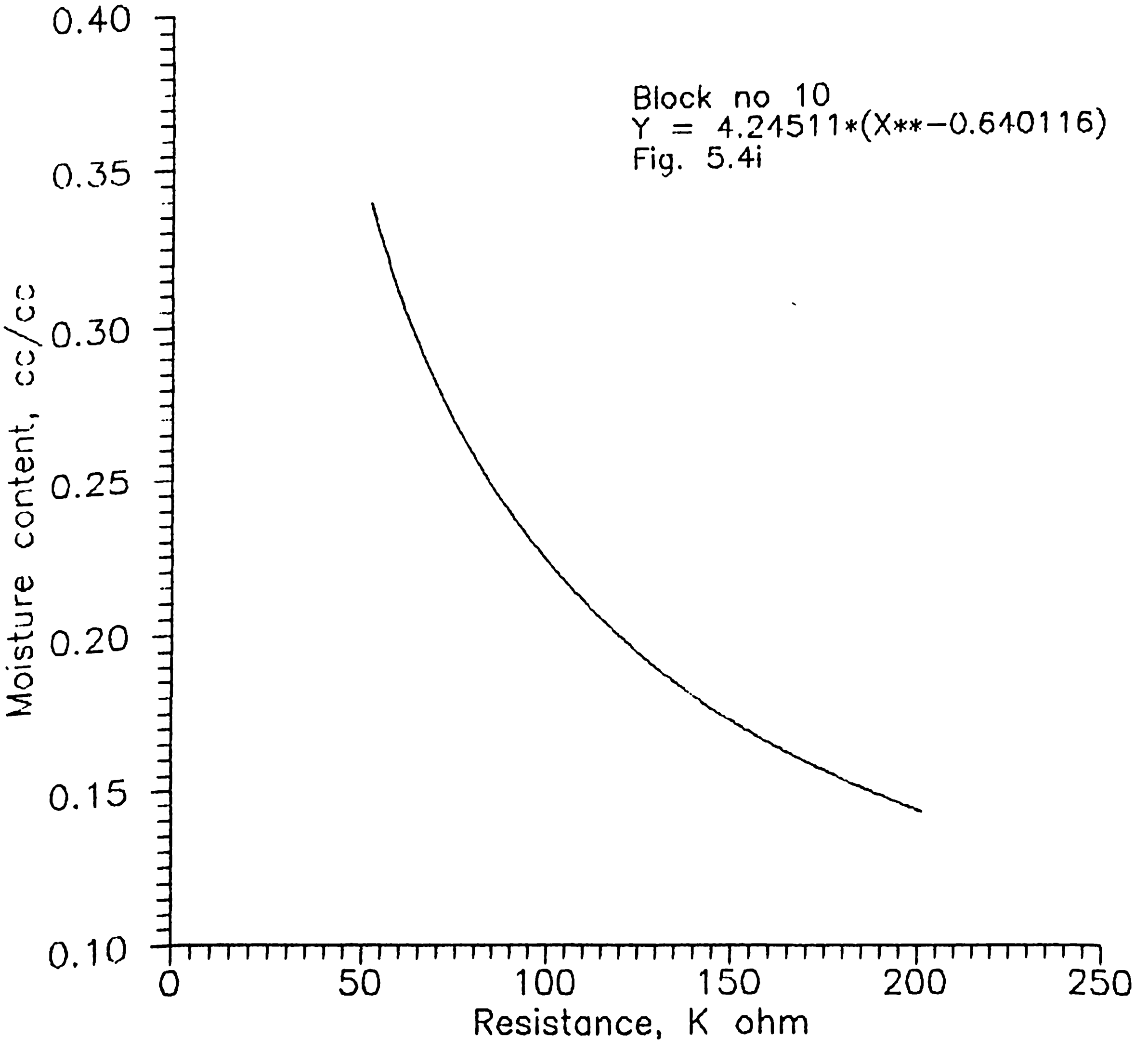


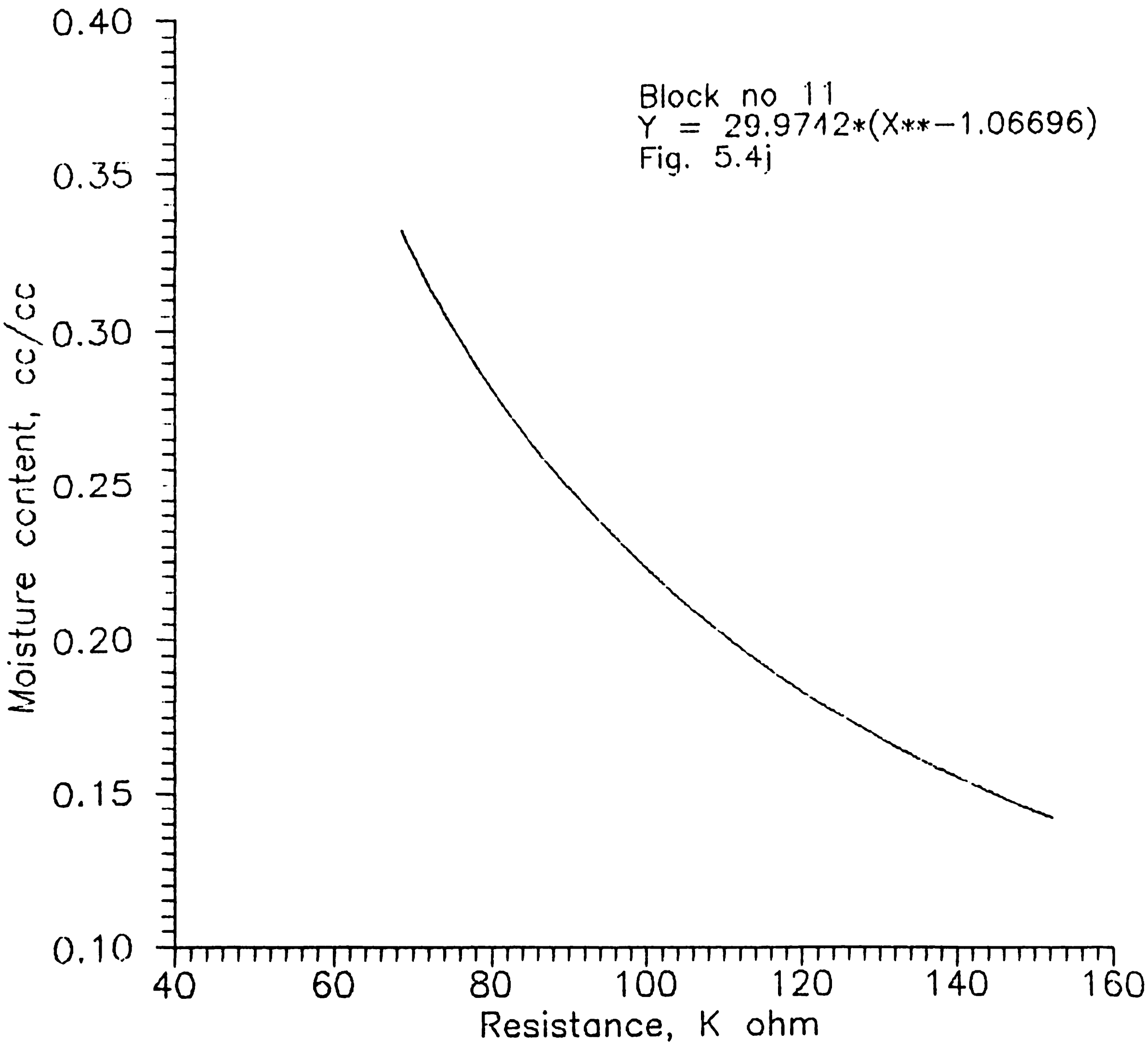
Block no 6
Y = 1131.78*(X**-1.92873)
Fig. 5.4e
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
50
60
70
80
90
100
110
Resistance, K ohm

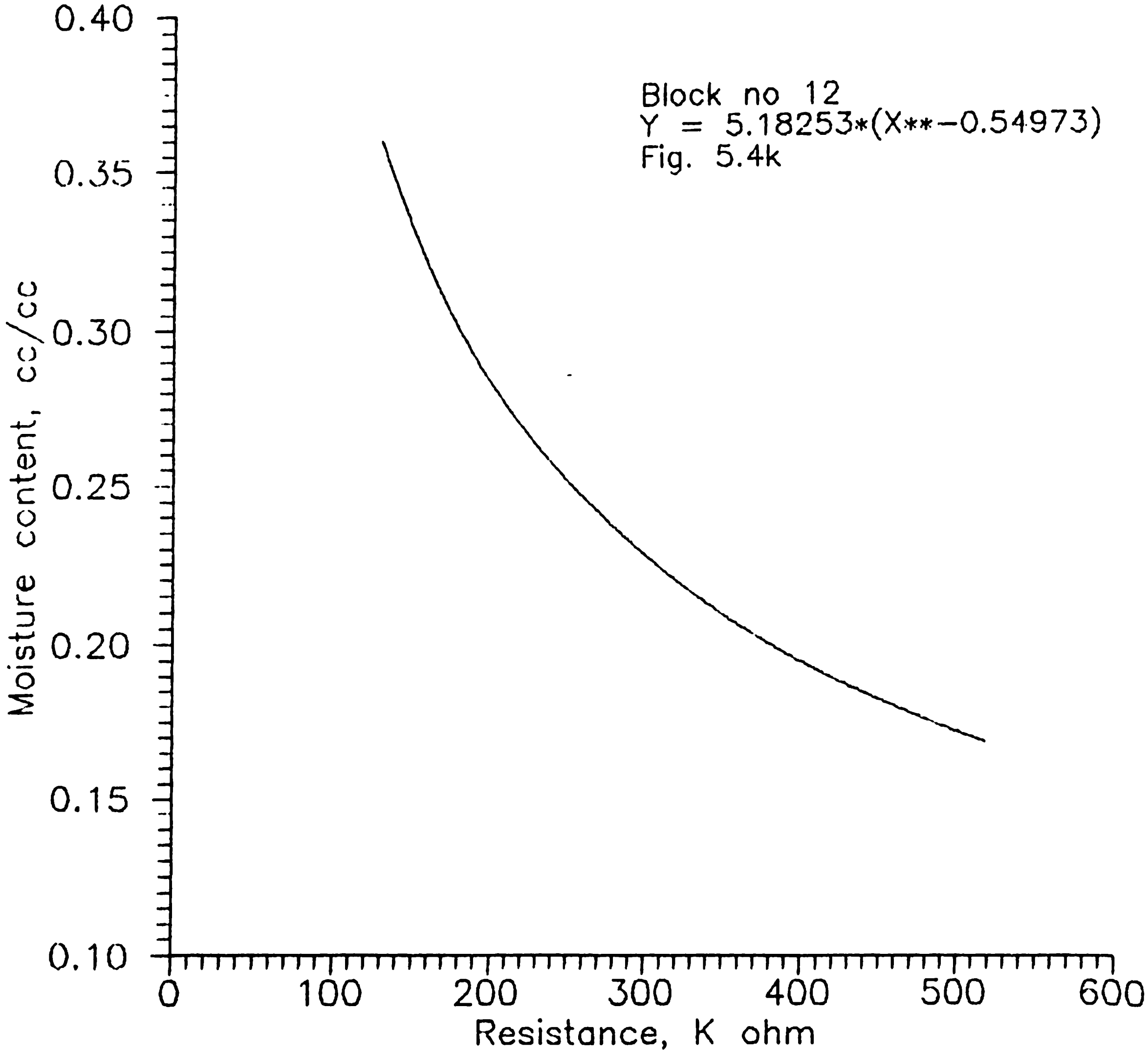

Block no 7
Y = 9.31494*(X**-0.725817)
Fig. 5.4f
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0
50
100
150
200
250
300
350
Resistance, K ohm


Block no 8
Y = 52.0723*(X**-1.09005)
Fig. 5.4g
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
40
80
120
160
200
240
Resistance, K ohm

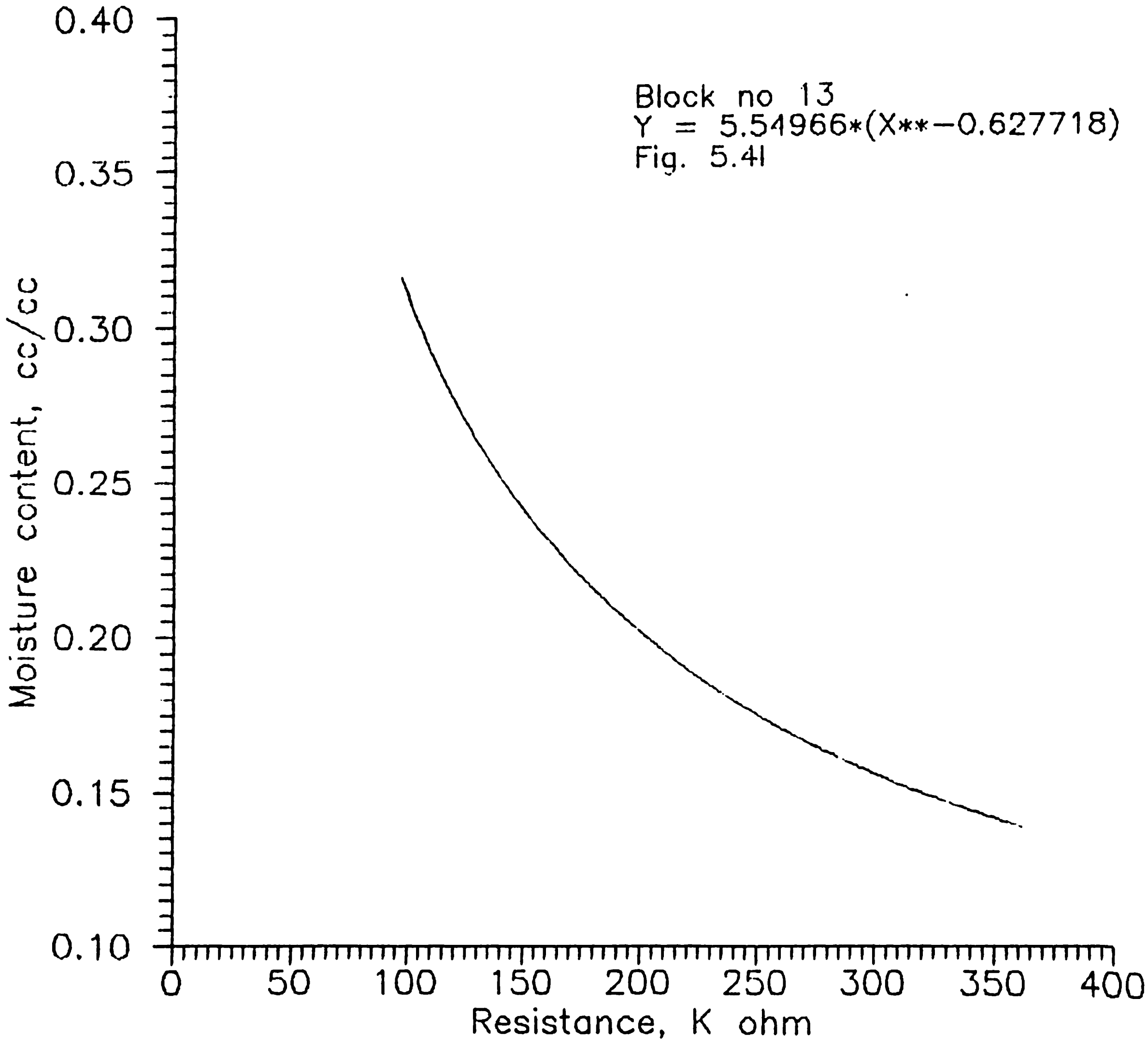

Block no 9
Y = 15.5619*(X**-0.769151)
Fig. 5.4h
0.40
0.35
0.30
0.25
0.20
0.15
0.10
Moisture content, cc/cc
50
100
150
200
250
300
350
400
450
Resistance, K ohm

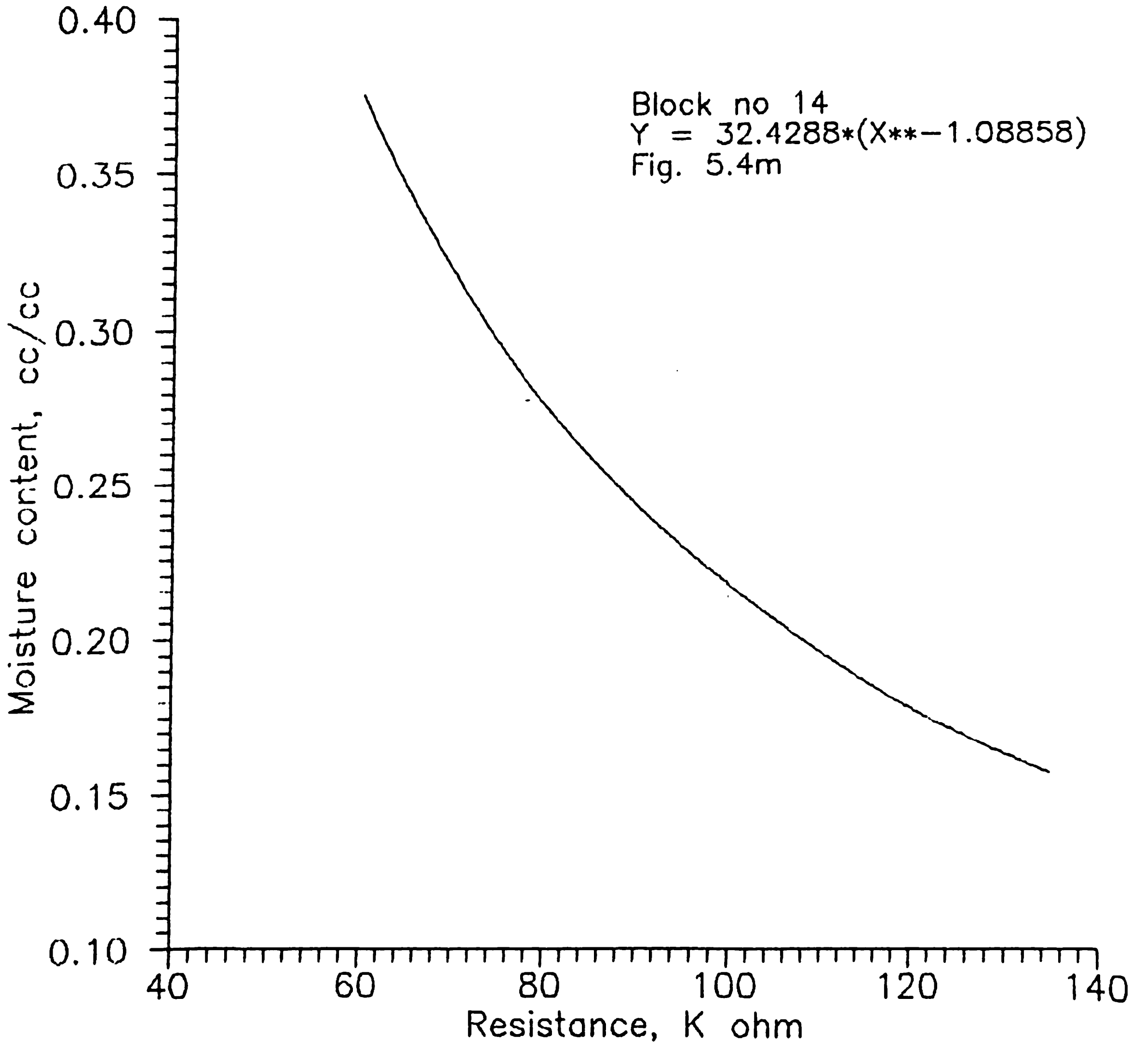

Block no 10
Y = 4.24511*(X**-0.640116)
Fig. 5.4i
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0
50
100
150
200
250
Resistance, K ohm

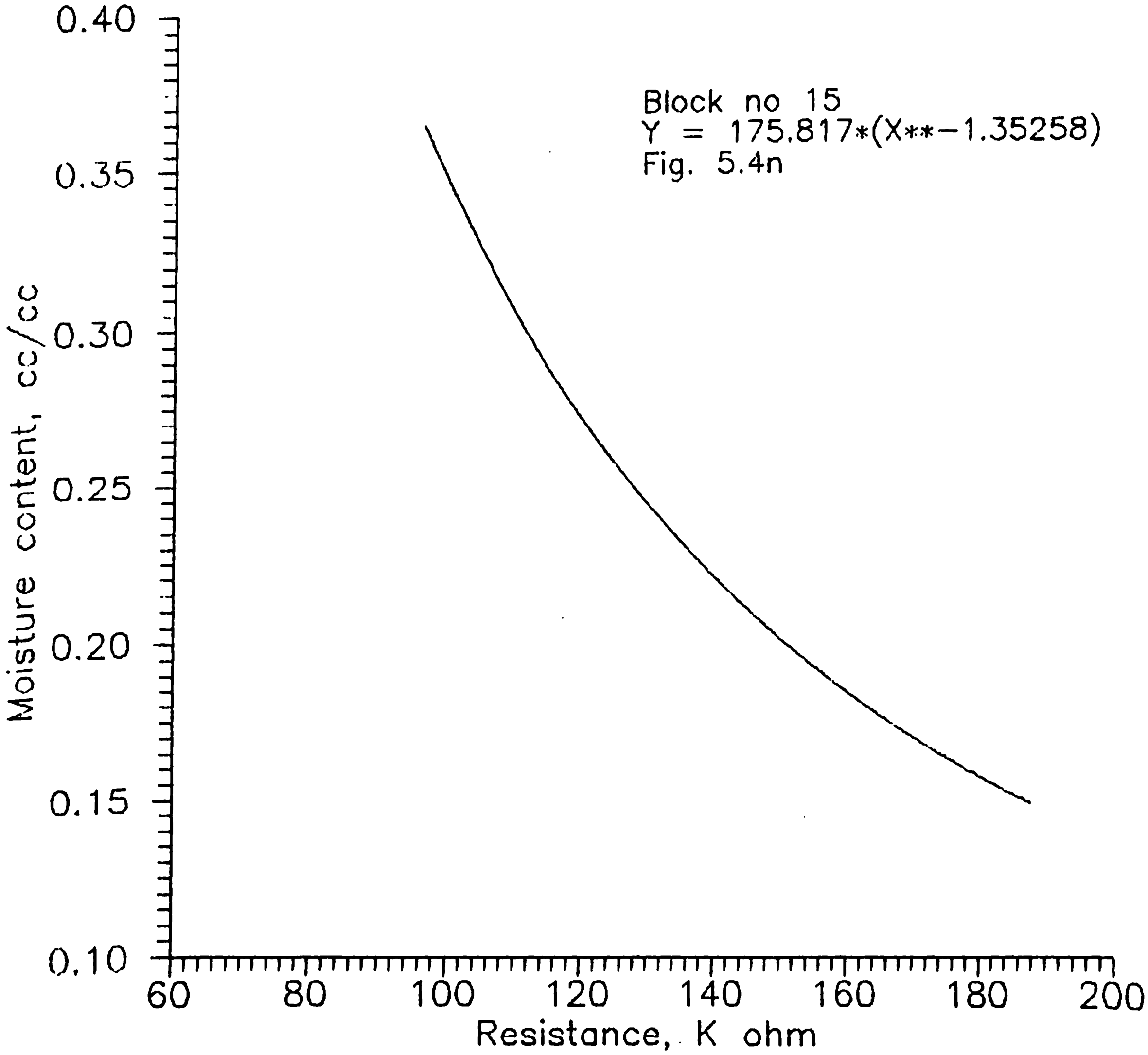

Block no 11
Y = 29.9712*(X**-1.06696)
Fig. 5.4j
0.40
0.35
0.30
0.25
0.20
0.15
0.10
Moisture content, cc/cc
40
60
80
100
120
140
160
Resistance, K ohm



Block no 12
Y = 5.18253*(X**-0.54973)
Fig. 5.4k
0.40
0.35
0.30
0.25
0.20
0.15
0.10
Moisture content, cc/cc
0
100
200
300
400
500
600
Resistance, K ohm


Block no 13
Y = 5.54966*(X**-0.627718)
Fig. 5.41
0.40
0.35
0.30
0.25
0.20
0.15
0.10
Moisture content, cc/cc
0
50
100
150
200
250
300
350
400
Resistance, K ohm


Block no 14
Y = 32.4288*(X**-1.08858)
Fig. 5.4m
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
40
60
80
100
120
140
Resistance, K ohm


Block no 15
Y = 175.817*(X**-1.35258)
Fig. 5.4n
Moisture content, cc/cc
0.40
0.35
0.30
0.25
0.20
0.15
0.10
60
80
100
120
140
160
180
200
Resistance, K ohm

5.4 Moisture Distribution Pattern

The moisture distribution pattern under point source is studied experimentally and prediction is made for the same using soil physical characteristics. The distribution patterns were studied for three discharges i.e. 1000 cc/hr, 1500cc/hr and 4000 cc/hr.

5.4.1 Observed moisture distribution

In Table 5.4, 5.5 and 5.6 the moisture content values for different discharges and various time intervals are shown. Observed moisture content distributions for the discharge rate of 1500cc/hr for time intervals of 120 min, 600 min and 890 min from the start of water application are shown in Figs 5.5, 5.6 and 5.7 respectively. Similarly the moisture distributions for the discharge rate of 4000 cc/hr is shown in Fig 5.8 and 5.9 for time interval of 360 min and 600 min respectively. From the moisture distribution values, the isomoisture lines are drawn to determine the approximate volume of wetting zone and also to determine the rate of movement of wetting boundary in both horizontal and vertical directions. The wetting zone of the soil mass is approximately taken as the soil volume bounded by 0.05 cc/cc isomoisture line and the two axes:

Table 5.4 Volumetric moisture content (θ) in cc/cc observed for the discharge rateof 1000 cc/hr.

(r,z) / Time (min)	0,10	10,10	20,10	25,10	0,20	10,20	20,20	25,20	0,30	10,30	20,30	0,40	10,40
60	0.046	0.06											
120	0.075	0.10											
180	0.089	0.112	0.148		0.079	0.134							
330	0.106	0.154	0.171		0.088	0.146	0.084						
450	0.188	0.172	0.183	0.143	0.102	0.160	0.124		0.137				
570	0.214	0.203	0.196	0.168	0.188	0.204	0.157	0.072	0.142	0.034			
690	0.262	0.213	0.213	0.182	0.210	0.214	0.165	0.094	0.163	0.091			
825	0.296	0.245	0.221	0.201	0.229	0.221	0.169	0.116	0.185	0.129	0.100		
945	0.314	0.283	0.254	0.228	0.233	0.226	0.171	0.127	0.196	0.158	0.127	0.041	0.036

Table 5.5 Volumetric moisture content (θ) in cc/cc observed for the discharge rate of 1500 cc/hr.

Time (min) \ (r,z)	0,10	0,20	0,30	0,40	10,10	10,20	10,30	10,40	20,10	20,20	20,30	25,10	25,20
120	0.093				0.069				0.038				
240	0.147	0.082			0.108				0.057				
360	0.189	0.104	0.048		0.131	0.066			0.082				
600	0.209	0.158	0.098	0.036	0.152	0.108	0.056		0.121	0.063		0.047	
890	0.233	0.196	0.149	0.102	0.208	0.185	0.082	0.071	0.148	0.116	0.091	0.098	0.056

Table 5.6 Volumetric moisture content (θ) in cc/cc observed for the discharge rate of 4000 cc/hr.

Time (min) \ (r,z)	0,10	0,20	0,30	0,40	10,10	10,20	10,30	20,10	20,20	25,10
120	0.048				0.031					
240	0.126	0.035			0.981	0.046				
360	0.172	0.109	0.037		0.153	0.091		0.042		
600	0.286	0.174	0.092	0.046	0.141	0.108	0.069	0.085	0.043	0.036

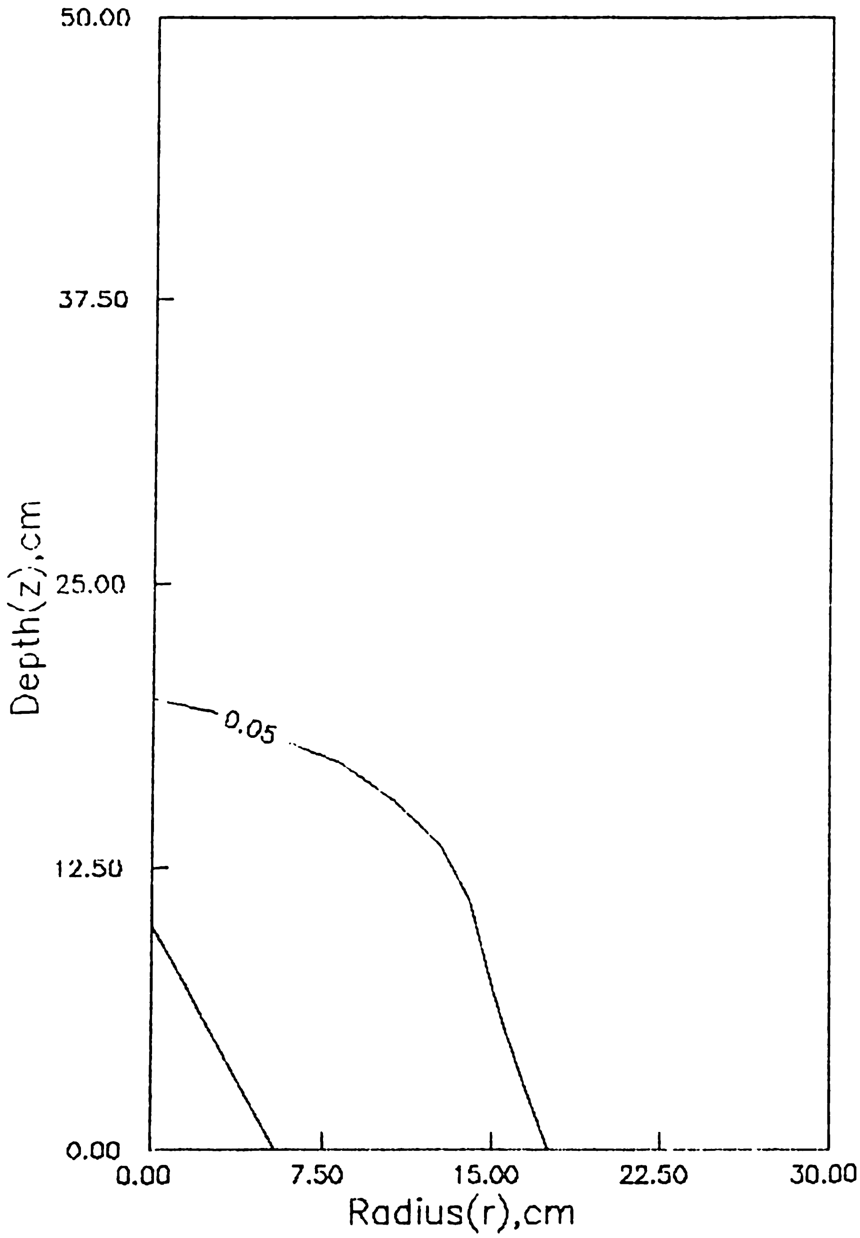


Fig. 5.5 Observe Moisture content distribution for t=120 min and q=1500 cc/hr.

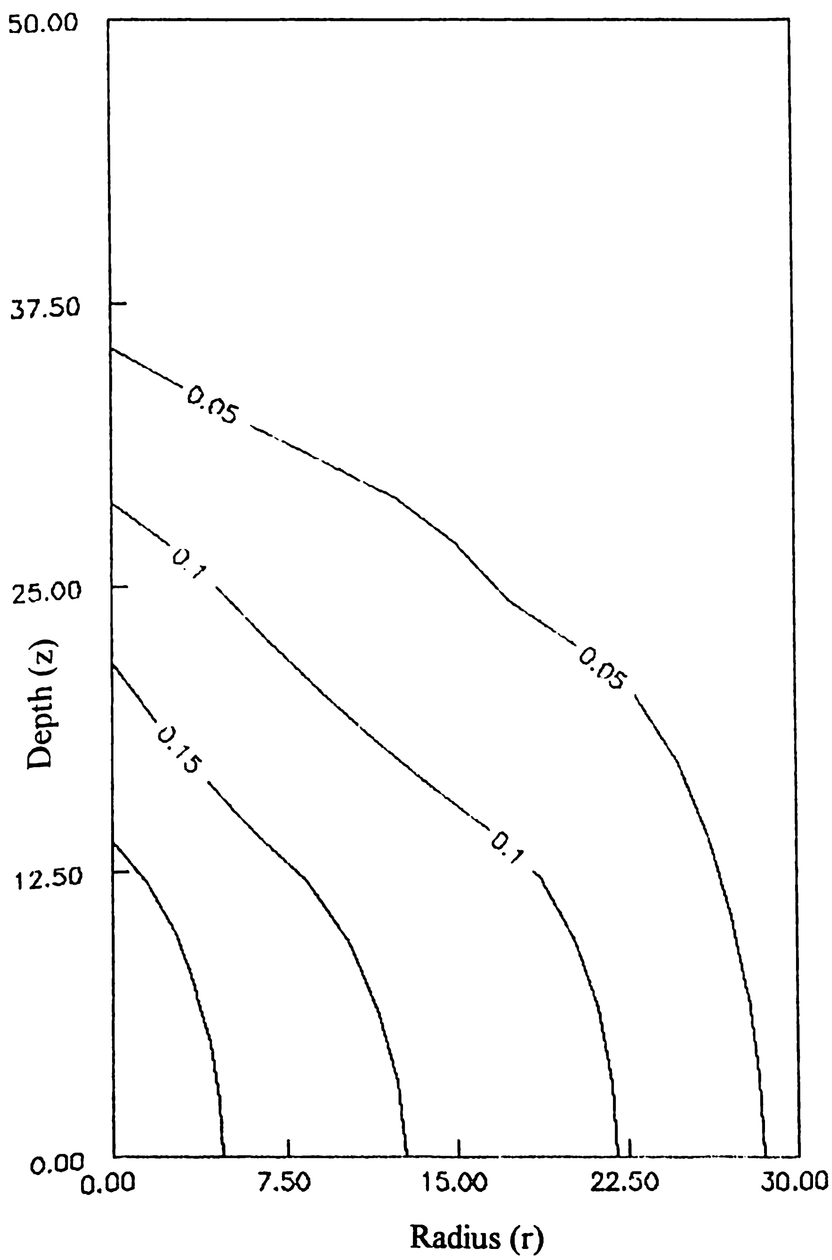


Fig. 5.6 Observed moisture content distribution for t = 600 min and q = 1500 cc/hr.

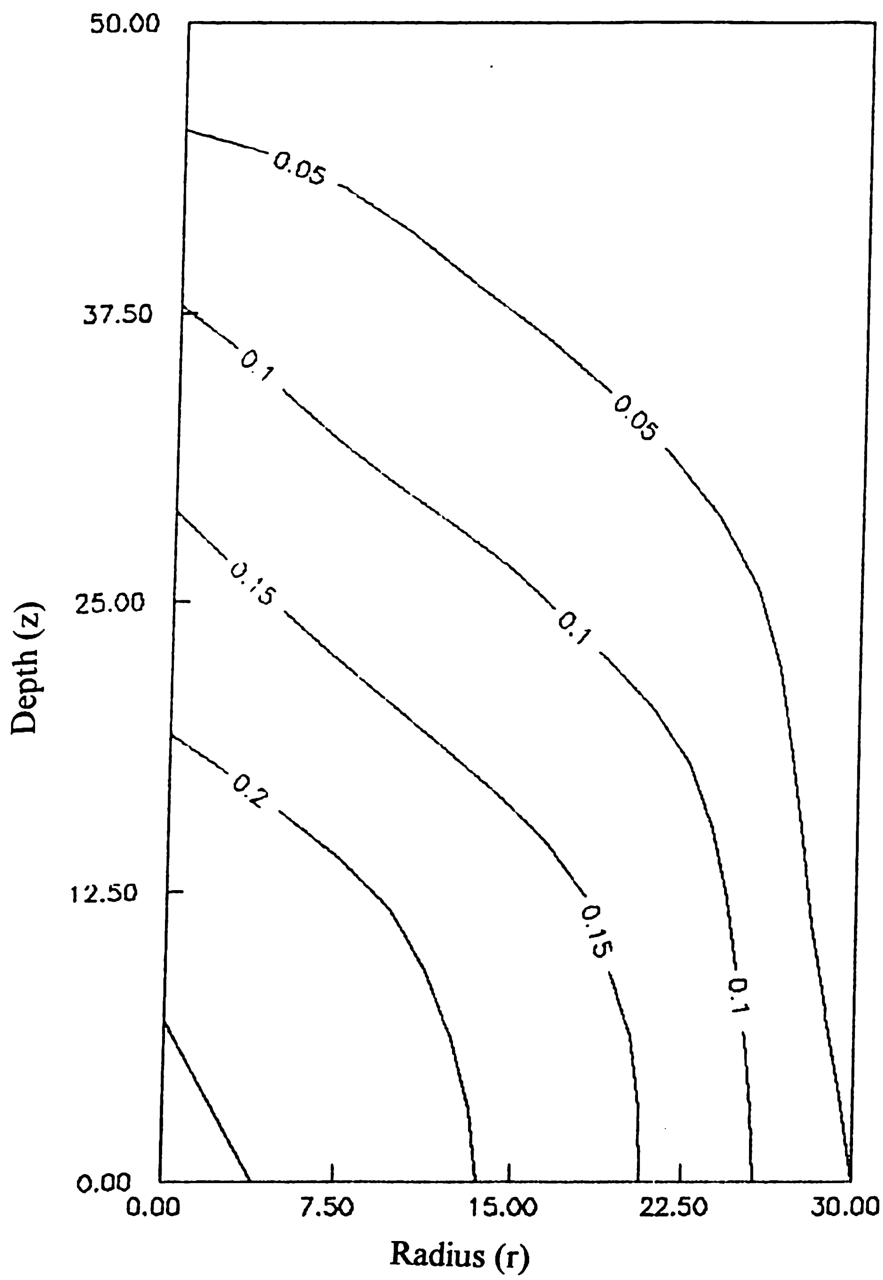


Fig. 5.7 Observed moisture content distribution for t = 890 min and q = 1500 cc/hr

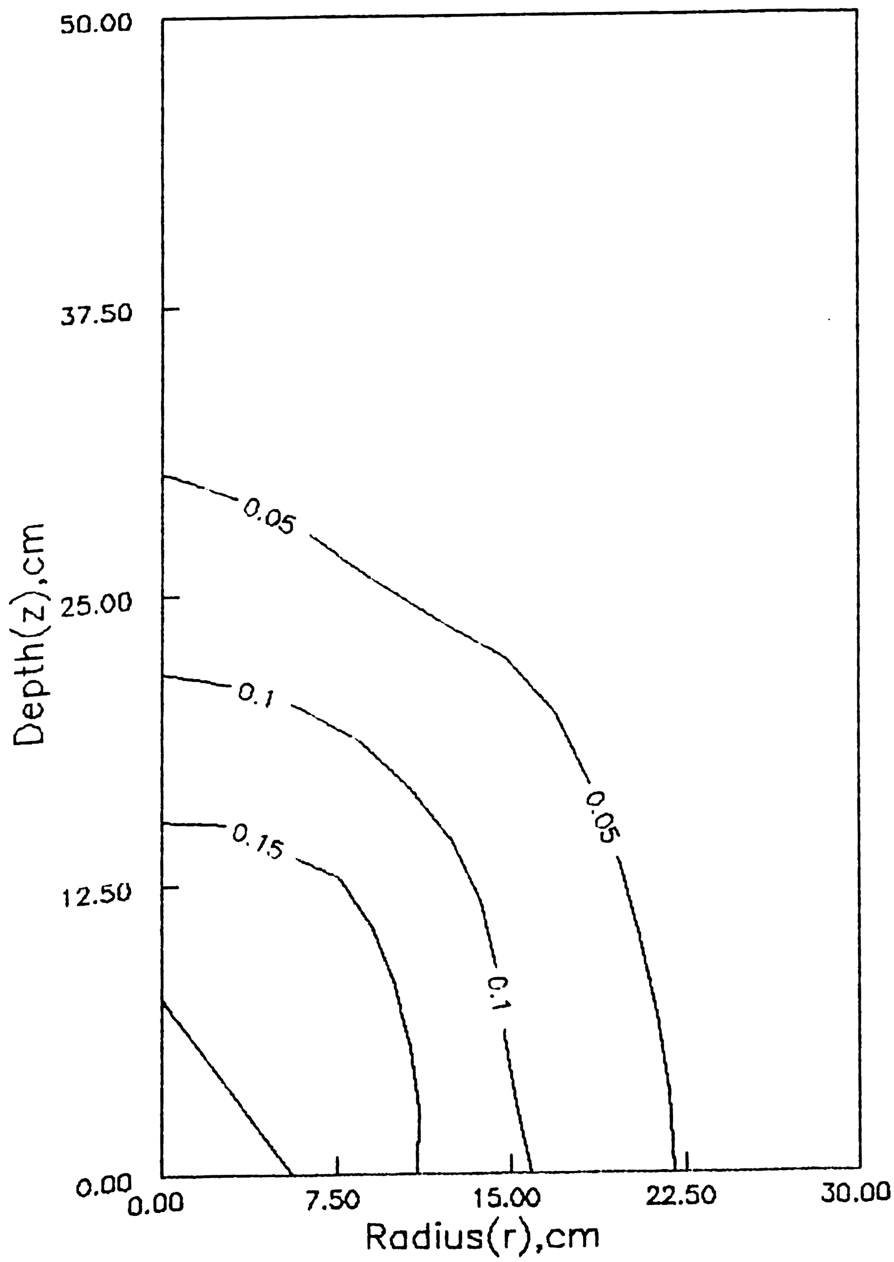


Fig. 5.8 Observed moisture content distribution for t = 360 min and q = 4000 cc/hr

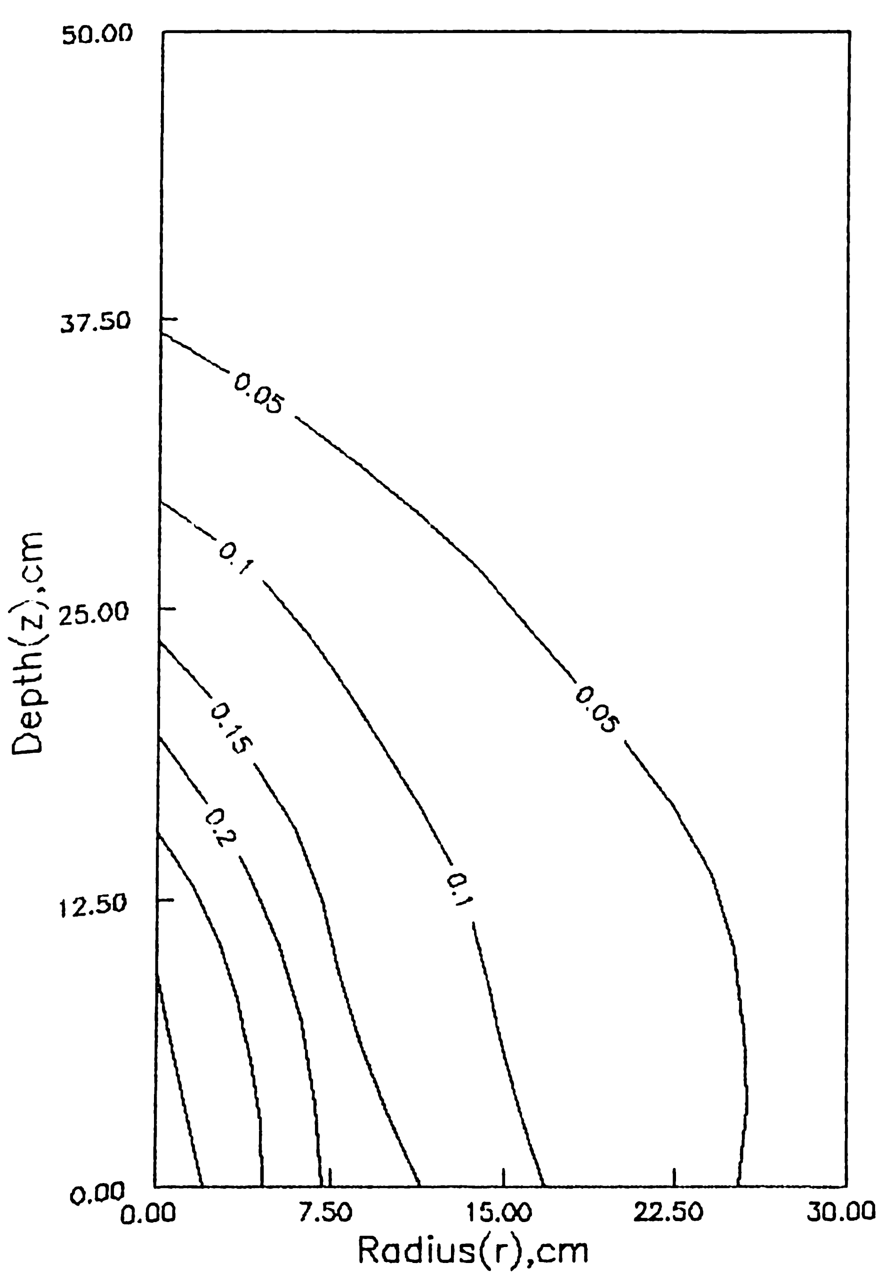


Fig. 5.9 Observed moisture content distribution for t = 600 min and q = 4000 cc/hr

From the Tables 5.4, 5.5 & 5.6 and Figs 5.5, 5.6, 5.7 5.8 & 5.9 seen that for lower discharges and less time of irrigation, the horizontal front movement is always lesser than that of the vertical front movement. For 1500 cc/hr discharge, horizontal advance from the point of application is approximately 17cm and vertical movement is approximately 18.75cm after 120 min. of irrigation. Similar types of results are obtained for irrigation time of 600 min and of 900 min. For low discharge and for longer time of irrigation the horizontal front approaches to a limit but the vertical front increases at a faster rate. At time t=600 min for discharge of 1500 cc/hr the horizontal front is approximately at 28 cm from the point of application and vertical front is at 35 cm. But at time t=890 min the horizontal front is at 30 cm while the vertical front is at 45.5cm. From this it is concluded that the matric potential differences have a limited effect on the water movement in the coarse textured soil.

For higher discharge rate the initial horizontal movement is comparatively higher than that of the vertical movement for lesser time of application. But for more time of application the vertical movement is higher than that of horizontal movement.,

Ahemad et al, 1976 found exponential relationship between time and vertical/horizontal advances under point source application of water.

They reported that the horizontal water movement during irrigation was small when compared to the vertical advance. This is found to be true when the application rate is low. Howerver when application rate is high, this trend is obtained for larger time of application.

Goldberg et al, 1971 also reported that it is possible to increase the lateral spread of wetting front by increasing the emitter discharge rate.

Brandt et al, 1971 reported that an increase in the trickle discharge rate resulted in an increase in the horizontal wetted area and decrease in the depth of the wetted soil.

Angelakis et al, 1991 reported that in sandy profile the horizontal wetting front approached a limit at longer times of water application. The vertical wetting fronts were always greater than the horizontal front.

The similar types of trends as discussed above are obtained in the experiment conducted in the laboratory and hence are acceptable.

5.4.2 Predicted moisture distribution

Using Warrick model, predicted moisture distribution patterns and water front advance for different rates of applications after various times were obtained. These values are presented in Tables 5.7, 5.8 and 5.9 and are shown in Figs 5.10, 5.11, 5.12 and 5.13. Critical study of the Tables and Figs shows that the predicted moisture pattern is approximately similar to the observed moisture pattern. Same is the case for the moisture front advances both in horizontal and vertical directions.

5.5 Validation of the Model

Warrick's model gave the predicted values of moisture content at different distances and depths. These values were compared with the observed moisture content values for validation of his model by comparing the reletive error percentage values.

At each point of time and location the relative error percentage is calculated for different discharges and is presented in Tables 5.10, 5.11 and 5.12 for trickle discharge rates of 1000, 1500 and 4000 cc/hr respectively. From the tables and the figures it is seen that in all the cases the linearised model underestimated the moisture content value. At each point the observed

Table 5.7 Volumetric moisture content (θ) in cc/cc predicted for the discharge rate of 1000 cc/hr.

(r,z) / Time (min)	0,10	10,10	20,10	25,10	0,20	10,20	20,20	25,20	0,30	10,30	20,30	0,40	10,40
60	0.039	0.04											
120	0.065	0.08											
180	0.077	0.091	0.128		0.068	0.115							
330	0.09	0.132	0.147		0.076	0.126	0.071						
450	0.159	0.150	0.157	0.124	0.087	0.139	0.106		0.116				
570	0.182	0.179	0.167	0.146	0.161	0.175	0.133	0.060	0.120	0.028			
690	0.222	0.184	0.181	0.158	0.179	0.182	0.140	0.080	0.137	0.075			
825	0.249	0.201	0.187	0.174	0.195	0.189	0.143	0.097	0.155	0.109	0.083		
945	0.262	0.241	0.214	0.196	0.198	0.192	0.144	0.105	0.163	0.134	0.104	0.032	0.029

Table 5.8 Volumetric moisture content (θ) in cc/cc predicted by linearised model for the discharge rate of 1500cc/hr.

(r,z) / Time (min)	0,10	0,20	0,30	0,40	10,10	10,20	10,30	10,40	20,10	20,20	20,30	25,10	25,20
120	0.081				0.058				0.031				
240	0.127	0.71			0.092				0.041				
360	0.156	0.084	0.038		0.104	0.053			0.066				
600	0.180	0.130	0.80	0.030	0.126	0.090	0.042		0.097	0.050		0.039	
890	0.190	0.157	0.119	0.079	0.156	0.150	0.068	0.056	0.116	0.198	0.070	0.082	0.046

Table 5.9 Volumetric moisture content (θ) in cc/cc predicted by linearised model for the discharge rate of 4000 cc/hr.

(r,z) / Time (min)	0,10	0,20	0,30	0,40	10,10	10,20	10,30	20,10	20,20	25,10
120	0.041				0.022					
240	0.108	0.029			0.803	0.038				
360	0.143	0.089	0.026		0.125	0.072		0.036		
600	0.243	0.162	0.067	0.032	0.106	0.084	0.055	0.071	0.035	0.031

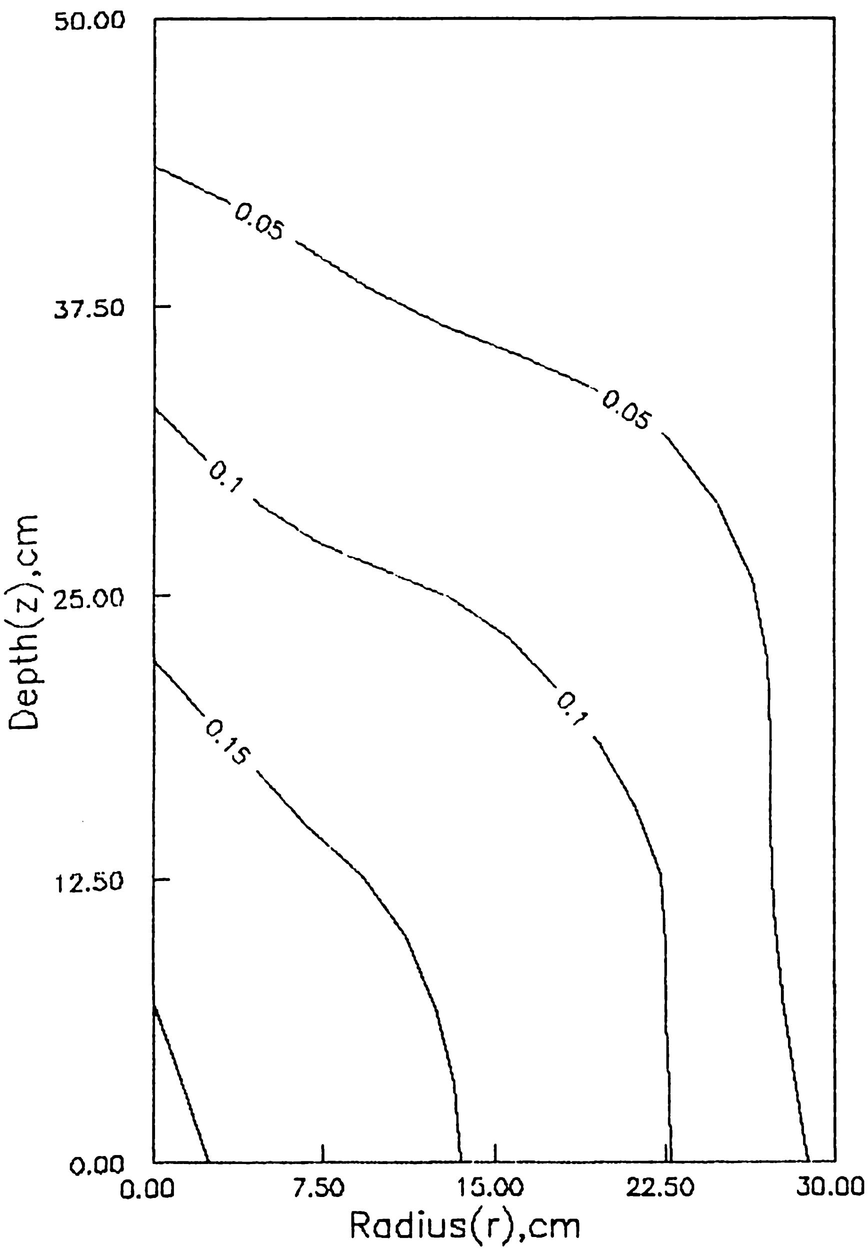


Fig. 5.11 Predicted moisture content distribution for t = 890 min and q = 1500 cc/hr

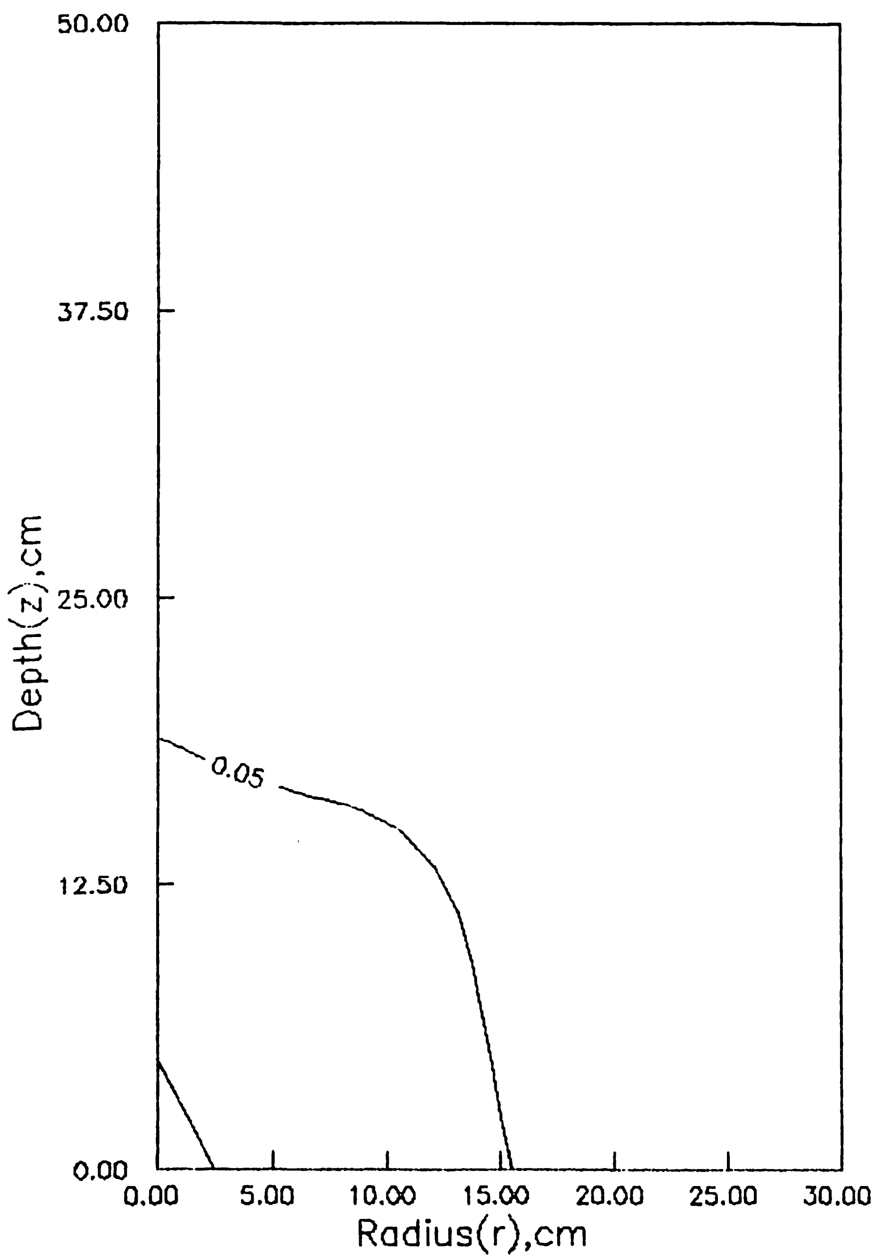


Fig. 5.10 Predicted moisture content distribution for t = 120 min and q = 1500 cc/hr

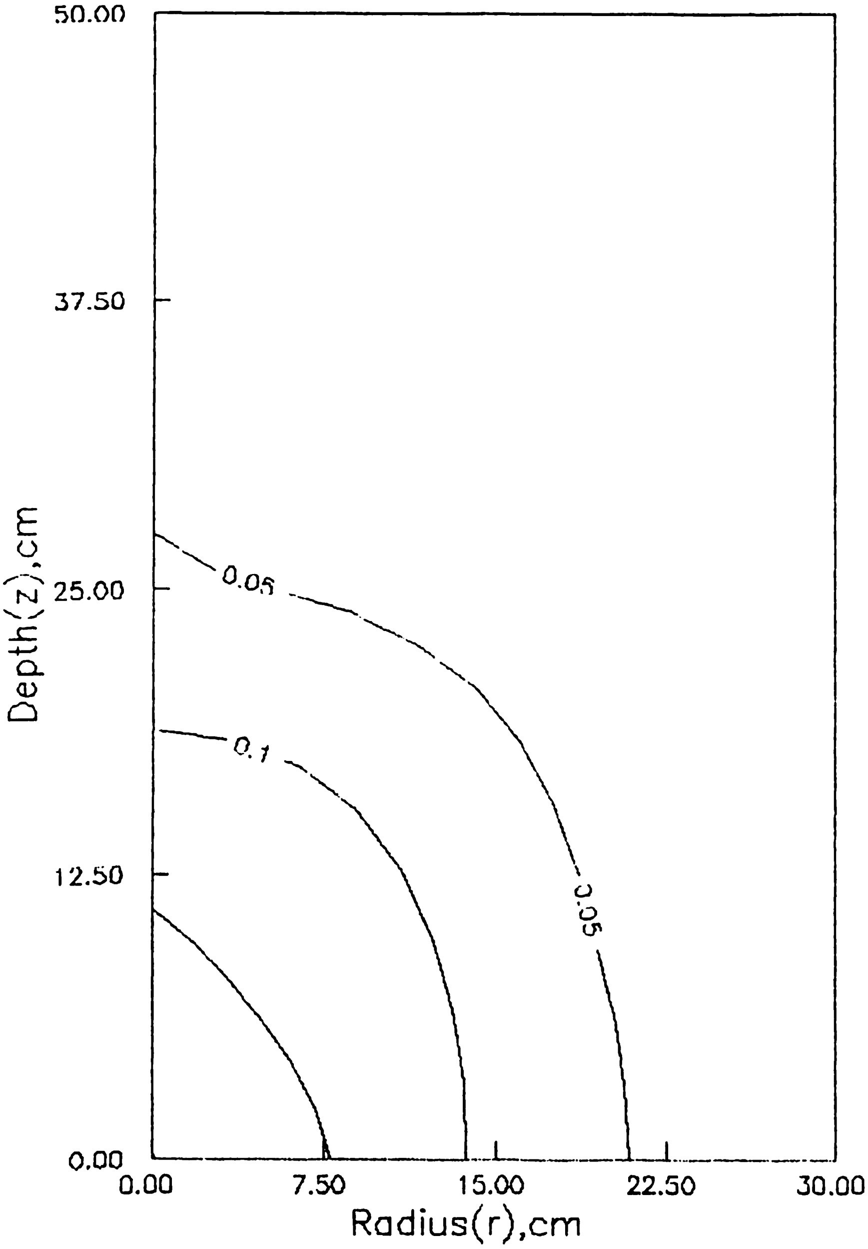


Fig. 5.12 Predicted moisture content distribution for t = 360 min and q = 4000 cc/hr

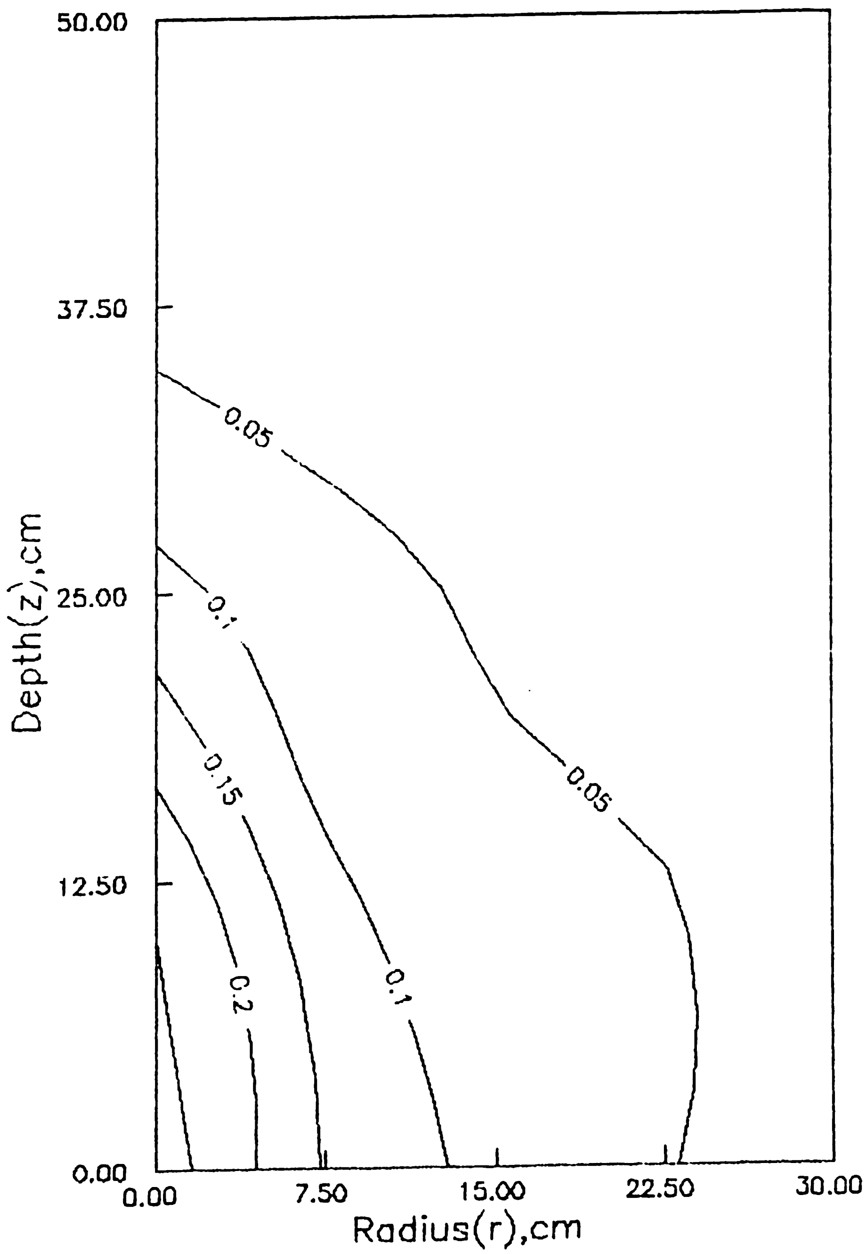


Fig. 5.13 Predicted moisture content distribution for t = 600 min and q = 4000 cc/hr

Table 5.10 Relative error percentage at different locations and time of irrigation for the discharge rate of 1000 cc/hr.

(r,z) / Time (min)	0,10	10,10	20,10	25,10	0,20	10,20	20,20	25,20	0,30	10,30	20,30	0,40	10,40
60	12.1	14.3											
120	12.7	13.9											
180	13.1	13.6	13.4		13.7	13.7							
330	14.0	13.8	13.6		13.2	13.6	14.1						
450	14.9	12.5	14.1	12.8	13.9	13.1	14.5		15.1				
570	14.8	12.5	14.3	12.6	14.1	13.9	14.7	15.3	15.4	14.6			
690	15.2	13.6	14.9	13.0	14.4	14.86	14.9	14.5	15.9	14.3			
825	15.7	14.1	15.1	13.4	14.5	14.4	15.1	15.8	16.1	14.9	16.8		
945	16.4	14.8	15.6	13.9	14.9	14.9	15.4	15.9	16.7	15.1	17.4	20.1	18.7

Table 5.11 Relative error percentage at different locations and time of irrigation for the discharge rate of 1500 cc/hr.

(r,z) / Time (min)	0,10	0,20	0,30	0,40	10,10	10,20	10,30	10,40	20,10	20,20	20,30	25,10	25,20
120	12.6				15.3				16.1				
240	13.1	13.4			14.8				18.8				
360	17.4	19.1	19.9	16.5	16.9	18.4			19.4				
600	13.7	17.6	18.1	20.6	20.1	16.5	14.3		19.7	20.1		14.9	
890	18.3	19.8	20.1	22.4	24.6	18.7	16.8	20.6	21.3	22.4	22.8	16.1	17.4

Table 5.12 Relative erroer percentage at different locations and time of irrigations for the discharge rate of 4000 cc/hr

(r,z) / Time (min)	0,10	0,20	0,30	0,40	10,10	10,20	10,30	20,10	20,20	25,10
120	13.4				14.5					
240	13.9	17.1			18.1	16.7				
360	16.3	17.6	27.3		17.9	20.2		13.6		
600	14.8	19.7	26.1	28.5	24.3	21.8	19.2	16.1	18.4	12.9

value is higher than that of the predicted values. For low discharge rate the percentage of error is comparatively less than that at higher discharge rates. For discharge rate of 1000 cc/hr the highest error percentage is 20.1%, for discharge rate of 1500 cc/hr it is 24.6% and for discharge rate of 4000 cc/hr it is 28.5%. Also the error percentage is less for lesser time of application than that of longer time of application. Except in some cases the percentage of error increases from lower time of application to higher. Some of the discrepency could be due to experimental error. So for low application rate and less time of application the predicted moisture content values model is comparatively more accurate.

Also the error percentage is more in vertical direction than that in horizontal direction. The calculated and measured horizontal component of soil moisture distribution is reasonably well. But the calculated vertical and observed vertical moisture front advance distances donot show close agreement. This is revealed from the table as the highest percentage of error is noticed at the point below the source.

Results obtained by Angolakis et al. (1991) are similar as above. According to them the linearized theory does not predict the dominance of gravitational forces in the sandy soil. Also they have reported that the agreement between predicted and observed values decreases at higher application rate.

The above discussions show that in case of linearised predication the observed values do not agree with that of predicted values. Further these disagreement in the observed and predicted values may be attributed to the following reasons.

(I) Inadequacy of the assumption that K(θ) was a unique linear function for linearized theory.

(ii) Variability in the size of the surface source of water during infiltration.

(iii) Variations in initial moisture content and packing conditions of soil.

(iv) Assumption about the medium that it is isotropic and homogeneous.

(v) Not taking the hystresis effect into account.

(vi) Lack of precision in observing the soil-water content.

(vii) Inaccuracy in using soil surface boundary conditions.

Taking the above reasons into account it can be concluded that the model can be used for prediction of the moisture content and wetting pattern position which can be used for design purpose. This can be used for design as the percentage of error lies between 12 to 20%.

CHAPTER - VI

SUMMARY AND CONCLUSIONS

CHAPTER-VI

SUMMARY AND CONCLUSION

For design of the trickle irrigation system it is required to know the volume of soil wetted by a single emitter. This wetted soil volume depends on soil type, discharge rate of emitter and time of application of water. To determine the wetted volume of soil under point source application a number of methods/models are available. However one difficulty involved in those models, is complicated and lengthy mathematical calculations. It is, therefore, necessary to find out some simpler approaches to study the phenomenon of moisture front advance under trickle irrigation system. For the above reasons this study was conducted with the following specific objectives:

(I) Determination of physico-chemical properties of soil

(ii) Laboratory study of moisture distribution under trickle point source.

(iii) Prediction of moisture distribution by using Warrick's linearised model.

(iv) Validation of the linearised model for practical application.

The soil was tested to determine its physico-chemical properties. The bulkdensity, EC and pH of the soil was determined using standard procedures. The textural class of the soil was determined by hydrometer analysis. The saturated hydraulic conductivity was determined by constant head permeameter. The soil moisture retention data was obtained by pressure outflow method. These data was used to determine the unsaturated hydraulic conductivity, relative hydraulic conductivity value for a particular value of soil suction pressure and moisture content using the VGM model.

The moisture distribution pattern in the soil volume was determined by using soil tank model. In this study three discharges were taken i.e. 1000 cc/hr, 1500 cc/hr and 4000 cc/hr.

The prediction of the soil moisture distribution pattern was made by Warrick's model for the three discharges. The comparision of the observed moisture distribution and predicted moisture distribution was done by calculating the relative error percentage.

Bulk density, EC and pH of the soil used in experiment was found out to be 1.714gm/cc, 0.418 millimhos/cm and 5.325 respectively. The soil was found to be sandy-loam. The saturated hydraulic conductivity and saturated moisture content of this test soil was found out to be 5.93 cm/hr and 0.354cc/cc.

From the moisture retention data it was seen that 0.017 is the residual moisture content of the soil. From the hydraulic conductivity value corresponding to particular values of moisture content obtained from VGM model, it is seen that at lower moisture content values the rate of decrease of the hydraulic conductivity is faster than that at higher moisture content values. As the moisture contant reaches near the saturated value, the hydraulic conductivity approaches a constant value with less rate of change with respect to moisture content. Also it is seen that the rate of change of conductivity is faster at higher suction pressures. As the suction pressure decreases the conductivity increases at a faster rate up to a suction pressure of 300 to 400 cm of water.

Hydraulic conductivity function K suction pressure Ψ need to have anexponential regression fit of the type $K = K_0 e^{\alpha\psi}$. In the present study value of K_0 and α was found out to be 1.84 & 0.004 and value of α was acceptable sinces it is to lie between 0.2 to 0.002 as given by Philip 1969.

For study of the moisture distribution pattern the 0.05 cc/cc isomoisture line was taken as the boundary between wetted zone and dry zone. From the soil tank model it is seen that for the discharge rate of 1500 cc/hr the horizontal advance and vertical advance of moisture front after 120 min. of application from the point of application is 17 cm. and 18.75 cm. Similar results are also obtained for the time of application of 600 min. and 890 min.

Hence, it is concluded that the horizontal front movement is always lesser than that of the vertical front movement for lower discharge rate.

At time of application of water t=600 min. for discharge rate of 1500 cc/hr the horizontal front is at 28 cm and vertical front is at 35 cm from the source of application. But at time t = 890 min. the horizontal front is at 30 cm and vertical front is at 45.5 cm. So for low discharge and after longer time of application the horizontal front approaches to a limit but the vertical front increases at faster rate.

For higher discharge rate and lesser time of application the initial horizontal movement of water front is comparably higher than that of the vertical movement. But for larger time of application the vertical movement is higher than that of horizontal movement.

From the observed and predicted value of moisture content in the soil profile it is seen that always the predicted value is less than that of observed one. It is seen that for discharge rate of 1000 cc/hr the highest error percentage is 20.1%, for 1500 cc/hr this is 24.6% and for 4000 cc/hr this is 28.5%. Hence for lower discharge rate the percentage of error is comparatively less than that at higher discharge rate. Also it is seen that the percentage of error is less for lesser time of application and more for higher time of application of water. So for low application rate and less time of application the predicted moisture content is comparatively more accurate. The error percentage is more in vertical direction than that in horizontal direction. The error percentage is highest at the point just below the source.

From the relative error percentage table it was seen that the error percentage lies between 12 to 29%.

Based on the results obtained following conculsions are drawn :

(I) The VGM model can be used for generating the unsaturated hydraulic conductivity data which can be used further for prediction of moisture distribution pattern.

(ii) The warrick model can be used for prediction of the soil moisture distribution under a point souce.

(iii) These predicted data can be used for design of the trickle irrigation system as the error percentage lies in the ressonable limit.

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APPENDIX - A

Weight values for different sampling points

Sl. No.	Sampling points (X_i)	Weight values (W_i)
1	$9.3308 * 10^{-2}$	0.2182
2	0.4927	0.3422
3	1.2150	0.2630
4	2.2699	0.1264
5	3.6676	$4.0207 * 10^{-2}$
6	5.4253	$8.5639 * 10^{-3}$
7	7.5659	$1.2124 * 10^{-3}$
8	10.1202	$1.1167 * 10^{-4}$
9	13.1309	$6.4599 * 10^{-6}$
10	16.6544	$2.2263 * 10^{-7}$
11	20.7765	$4.2274 * 10^{-9}$
12	25.6239	$3.9219 * 10^{-11}$
13	31.4075	$1.4565 * 10^{-13}$
14	38.5307	$1.4830 * 10^{-16}$
15	48.0260	$1.6000 * 10^{-20}$

APPENDIX- 6

```
/****************************************************************************/
/*          PROGRAM TO ESTIMATE UNSATURATED HYDRAULIC CONDUCTIVITY          */
/*                         USING Van-Genuchten Model                        */
/*                                                                          */
/****************************************************************************/
#include <stdio.h>
#include <conio.h>
#include <graphics.h>
#include <math.h>
#include <stdlib.h>
#include <ctype.h>
#define REV_VIDEO 0
main()
  {
   FILE *fp,*fp1;
   char opt,fn[20],fn1[20],title[100];
   float *relhy,*hydc,*theta,*he_ge,*he,*te,ks;
   int n_dat,i,j=1,n_gen,n_layer;
   static char *s[]={"First","Second","Third","Fourth","Fifth","Sixth","Seventh"
   /***************************************************************************
   /********************** function prototype declaration *********************
   /***************************************************************************
   void sort_dat_asc(float *a,float *b,int n);
   void swap(float *a,float *b);
   float lin_pol(float *a,float *b,int n,float aa);
   float slope(float *a,float *b,int n,float aa);
   double pow1(double x,double m);
   double log101(double x);
   void hydk_gen(FILE *fp,float ks,float *he,float *te,int n_dat,int n_gen,float
   float *falloc(int n);
   void my_printxy(int x,int y,char *s,int att,int mode,int color);
   void print_line(FILE *fp,char *s,int n);
   /***************************************************************************
   clrscr();
   my_printxy(36,13,"HYDCON",0,C80,BLUE);
   my_printxy(30,23,"                        ",0,C80,RED);
   getch();
   textmode(C80);
   clrscr();
   while(1)
   {
   printf("\nWant to read input from file or key board (F/K) :");
   if((opt=toupper(getche()))=='F')
   break;
   }
   switch(opt)
   {
   case 'F' :
             printf("\nEnter the file name :");
             scanf("%s",fn);
             fp=fopen(fn,"r+");
             if(fp==NULL)
             {
             printf("\nError opening input file..\n");
             exit(1);
             }
  case 'K'  : break;
  }
             fscanf(fp," %[^\n]",title);
             fscanf(fp,"%d",&n_layer);
```

```
   printf("Enter the outfile name :");
   scanf("%s",fn1);
   fp1=fopen(fn1,"a");
   print_line(fp1,"=",60);
   fprintf(fp1,"\n\t\t%s\n",title);
   print_line(fp1,"=",60);
   printf("\nEnter the no of data to be generated :");
   scanf("%d",&n_gen);

  while(j<=n_layer)
    {
              print_line(fp1,"-",60);
              fprintf(fp1,"\n\t\t%s\tLayer",*(s+j-1));
              print_line(fp1,"-",60);
              fscanf(fp," %d",&n_dat);
              he=falloc(n_dat);
              te=falloc(n_dat);
              for(i=0;i<n_dat;i++)
              fscanf(fp,"%f %f",&he[i],&te[i]);
              fscanf(fp," %f",&ks);
              fprintf(fp1,"\nSaturated Hydraulic conductivity=\t%f(cm/hr)",ks);
   hydc=falloc(n_gen);
   theta=falloc(n_gen);
   he_ge=falloc(n_gen);
   relhy=falloc(n_gen);
   print_line(fp1,"*",60);
   hydk_gen(fp1,ks,he,te,n_dat,n_gen,theta,he_ge,relhy,hydc);
   print_line(fp1,"*",60);
   free(relhy);
   free(hydc);
   free(theta);
   free(he_ge);
   free(he);
   free(te);
   j++;
   }
   fclose(fp);
   fclose(fp1);
/*main ends here*/}

void hydk_gen(FILE *fp,float ks,float *he,float *te,int n_dat,int n_gen,float *t
   {
    double dum1,dum2,dum4,dum5;
    float *h,*t,r_th,s_th,m_th,hp,slm_th,dx,g;
    double m,sp,pht,beta;
    int i;
    h=he;
    t=te;
    sort_dat_asc(he,te,n_dat);
  r_th=*(t+n_dat-1);
  s_th=*t;
  m_th=(r_th+s_th)*0.5;
  hp=pow1(10,(double)(lin_pol(t,h,n_dat,m_th)));
  slm_th=slope(t,h,n_dat,m_th);
  fprintf(fp,"\nResidual moisture content :\t%f",r_th);
  fprintf(fp,"\nSaturated moisture content :\t%f",s_th);
  fprintf(fp,"\nIntermediate moisture content :\t%f",m_th);
  fprintf(fp,"\nSlope at intermediate moisture content :\t%f",slm_th);
  fprintf(fp,"\nsuction head at intermediate moisture content :\t%f",hp);
```

```
sp=(1.0/(s_th-r_th))*fabs((double)slm_th);
if(sp>0.0 && sp<=1.0)
m=1.0-exp(-0.8*sp);
else
m=1.0-(0.5755/sp)+(0.1/powl(sp,2.0))+(0.025/powl(sp,3.0));
fprintf(fp,"\nThe value of m=%lf",m);
beta=powl(2.0,(double)(1.0/m))-1.0;
beta=powl((double)beta,(double)(1.0-m))/hp;
fprintf(fp,"\nThe coefficient beta :\t%lf",beta);
print_line(fp,"*",60);
dx=(s_th-r_th)/(float)(n_gen-1);
i=0;
print_line(fp,"#",60);
fprintf(fp,"\ntheta\t\t  head\t\t  relhy\t\thydc");
print_line(fp,"#",60);
g=r_th+0.000001;
for(i=0;i<n_gen;i++)
{
  if(g>s_th)
  g=s_th;
  pht=(g-r_th)/(s_th-r_th);
  dum1=1.0-powl(pht,(1.0/m));
  dum2=1.0-powl(dum1,m);
  relhy[i]=powl(pht,0.5)*powl(dum2,2.0);
  hydc[i]=ks*relhy[i];
  theta[i]=g;
  dum5=-1.0/m;
  dum4=powl(pht,dum5)-1.0;
  he_ge[i]=log10l((double)((1.0/beta)*powl(dum4,(1.0-m))));
  fprintf(fp,"\n %f\t%f\t%e\t%e",theta[i],he_ge[i],relhy[i],hydc[i]);
  g+=(dx);
}
  fprintf(fp,"\n %f\t%f\t%e\t%e",s_th,he_ge[n_gen-1],1.0,ks);
}

void sort_dat_asc(float *a,float *b,int n)
{
  int i,j;
  for(i=0;i<n-1;i++)
  {
    for(j=i+1;j<n;j++)
    {
     if(*(a+i)>*(a+j))
     {
     swap((a+i),(a+j));
     swap((b+i),(b+j));
     }
    }
  }
   return;
}
void swap(float *a,float *b)
{
 float temp;
 temp=*a;
 *a=*b;
 *b=temp;
 return;
}
float lin_pol(float *a,float *b,int n,float aa)
```

```
{
  int i;
  float bb;
  for(i=0;i<n-1;i++)
    {
    if(aa<=*(a+i) && aa>=*(a+i+1))
    if((fabs((double)(*(a+i)-aa)))>(fabs((double)(*(a+i)-aa))))
    bb=*(b+i+1)+((aa-*(a+i+1))*(*(b+i+1)-*(b+i)) /(*(a+i+1)-*(a+i)));
    else
    bb=*(b+i)+((aa-*(a+i))*(*(b+i+1)-*(b+i)) /(*(a+i+1)-*(a+i)));
    }
 return(bb);
}

/*float slope(float *a,float *b,int n,float aa)
{
  int i;
  float bb;
  for(i=0;i<n-1;i++)
    {
    if(aa<=*(a+i) && aa>=*(a+i+1))
    {
    bb=(*(a+i)-*(a+i+1))/(*(b+i)-*(b+i+1));
    break;
    }
    }
    return(bb);
 }*/
double pow1(double x,double m)
{
  if(x<1e-32)
  return 0.0;
  else
  return (pow(x,m));
}
double log101(double x)
{
  if(x<1)
  return 0.0001;
  else
  return (log10(x));
}
float *falloc(int n)
{
  return((float *)malloc(n*sizeof(float)));
}
void my_printxy(int x,int y,char *s,int att,int mode,int color)
 {
   if(att==REV_VIDEO)
    {
     textmode(mode);
     gotoxy(x,y);
     textbackground(color);
     textcolor(WHITE+BLINK);
     cprintf(s);
     textbackground(BLACK);
     textcolor(WHITE);
    }
    else
    {
```

```
      gotoxy(x,y);
      cprintf(s);
      }
    }
  void print_line(FILE *fp,char *s,int n)
   {
    int i;
    fprintf(fp,"\n");
    for(i=1;i<n;i++)
    fprintf(fp,"%s",s);
   }


float slope(float *a,float *b,int n,float aa)
{
  int i;
  float bb,bb1,bb2;
  for(i=0;i<n-1;i++)
    {
    if(aa<=*(a+i) && aa>=*(a+i+1))
    {
    bb=(*(a+i)-*(a+i+1))/(*(b+i)-*(b+i+1));
    bb1=(*(a+i-1)-*(a+i))/(*(b+i-1)-*(b+i));
    bb2=(*(a+i+1)-*(a+i+2))/(*(b+i+1)-*(b+i+2));
    break;
    }
    }
    return((bb+bb1+bb2)/3.0);
 }
```

APPENDIX - C

```
C     PROGRAM FOR ANALYSIS OF MOISTURE CONTENT BY WARRICK'S
C     MODEL
      REAL K(104),H(104),THE(104),PHY(104),KS,X(104),W(104),K
      CHARACTER*10 NULL
      WRITE(*,*)'Input file :'
      READ(*,*)null
      OPEN(1,FILE=NULL,STATUS='OLD')
      WRITE(*,*)'Output file :'
      READ(*,*)NULL
      OPEN(2,FILE=NULL,STATUS='NEW')
      READ(1,*)N,R,Z,T,Q
C     N NO. OF OBSERVAION
C     R HORIZONTAL RADIUS
C     Z VERTICAL DEPTH
C     T TIME OF RUN
C     Q DISCHARGE RATE
      DO 10 I = 1,N
      READ(1,*)THE(I),H(I),ZR,K(I)
10    H(I)=10**H(I)
C     K  UNSATURATED CONDUCTIVITY
C     H  PRESSURE IN CM
C     THE VOLUMETRIC MOISTURE CONTENT
      slnk=0
      sh=0
      shlnk=0
      sh2=0
      do 20 I = 1,N
      SLNK=SLNK+ALOG(K(I))
      SH=SH+H(I)
      SH2=SH2+H(I)*H(I)
20    SHLNK=SHLNK+H(I)*ALOG(K(I))
      ALPHA=N*SHLNK-SH*SLNK
      ALPHA=ALPHA/(N*SH2-SH*SH)
      K1=EXP((SLNK-ALPHA*SH)/N)
      DO 30 I = 1,N
      PHY(I)=K(I)/ALPHA
30    WRITE(*,*)PHY(I)
      RB=ALPHA*R/2
C     RB NORMALISED R
C     ZB NORMALISED Z
      ZB=ALPHA*Z/2
      READ(1,*)THES,KS
C     THES SATURATED MOISTURE CONTENT
C     KS SARURATED CONDUCTIVETY
      THEI=THES-.02
C     THEI THETA

C     THEK K VALUE FOR THETA
      CALL INTPOL(THEI, THE,K,N,THEK)

1     DK=KS-THEK
      DTHE=THES-THEI
C     SK DK/DTHETA
```

```
      SK=DK/DTHE
C     TB NORMALISED TIME
      TB=ALPHA*SK*T/4
      RHO=SQRT(RB*RB+ZB*ZB)
      READ(1,*)(X(I),W(I),I=1,15)
      S=0

C     RHOE RHO VALUE PUTTING ZB=ZB+X(I)/2
      DO 50 I = 1, 15
      RHOE=SQRT(RB*RB+(ZB+X(I)/2)**2)
      U=RHOE/(2*SQRT(TB))+SQRT(TB)
      V=RHOE/(2*SQRT(TB))-SQRT(TB)
      CALL ERFC(U,T1)
      CALL ERFC(V,T2)

      PHIB1=(EXP(ZB+X(I)/2)/(2*RHOE))*(EXP(RHOE)*T1+EXP(-RHOE)*T2)
50    S=S+W(I)*PHIB1
C     PHIB1 NORMALISED POTENTIAL PUTTING ZB = ZB+X(I)/2

      U1=RHO/(2*SQRT(TB))+SQRT(TB)
      V1=RHO/(2*SQRT(TB))-SQRT(TB)

      CALL ERFC(U1,T3)
      CALL ERFC(V1,T4)

C     PHIB NORMALISED POTENTIAL FOR BURRIED SOURCE
C     PHI NORMALISED POTENTIAL FOR SURFACE SOURCE
      PHIB=(EXP(ZB)/(2*RHO))*(EXP(RHO)*T3+EXP(-RHO)*T4)
      PHI=2*PHIB-S

      PHIS=PHI*ALPHA*Q/(8*3.141)
C     PHIS POTENTIAL FOR SURFACE SOURCE

      CALL INTPOL(PHIS,PHY,THE,N,THETA)
      CALL INTPOL(PHIS,PHY,K,N,KTHE)
      KS=KTHE
      THES=THETA
      IF (THES-THEI .GT. 0.02) GOTO 1
      WRITE(*,*)THETA
C     THETA MOISTURE CONTENT AT POINT (R,Z) FOR TIME T
      STOP
      END
      SUBROUTINE INTPOL(R,X,Y,N,Q)
      DIMENSION X(N), Y(N)

      Q=0
      DO 240 I = 1,N
      P=1
      DO 235 J = 1,N
      IF (J.NE.I) P=P*(R-X(J))/(X(I)-X(J))
235   CONTINUE
240   Q=Q+Y(I)*P
      RETURN
      END
      SUBROUTINE ERFC(V1,EV1)
      SV1=1/V1
      DO 100 I =2,50
```

```
      KV=2*I-3
      P=1
      DO 95 J = 1,KV,2
95    P=P*J
      VT=((-1)*(I-1))*P/(2**(I-1))*(V1**(2*I-1))
100   SV1=SV1+VT
      EV1=(1/SQRT(3.14))*EXP(-V1**2)*SV1
      RETURN
      END
```