FIELD CALIBRATION OF A CPN HYDROPROBE EMPLOYED TO STUDY THE HYDROLOGICAL PROPERTIES OF A LATERITIC SOIL

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

MASTER OF SCIENCE IN AGRICULTURE

[AGRICULTURAL CHEMISTRY, SOIL SCIENCE AND BIOCHEMISTRY]

BY

Prodeep Kumar Rath

Department of Agricultural Chemistry,
Soil Science & Biochemistry
COLLEGE OF AGRICULTURE
Orissa University of Agriculture and Technology
BHUBANESWAR

1991

THESIS ADVISOR Dr. C. MISRA

DEDICATED TO
MY BELOVED PARENTS

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APPROVED BY :

1. CHAIRMAN : 13/7/9

3. EXTERNAL : 13.7.9

2. MEMBER :

4. MEMBER : 13-7-92

DR. C. MISRA, Ph.D. (California)
Professor of Soil Physics
Orissa University of Agriculture
and Technology
Bhubaneswar

CERTIFICATE

Certified that the thesis entitled **"FIELD CALIBRATION OF A CPN HYDROPROBE EMPLOYED TO STUDY THE HYDROLOGICAL PROPERTIES OF A LATERITIC SOIL"** submitted in partial fulfilment for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (Agricultural Chemistry, Soil Science and Biochemistry)** of Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of the bonafide research work carried out by **Sri Pradeep Kumar Rath**, under my constant supervision and guidance and that no part of the thesis has been submitted in any form for award of any other degree or diploma. It is further certified that all possible helps and sources of information, availed of during the course of this investigation, have been duly acknowledged by him.

(C. MISRA)
1.5.92

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Pradeep Kumar Rath
7.5.92
(PRADEEP KUMAR RATH)

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FIELD CALIBRATION OF A CPN HYDROPROBE EMPLOYED TO STUDY THE HYDROLOGICAL PROPERTIES OF A LATERITIC SOIL

A B S T R A C T

Field experiments were conducted during 1991-92 at the lateritic (Typic haplustult) upland site of the Central Research Station, Orissa University of Agriculture and Technology, Bhubaneswar (20°15'N, 85° 50'E an 26 m altitude), Orissa, India, in order to calibrate a neutron hydroprobe using different access pipes and to study the hydrological properties of the soil in the experimental site employing this instrument. For this purpose a CPN neutron hydroprobe was calibrated in bare field condition in which Hg-H_2O tensiometers had been installed in order to measure soil water pressure head, h (c.m), changes in the soil.

Insitu hydraulic conductivity, K (θ) was determined based on the internal drainage method for the evaporating profile that had been brought to near saturation employing both tensiometric and Libardi et al.'s method.

The soil, classified as a Typic haplustult, is a sandy loam up to 60 c.m and sandy-clay loam between 60-105cm. depths. It was acidic (pHw 5.1) having low values of CEC (4 meq/100 gm soil) and organic carbon (0.45%). The steady

state volumetric water content, θ, was 0.27 cm^3/cm^3 for the entire profile and steady state hydraulic conductivity, K(θ), was 0.55 cm/h. and 1.23 cm/h. as inferred by the tensiometric and Libardi _et al_.'s method respectively for the 90 cm. soil depth.

The calibration curves for the CPN neutron hydroprobe (which is a plot of count ratio and soil water content for different access pipes) are described by the following linear relationship

Aluminum : For soil layer 7.5 - 97.5 cm.

$$C.R. = 0.01 + 6.58\,\theta;\ r = 0.92^{**}\ (n=48)$$

GI (thick gauge) : for soil layer 7.5 - 97.5 cm

$$CR = 0.11 + 5.16\,\theta;\ r = 0.84^{**}\ (n=52)$$

PVC : For soil layer 7.5 - 67.5 cm.

$$CR = 0.25 + 3.09\,\theta;\ r = 0.92^{**}\ (n=39)$$

GI (thin gauge): For soil layer 7.5 - 67.5 cm.

$$CR = 0.27 + 4.11\,\theta;\ r = 0.88^{**}\ (n=39)$$

for bare land conditions.

Stemming from the insitu measured θ, inferred from the calibration curve (neutron hydroprobe) and tensiometer readings (h), the soil water characteristic curve for the entire profile (0-90 cm.) was observed to be representd by

$$\theta = 0.27 \exp(-0.0015\,h);\ r = 0.84^{**}$$

An exponential formulation

$K = Ko \exp [\alpha(\theta - \theta o)]$, where Ko and θo are the mean steady state values of K and θ respectively, could be used to successfully predict the soil water flux below 90 cm soil depth upto 490 h. The hydraulic conductivity, K (θ) based on Libardi _et al_.'s (1980) method could be formulated as

$K (\theta) = 1.23 \exp [120 (\theta - 0.27)]$ and that based on the tensiometric method as

$K (\theta) = 0.55 \exp [73 (\theta - 0.27)]$.

CHAPTER I

INTRODUCTION

INTRODUCTION

1.1. Soil Water :

Water is one of the most important input for agricultural production. Water required for plant growth is met from that stored in the rootzone with in the soil. In high rainfall areas and temperate regions, soil water is continuously replenished with rainfall and is therefore not a major constraint for agricultural production. But due to low and erratic rainfall in arid and semiarid regions, water scarcity is a serious problem for agricultural production. Agricultural production can be increased with efficient use of soil water even when it is available in limited amounts.

1.2. Role of soil waterin growth of crops :

Water is the principal constituent of all the living organisms, plants and animals. It is one of the governing factors of plant growth. Respiration of roots, microbial activity and many other physio-chemical processes in the soil system are regulated by the availability of soil water. Soil water is also the medium for the availability and uptake of nutrient from soil by the plants and hence is indispensabel for their survival and growth of green plants.

Scarcity of watch reduces crop yield in arid and semiarid regions. Supply of water through irrigation/rainfall helps enhace the growth and production of crops suffering due to water scarcity.

1.3. Importance of soil hydrological properties :

Knowledge of the hydrological properties and behaviour of the field soil is useful for determining the amount of irrigation as well as fertiliser required during crop growth. The magnitude of spatial variation in field measured soil water properties will also guide to more precisely predict the salt and plant nutrient loss form the rootzone of the crop plants. Richards *et al*. (1956) and other workes have demonstrated the reliability and usefulness of field measurd hydraulic properties of soil. Many workers have used field measured K (Θ) function for determining recharge/percolation amounts across deeper soil layers to/from crop rootzone as well as the size of the root sink in the case of field crops. The importance of the knowledge of hydrological properties has been well recognised in irrigation planning, land reclamation, fertiliser management and environmental pollution control.

1.4. Method of measurement of soil water :

Gravimetric sampling is the trditional, direct, time consuming and destructive method of measuring the amount of water present in a soil. This method is acceptable only when area of operation is limited and labour is cheap.

There are other indirect methods of measurement of soil water. Tensiometers are employed to measure soil water pressure which is equivalent of pressure potential energy per unit volume. It has been demonstrated that soil water pressure is dependant upon the soil water content and vice-versa. Soil watercontent can also be measured by using resistance and capacitance block using calibration curves that relate water content to either resistance or capacitance measured in the blocks. Time- domain reflectometry method measures bulk soil dielectric constant which is primerily a function of soil water content.

Among all the direct and indirect methods known for measuring the soil water content, neutron scattering method has been considered to be quite useful and acceptable. In recent times portable neutron hydroprobes are available for nondestructive soil water measurement under field situations. This instrument can provide reliable and rapid soil water content data at the desired depth and time. With the aid of such equipment, the effect of various water management and conservation practices, on variable plant population and geometry can be quantitatively and quickly evaluated.

A calibration curve is needed to convert the neutron counts, measured with a neutron hydroprobe, to water content. However a calibration curve is generally expected to be valid only for a given soil type for which it has been developed. Greacen et al. (1981) and others have reviewed the methods used for calibration of neutron hydroprobes. Jena (1985) has demonstrated that the calibration curve derived for a bare soil is not fully suitable for a cropped field on account probably of the changing biomass content in the rootzone of growing crops.

Aluminum, aluminum alloy, brass and stainless steel pipes are among the most commonly used materials as access pipes employed for the descent of the neutron probe. Eales (1969) demonstrated that aluminum is the most transparent material to thermalised neutrons. However, efforts do not appear to have been made for rating other materials such as galvanised iron and PVC used as access pipes.

1.5. Objectives :

* The objectives of the present study were to calibrate a CPN hydroprobe using access pipes made up of different materials viz. aluminum, PVC, galvanised iron (thick gaze) and galvanised iron (thin gaze) installed in the field.

* Determine soil water flux and hydraulic conductivity of the soil profile as a function of soil water content and depth by insitu methods.

* Attempt to verify if the calibration curves derived from a bare soil profile can be validly employed to assess soil water content, under cropped situations.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE AND THEORETICAL DEVELOPMENTS

2.1. Soil Water :

The term soil water refers to the water present and moving within the soil matrix. The physical behaviour, measurement and management of soil water is of great interest and importance for the soil physicist, hydrologist, irrigation scientist and the meteorologist. The modern dynamic concepts of soil water has emerged and developed through the contributions of Buckingham (1907), Green and Ampt (1911), Richards (1931). Childs and Coolis George (1950) Gardner (1956), Bruce and Klute (1956) Nielsen et at. (1973) an others.

2.2. Soil water content :

Soil water content is presently expressed on volume basis cm^3/cm^3 in preference to the mass basis (g/g). The two expressions are related to each other by means of the bulk density 0 = W (Pb/Pw) where 0 is the volumetric water content cm^3/cm^3, W, the gravimetric water content (g/g), Pb, the bulk density and Pw, the density of water.

Soil water content is one of the governing factors of plant growth. Other soil properties like gaseous exchange at the soil surface that affect root respiration and microbial growth, also depend upon soil water content. The wettest possible condition of the soil is saturation point, when all the pores are filled with water and the driest possible condition is the "Oven dry" state.

2.2.1. Measurement of soil water content :

The need of determine the amount of water contained in the soil arises frequently in many agronomic, ecological and hydrological investigations to understand the soil's mechanical, hydrological, chemical and biological relationship. There are direct and indirect methods for measurement of soil water content (Gardner, 1965).

2.2.1.1. Direct Method :

Gravimetric sampling is the direct and most commonly adopted method for the determination of soil water content. In this method samples are taken from the field by augering, dried in the oven at 105°C for 24 hrs or longer until constant weight is attained. The difference in the initial and final weights is expressed as a fraction of unit of dry soil mass. An alternative method to drying is to impregnate the sample in a heat resistant container with alcohol, which is then burnt leading to vaporisation of the water present, (Bouyoucos, 1937).

The gravimetric method is laborious and time consuming. The standard method of oven drying is itself arbitrary.Some clays may still contain appreciable amount of adsorbed water(nutting, 1943) which escapes very slowly even when dried at 105°C. The sampling method is destructive and may disturb an experimental plot sufficiently so as to distort the experimental findings.

2.2.1.2. Indirect Method :

There are a number of indirect methods for measurement of soil water content. The modern indirect methods have emerged and developed by Gardner (1965), Holmes (1956), Van Bavel (1963) and Dalton et al. (1984).

2.2.1.2.1. Tensiometric Method :

Watermoves in soil from areas of high to low hydraulic potential.Tensiometers are employed to record soil water pressure potential.

In soil water studies, hydraulic potential of water is usually expressed as the equivalent of height (H) of water per weight of unit volume of water (Pg) and it is called hydraulic potential head such that H = h + z Where H is total hydraulic head (cm), h, the pressure head and z, the gravitational head. Under saturated conditions, the pressure head (h) is zero or positive and can be measured with either tensiometers or Piozometers; under unsaturated conditions, however, it is negative and is measured with tensiometers. Gardner (1920) showed how the soil water pressure (potential) head is related to soil water content. Richards (1931) developed the tensiometer for measuring soil water pressure potential insitu.

2.2.2.2. Use of resistance and capacitance Blocks :

These methods are based on resistance on capacitance measurements made using two metal conductors imbeded into a porous material either made of gypsum (Bouyoucos and Mick, 1940) or nylon (Colman and Hendrix, 1949). The blocks are placed at differnt soil depths and measuring sites of interest. An equilibrium exists between water within the porous blocks and water in soil. Soil water content can be measured indirectly with these porous blocks using calibration curves that relate water content to either resistance or capacitance measured.

2.2.2.3. Time-domain reflectometry :

The newly developed time-domain reflectometry (TDR) measures the bulk soil dielectric constant. It has been shown that the soil dielectric constant is primarily a function of soil water content, but only weakly dependant on soil type, soil density, soil temperature and salt content (Toppand Davis, 1985). Measurements of soil water content with this method gives high correlation when compared to gravimetric sampling (Topp et al. 1984). T.D.R. can also measure bulk soil electrical conductivity along with soil water content (Dasberg and Dalton, 1985).

2.2.2.4. Gammaray absorption :

The gammaray absorption method is used mostly in the laboratory, where the dimension and density of soil sample, as well as the ambient temperature, can be precisely controlled. A double probe gamma-ray method has also been adopted to field use (Vomocil, 1954). This technique offers several advantages over the neutron moisture meter in that it follows much better depth resolution in measurement of soil moisture profile, sufficient to detect discontinuities between profile layers as well as movements of wetting fronts and conditions prevailing near the soil surface. Disadvantage is accurate installation in the field and determination of soil bulk density as it might vary in depth and time and the health hazard associated with exposure to Gamma radiation.

2.2.3. Neutron Scattering : ✓

This method, first developed in the 1050s, has gained widespread acceptance as an efficient and reliable tecnique for monitoring soil moisture in the field (Holmes, 1956, Van Bavel, 1963). It's principal advantages over the gravimetric method are that it is less laborious, more rapid, non-destructive and periodically repeatable measurements, in the same locations and depths avoiding many possible errors. This method is practically independent of temperature and pressure of soil water.

It's main disadvantages, however, are the high initial cost of the instrument, low degree of spatial resolution, loss of accuracy in measuring moisture in the soil surface zone and the health hazard associated with exposure to neutron radiation.

2.2.4 Neutron Source :✓

Barrada (1980) has presented details of nuclear reactions leading to the production and detection of neutrons. Neutron flux is produced according to the following reaction.

$${}_{2}He^{4} + {}_{4}Be^{9} \rightarrow {}_{0}n^{1} + {}_{6}C^{12} + 5.6 \text{ MeV}. \quad ....(I)$$

For best use of short range α particles ${}_{2}He^{4}$, a fine powder of beryllium is thoroughly mixed with a small amount of radioactive material, and the mixture is compressed to approximate a point source. Ra-Be is a commonly used neutron source, but has the disadvantage of a high γ/n ratio. Now-a-days Am-Be gained much importance owing to low γ/n ratio that results in the emittance of very weak γ photons.

2.2.5. Properties of neutrons :

When a source of fast neutrons are placed in a medium, the neutrons collide with nuclei of surrounding atoms and are scattered randomly in all directions. Such collisions thermalise the neutrons. This thermalisation process continues until the kinetic energy approaches the average kinetic energy of atoms in the scattering medium. The average energy loss by a fast neutron is much greater, in collisions with atoms of low atomic weight than in collisions involving heavier atoms (Gardner and Kirkham, 1952). In a soil system hydrogen is the most effective neutron moderator. On an average, only 18 collisions are needed to thermalise a neutron. Thus a relationship could be established between the soil water content per unit volume and the number of slow neutrons arriving per unit time at the detector.

2.2.6. Slow neutron detector :✓

Borontrifluoride (BF_3) tubes are widely used as slow neutron detector based on the following reaction :

$$_5B^{10} + {}_on^1 \rightarrow {}_3Li^7 + {}_2He^4 + 2.78 \text{ Mev.} \quad .....(II)$$

To achieve high measurement efficiency, detection tube is made relatively large in volume (50-100 cm^3); and is filled with about 96% $_5B^{10}$ enriched BF_3 gas to benefit from the large cross section of this isotope.

2.2.8 Resolution of the neutron hydroprobe :✓

The sphere of influence of the neutron hydroprobe varies with the soil water content. Its radius is confined to a minimum of about 15 cm. in water and a maximum of 40 cm. in very dry soil. The use of the depth probe to measure the moisture content of the top soil layer is difficult in low resolution, because, an appreciable amount of the neutron escape to the air. The use of a special calibration curve may enable one to make measurements between 0 - 15 cm. of the surface zone. The following equation can be used to obtain a rough estimate of the diameter of the sphere of influence of the neutron probe :

$d = 30\ (100/\theta)^{1/3}$. Where θ is the volumetric water content and d is diameter of volume of influence in cm. (Jena, 1985), Ph.D.thesis).

2.2.8. Calibration of the neutron hydroprobe :

The neutron hydroprobe has become popular as a dependable instrument for assessing changes in soil water content in the field. When an accurate calibration curve is used, neutron hydroprobe gives many significant advantages.

Greacen et al. 1981, have reviewed the methods used in calibration of neutron gauges and discussed various sources of errors encountered in the calibration. Neutron scattering technique is used to measure the soil water content for calculating the percolation loss of water below the root zone.

Shachori et al. (1967) observed that this technique offers difficulty in rocky soils. Correlation coefficients of the calibration curves, may some times be very low, particularly in gravelly soils. This is attributed to field heterogeneity and inherent problems associated in gravimetric water content measurements in gravelly soils (Babalola, 1978), Lal (1977), studied the effect of concentration and size of gravel in relation to neutron hydroprobe calibration. Misra (1990) observed that correlation coefficients of the calibration curve may be low due to high organic carbon content. Several factors like growing roots (organic matter content), above ground crops conopy, change in soil bulk density, lining of the access tube outer wall with hydrated ferric oxide etc. may result low correlation coefficient, when a calibration curve under bare soil condition is used in a cropped field (Jena, 1985).

Field calibration relations carry combined errors arising from field soil heterogeneity and compaction of volumetric soil samples. The following sources of errors are most important in field calibration procedure.

* Soil water content measured by direct soil sampling does not necessarily represent soil water content within the sphere of influene of a neutron gauge.

* Volumetric soil samples needed for calibration may

be compacted at some level but there are no easy means of measuring or estimating the resulted error.

* The field calibration relation is influenced by soil horizons which differ in chemical composition and soil bulk density (Lal, 1974, Marais & Smith, 1960, Gardner, 1965).

Also, the measurement of soil water by neutron scattering is associated with many practical problems. Several designs of the instrument are available and a number of valuable critical evaluations have been published listing their advantages and disadvantages (Schultz, 1967).

Despite all the methods proposed one can face problems with same type of instrument for different types of soil (Normand, 1973). The manufacturers generally supply a curve/a set of curves which can be used for taking the effect of density into account and which represents the calibration for a standard soil. This primary calibration usually has to be corrected when a new soil is to be investigated. Vachaud et al. (1973), Calibrated the neutron probe by taking gravimetric soil samples combined with gamma gauge scanning, and also by neutron scattering measurements of the soil cross section.

At a given level, in a given soil, neutron measurements show considerable scatter. This is due to the non-uniformity of the soil insitu and to the small volume explored by the probe during each measurements. Cardon (1973) studied the variation in measurements for three different levels. Cardon (1973) also measured the change in soil water content of the profile down 2 m soil depth under two different graminaceous crops with the help of the neutron hydroprobe. He calculated the evapotranspiration for both the crops. The reslts obtained were in agreement with the data obtained from a weighable evapotranspirometer.

Sharif et al. (1973) calibrated the neutron probe in the field. There was a linear relationship between the counts and the moisture content. They used gravimetric method for moisture measurement in the top layer.

Vachaud et al. (1977), showed that the theoretial calibration was well suited for determining the calibration curve of clay soils and of heterogeneous gravelly soils for which field calibration may present difficulties.

Paltineanu et al. (1973), used two neutron moisture probes one having Am-Be and other Ra-Be made by the Atomic Physics Institute, Bucharest, Romanic, to study the water use efficiency under different methods of irrigation.

The probe having a Ra-Be source of 10 mci can be used both for soil water content and density measurements. They calibrated the probe both under laboratory and field situations. The relationship for the calibration curve in the laboratory for the neutron probe having Ra-Be source (10 mci) is -

$y = 485.70 + 239.699\ X\ ;\ r = 0.9994$ ....(4)

Relationship for the probe having Am-Be source is

$y = 569.69 + 569.286\ x\ ;\ r = 0.999$ ....(5)

Where y = counts /100 sec

X = Soil water content (% by volume).

But under field conditions, the calibration was made in an aluminum accesstube placed in the corn plot which received no irrigation. As water was depleted from the soil by the corn Crop, soil water content was determined gravimetrically from different points. The equation for field calibration curve is :

$Y = 0.1988 + 0.1250\ X;\ r = 0.959$ .... (6)

Jena (1985) derived the mean neutron moisture meter calibration curve for the entire profile (0--90 cm) in a fallow land situation using aluminum access pipe. The equation of the calibration curve is :

$Y = 0.638 + 0.037\ X\ ;\ r = 0.91.$

2.2.9. Access pipe installation :

Aluminum, aluminum alloy, brass and stain less steel tubes are among the commonly used material for neutron access tubes. Eales (1969), discussed all aspects of access tube and their installation. The factors like soil chemistry, durability of the tubing material and depth of accss tube installation affect the choice of the tubing material, Prebble _et al_. (1981), summarised different procedures used in access tube installation, which would normally vary depending on the nature of work and soil types. Misra (1990) discussed procedures of installation of access pipes (like depth of reaching below and remaining above), site of installation in the field and the method of taking count readings.

2.2.10. ✓Use of neutron hydroprobe in hydrological and agronomical research :

Some workers believed that the neutron hydroprobe is not helpful in rocky layered soils. But once drilled it is easier to insert an access pipe than to drill repeatedly to take samples.

Hillel _et al_. (1973), employed the neutron hydroprobe for evaluating hydraulic conductivity as a function of soil water content using two methods i.e.

infiltration method and internal drainage method. The two methods gave mutually consistent results Marcesse *et al.* (1973), studied the hydrodynamic behaviour of different types of soil using an automatic neutron moisture gauge. Babalola *et al.* (1973), used neutron hydroprobe and Beta gauging technique to investigate plant water relations for maiza in western Nigeria. Depths of soil water depletion can be used as indirect means of estimating plant root activity distribution in soil profiles (Levin *et al.* 1973, Castle and Urezdon, 1977; Stone *et al.* 1976).

Mc Gowan (1973), used neutron hydroprobe and tensiometer to study the effective depth of the soil influenced by root water extraction. Dasberg *et al.* (1973), measured water distribution pattern in an orchard by neutron hydroprobe. Measurement of the soil water content by the neutron scattering showed that the water applied by irrigation does not penetrate to the whole depth of the root system, but that during the winter season rain does penetrate to the whole depth.

2.3. Energy status of soil water :

Like other physical bodies in nature, soil water also possess both kinetic and potential energy states. Due to small velocity values kinetic energy is considered negligible for moving in soil pores (Hillel, 1971), but the potential energy is determined by its position of configuration, water moves constantly in the direction of decreasing potential energy. The negative of the potential gradient governs the flow of water. Gardner (1920), showed how this potential is dependant upon soil water content.

2.3.1 Total soil water potential :

Soil water is subjected to a number fo force fields i.e. the attraction of solid matrix for water, presence of solutes and action of external gas pressure and gravitation. Ordinarily, the total potential of the soil water can be reprsented by : $H_T = H_h + H_o$ ..(7)

Where H_T = Total potential

H_h = Hydraulic potential = $H_p + H_g$

H_g = Gravitational potential.

H_p = Pressure (matrix) potential

H_o = Osmotic potential.

The hydraulic potential is the sum of the gravitational and pressure potential and usually expressed as heads measureable as centimeters of water. Therefore instead fo $H_h = H_h + H^p$. One could write.

$$H = H_t/P_g = H_p/P_g + H_g / P_g \;........(8)$$

Where P is the density of water, g, the acceleration due to gravity, H, the total potential head of soil water, z, the gravitational potential head and h, the pressure potential head.

2.3.2. Measurement of soil water potential :

Soil water potential measurements are made (Richards, 1931, Phillips, 1960) by means of gadgets like tensiometer, pressure plate and pressure membrane apparatus and soil psychrometer based on the principles of thermodynamics governing conditions of equilibrium. The tensiometer with the Hg + H_2O manometer is a simple and effective device for estimating the work required to remvoe water from soil (Richards, 1965).

2.4. Soil water characteristics curve :

Soil water characteristics curve describes the relationship between the volumetric water content, θ of a soil and the corresponding soil water pressure potential head, h.

Childs (1940) experimentally measured the function

θ (h) and represented it graphically by a curve known as the soil water characteristics curve.

Equations to describe the relationship between soil water content and matrix suction have been proposed by Visser (1966), Brooks and Corey (1966), Laliberte (1969), White et al. (1970) and Van Genuchten (1978).

Klute (1965) determined the Laboratory methods for determining soil water characteristics curve. Laboratory measured values are not necessarily reliable owing to soil structural changes under field situations (Perrier and Evans, 1961).

Soil water characteristics curve is helpful in identifying the pore size distribution, water retention and release capacity with in a soil. it is of theoretical and practical importance because, calculation of infiltration, redistribution, plant absorption, evaporation and percolation below plant roots are frequently made based upon the θ values inferred from the θ (h) curve correspondign to tensiometer readings and measured hydraulic conductivity K (θ), (Nielsen et al. 1972). With the help of the neutron hydroprobe together with tensiometers one can measure both the water content and pressure head of soil water directly in the field.

2.5. Hysteresis :

The relationship between matrix potential and soil water content can be obtained by two ways.

1. During desorption
2. During sorption.

In general, the continuous curves obtained from these two methods will not be identical because of a phenomenon termed as hysteresis. Hysteresis in the soil water characteristics was examined by Miller and Miller (1956), Topp and Miller (1966) and Topp (1969).

Redistribution of soil water following infiltration is gradually affected by hysteresis (Breseer et al. 1969, Vachaud and Thony, 1971 and Watson, 1975).

2.6. Movement of soil water under field situations :

Water movement in field soil profile is a continuously changing process (Richards, 1960). Water enters into the profile during infiltration and continues to redistribute and wet greater depths after infiltration has ceased (Davidson et al. 1969). This process continues for langer times even though the rate of movement may be smaller

(La Rue *et al*. 1968) Wateralso moves in the soil profile due to evaporation and transpiration (Rose and stern, 1967).

A neutron hydroprobe measures the change in soil water content in a field profile by allowing measurements to be taken frequently without disturbing the soil (Van Bavel *et al*. 1968).

2.7. Water flow in saturated soils :

Henry Darcy (1856) derived the steady state flow equation during investigations on seepage rates through sand filters. Slichter (1899) generalised Darcy's law for saturated porous media in to a three dimentional macroscopic vector equation of the form.

$$q = -K \nabla H \quad \ldots\ldots\ldots\ldots \quad (9)$$

Where q = Soil water flux (cm/h)

∇H = Hydraulic potential head gradient (cm/cm)

In one dimentional system the law takes the form of :

$$q = -K\, dH/dz \quad \ldots\ldots\ldots \quad (10)$$

Where H is the hydraulic head = Pressure head h + Gravity head, z.

2.8. Water flow in unsaturated soil :

Flow of water in the root zone of most crops occur under such conditions is complex; as it involves variation of soil water content, suction, hydraulic conductivity in addition to hysteresis.

Richards (1931), extended Darcy's law to unsaturated flow, with the provision that K is a function of the matrix suction head i.e. K = K (h) such that :

$$q = -K\ (h)\ dH/dz \qquad \ldots\ldots\ldots \qquad (11)$$

Where dH/dz is the hydraulic head gradient. Childs and Collies George (1950) demonstrated experimentally, that Darcy's law is also valid for describing the flow of water in unsaturated soil. But Miller and Miller (1956), pointed out that, this formulation fails to take into account the hysteresis of soil-water characteristics. However,the relation of K to volumetric water content, θ i.e. K (θ) is affected by hysteresis to a much lesser degree than is the K (h) function. Thus, Darcy's law for unsaturated soil can be expressed as :

$$q = -K\ (\theta)\ dH/dz \qquad \ldots\ldots\ldots\ldots \qquad (12)$$

using equation (12) in the equatioln of continuity

$$\partial\theta/\partial z = -\partial q/\partial z \qquad \ldots\ldots\ldots \qquad (13)$$

One can arrive at :

$$d\theta/dt = d/dz\ [K(\theta)\ dH/dz] \qquad \ldots\ldots \qquad (14)$$

Eq.14 is the basic equation that describes the soil water flow in unsaturated soil system in vertical direction under transient as well as steady state conditions. Setting $d\theta/dt = 0$ (steady state) one can show that Eq. 14 leads to Eq 12.

2.9. Field measurements of hydraulic conductivity :

Richards et al. (1956), were the pioneer workers to determine K (θ) directly in the field by the transient method using soil water pressure values measured by tensiometers and soil water content by gravimetric method. Patro (1983) observed that the laboratory measured saturated hydraulic conductivity values are entirely unrealistic in comparision to that of insitu method. Again θ (h) function derived directly in the field by means of neutron probe and tensiometer have yielded more realistic K (θ). Jena (1985) and Misra (1990) determined K (θ) by using neutron hydroprobe and tensiometer for determining θ and h respectively.

Field measured values of hydraulic conductivity as a function of soil water content can be used in soil water plant management studies. The neutron hydroprobe provides a convenient means of meauring changes in soil water content information required for inferring the hydraulic conductivity.

Under transient conditions when the flux and water content change with time Eq. 14 may be integrated for z = -z to yield a relationship helpful in the determination of K (θ).

$$\int_{0}^{-z} \frac{\partial\theta}{\partial t}\, dz = K \frac{\partial H}{\partial z}\Big|_{z=-z} - K \frac{\partial H}{\partial z}\Big|_{z=0} \quad \ldots\ldots \quad (15)$$

2.9.1. **Estimation of hydraulic conductivity by internal drainage method :**

By monitoring the transient flux and the corresponding potential gradient values withinthe profile as a function of depth and time, measurement of hydraulic conductivity can be made during internal drainage, K (θ) measurements based on this method have been reported by Rose et al. (1965), Gardner (1970), Hillel et al. (1972), Ogata and Richards (1957), Nielsen et al. (1964), Rice (1975), Rolston et al. (1976) and Vachaud et al. (1978).

In the soil profile at near saturation with surface covered to prevent evaporation, only downward flow takes place. Then the second term in the right hand side of the equation 15 vanishes, substituting (h +z) for H Eq.15 becomes :

$$\int_{0}^{-z} \frac{d\theta}{dt}\, dz = K\ (\theta)\ [\frac{dh}{dz} + 1]\ z = -z \quad \ldots.(16)$$

In order to use discrete experimental values in equation 16 one defines $\Delta\theta = (\theta_{i+1} - \theta_i)$ and $t = (t_{i+1} - ti)$ where the subscripts represent two differnt time values. The Eq. 16 can be written as :

$$K(\bar{\theta}) = \frac{1}{(t_{i+1} - t_i)\left(\frac{\partial \bar{H}}{\partial z}\right)} \int_0^{-z} \left[\theta_{i+1}(z) - \theta_i(z)\right] dz \quad \text{- - - - - .} (17)$$

2.9.2. Estimation of hydraulic conductivity by Evaporating profile method :

First Richards et al. (1956) measured the K (θ) by evaporating profile method. The soil water content was determined gravimetrically and soil water pressure by tensiometrs. They separated the zone of evaporation and drainage by "zero flux plane". The "zero flux plane" tends to move downward with time depending upon the meteorological as well as the soil conditions. The K (θ) values can be calculated by monitoring the "zero flux plane".

For $-zo < -z < -ze$

$$K(\theta) = \left[\int_{-zo}^{-ze} \frac{\partial \theta}{\partial t} dz\right] \left[\frac{\partial h}{\partial z} + 1\right]^{-1}_{z=-ze} \quad \text{- - - - - -} (18)$$

and for $-zd < -z < -zo$

$$K(\theta) = \left[\int_{-zd}^{-zo} \frac{\partial \theta}{\partial t} dz\right] \left[\frac{\partial h}{\partial z} + 1\right]^{-1}_{z=-zd} \quad \text{- - - - -} (19)$$

Where zo is depth of "zero flux plane", ze is soil depth above zo and zd is soil depth below zo.

Van Bavel *et al*. (1968) and Vachaud *et al*. (1978) observed that K (θ) values both by draining and evaporting profile methods are complementary by each other. Patro (1983) observed that K (θ) derived by internal drainage method both in presence and absence of surface evaporation are complement and suplement one another. The soil water content and pressure changes were monitored by neutron hydroprobe and tensiometers respectively.

Libardi *et al*. (1980) derived a simple field method for estimating K (θ), which assumes an exponential relationship (between K and θ) :

$$K = Ko \exp [\alpha(\theta - \theta o)] \quad ...... \quad (20$$

Where θo and Ko are the steady state water content and hydraulic conductivity respectively and α is a constant.

Also due to their assumptionof prevalence of unit gradient in an internal draining profile the Eq. 12 becomes :

$$\frac{d\theta}{dt} dz = q = -K (\theta)$$

$$\text{Or } K (\theta) = - \frac{dq}{dt} dz \quad .... \quad (21)$$

$\frac{d\theta}{dt}$ was determined based on the model $\theta = aT^b$ ...(22)

$$\text{Or } \frac{d\theta}{dt} = aT^{b-1} \quad ....(23)$$

Where T is time after steady state infiltration and a and b are constants.

Misra (1990) observed lower α values using Libardi *et al.*'s method as compared to that using tensiometric method with out the assumption of unit gradient. He concluded that the latter method is more precise than the former.

CHAPTER III

MATERIALS AND METHODS

MATERIALS, EXPERIMENTAL AND COMPUTATIONAL METHODS

3.1. MATERIALS :

3.1.1. Site and soil characteristics :

The experiments were caried out at the upland experimental site of the central research station, O.U.A.T., Bhubaneswar, Orissa, India (20° 15' N, 85° 50' E and 26 m altitude). The climate is characterised by mean maximum temperature of 38.3°C in April and May and mean minimum temperature of 15.6°C during December-January. The mean annual rainfall is 1481 mm, 77% of which is received in the month of June to Septembe. The rainfall distribution pattern is characterised by intermitant short and long dry spells. Mean relative humidity of 84% prevails during the monsoon season (Mid June-Mid October) while it remains almost constant around 70% during the rest of the year.

The soil (Murty et al., 1982) is a member of fine loamy, mixed isohyperthermic family of Typic haplustult. The A horizon is yellowish-red, very strongly acidic sandy loam. The B horizon is yellowish-red to red in colour, very strongly acidic, sandy clay loam to clay in texture. The C horizons contains vesicular laterite. The soil is developed in ferruginous sand stone of the Gondwana rock system in the district of Puri in Orissa , India.

3.1.2. Neutron hydroprobe :

The neutron hydroprobe was supplied by Campbell Pacific Nuclear Agency. It consists of a probe containing Am-Be radiation source and BF_3 slow neutron detector as well as an electronic digital counting unit. A rechargeable battery serves as the power supply.

3.1.3. Access Pipes :

for field calibration of this neutron hydroprobe, access pipes made up of four different materials wereused.

3.1.3.1. Al-uminum Pipe :

Aluminum is the most commonly used material used as neutron access pipes. The pipes used for this study had also been supplied by the CPN Agency. These pipes have internal diameter of 5 cm and wall thickness 1 mm and were smooth both internally and externally.

3.1.3.2 PVC Pipes :

These pipes were purchased from the local market. The internal diameter of these is 5.4 cm and wall thickness

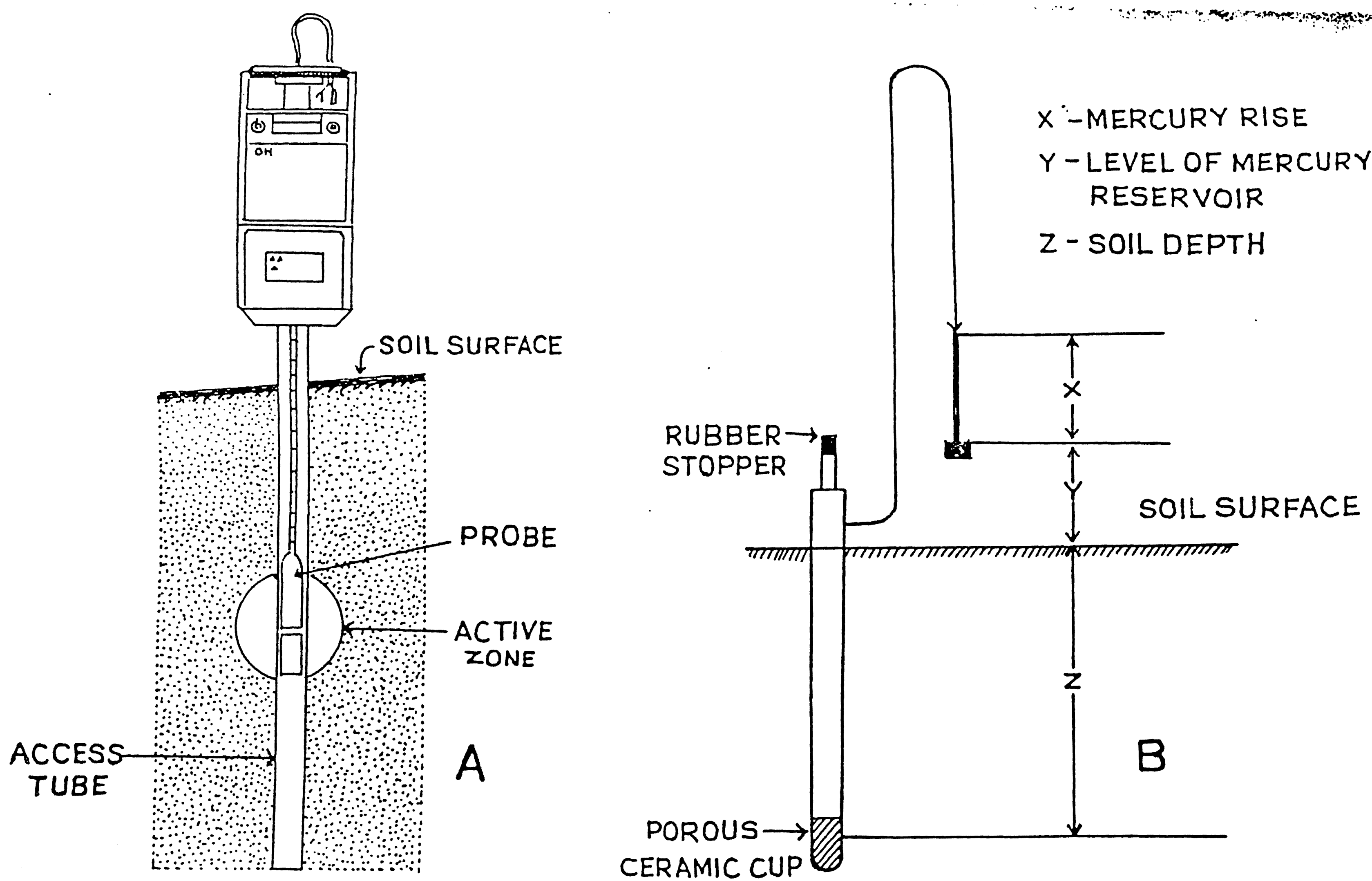
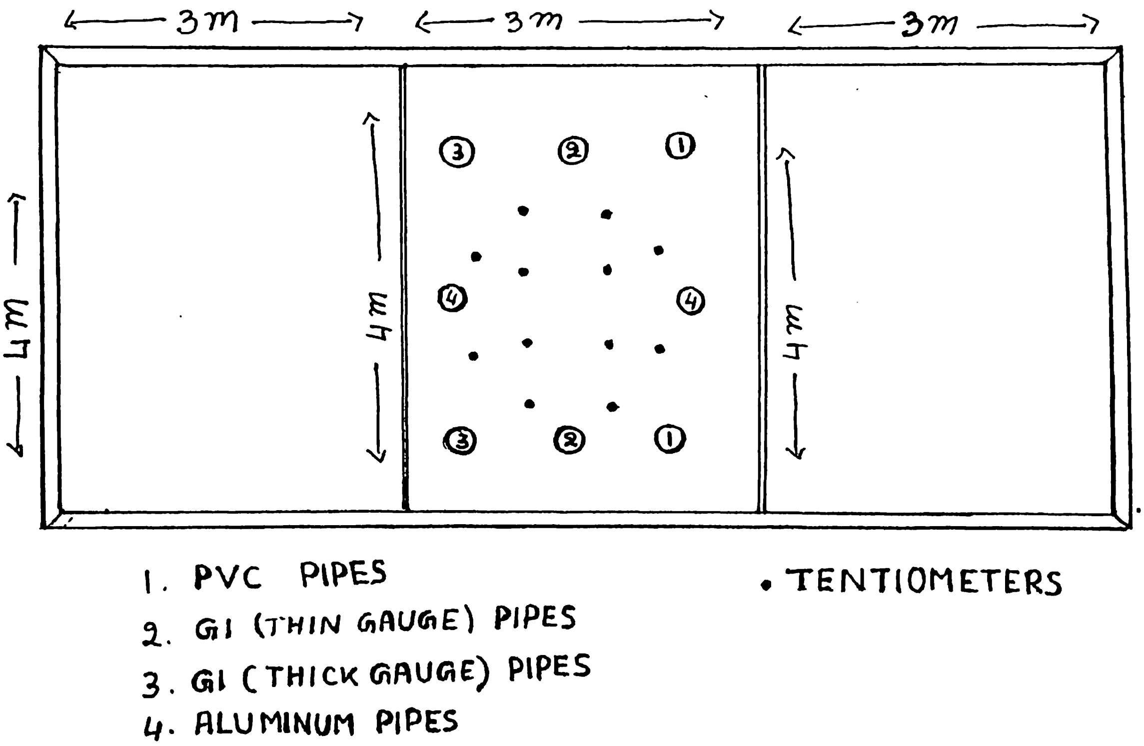


Fig.1: Shematic view of (A) CPN neutron moisture meter and (B) mercury water tensiometer.

CPN HYDROPROBE IN THE FIELD

Fig. 2. Schematic view of tensiometers and access pipes as installed in the field site



3 mm. Pipes were smooth both internally and externally.

3.1.3.3. Galvanised iron (GI) thick gaze pipes :

These were heavier and harder than the aluminum pipes, purchased from the local market. Internal surface was not smooth. Their internal diameter was 5.4 cm. and thcikness 3 mm.

3.1.3.4. Galvanised iron (GI) thin gaze pipes :

These pipes were prepared from thin sheets of GI purchased from the local market. These were thin and smooth both internally and externally. Diameter of the pipes were not eutiely uniform. The mean internal diameter was 6.2 cm. and wall thickness 1 mm.

3.1.4. Tensiometers : (Construction testing and installation)

Hard PVC (poly venyl chloride) pipes (1.5 cm. internal diameter and 0.2 cm wall thickness) and porous ceramic cups (5 cm. long, 1.5 cm internal diameter) supplied by M/S Agro-instruments Corporation, Calcutta, were used in preparing tensiomenters. The tensiometers were installed to have their cups reach the soil depths of 15, 30, 50, 65, 90 and 105 cm. The neck portion of the ceramic cups were inserted ad sealed into one of the smooth-end of the pipes using araldite gum. PVC tubing 2 mm I.D. obtained from the dofpen refill manufaturing factory was glued into a small hole drilled near the other end of the pipes (Fig. 1) so as to serve as manometers.

To test the sensitivity and functioning, tensiometer of equal length were clamped on a stand. Then it is filled with deaerated distilled water and the free ends of the nylon tubings were dipped into a mercury reservoir. Top ends of the tensiometers were closed with No.4 rubber stopper. The tensiometers registering rise of mercury (due to evaporation of water through the porous cups) to equal heights were selected and their cups were dipped in water. This caused the mercury column to fall off in a short while to the levels predictable by hydrostatics. In this way tensiometers of different lengths were tested for sensitivity and installed in the field reaching 15, 30, 60, 90 and 105 cm soil depths. A tube auger of bore slightly larger than that of the tensiometer pipe was used to dig vertical holes. The soil collected was used to pack up the gap nearly to the field bulk density, after tensiometer pipes were planted. The mid plane of the cups corrosponded to the depth desired. The tensiometer pipes werefilled with deaerated distilled water and the free ends of the nylon tubings were dipped in mercury reservoirs. After filled with water, the top ends of the tensiometer were closed by No.4

rubber stoppers and then sealed with parffin wax. If air bubbles were observed inside the nylon tubing (due possibly to gaseous diffsion through the joints), then the tensiometers were reserviced by sucking out such entrapped air and refilling the whole sysem with deaerated water.

One mercury reservoir was used for a set of two or more manometers reaching the same depth. Half meter scales were fixed behind each mercury reservoir as to facilitate recording of the height of mercury rise in the manometer. Schematic views of the CPN hydroprobe and Hg-H_2O tensiometer are presented in the Fig.1.

3.2. EXPERIMENTAL PROCEDURE :

3.2.1. Calibration of CPN neutron hydroprobe using access pipes of different materials :

Three small (4x3m) adjacent field plots were selected for this purpose. These plots were separeated from each other by 15 cm. height earth bonds in order to store water and to prevent surface runoff .

3.2.2 Access pipe installation :

All aspects of access tubes and their installation have been discussed by Eales (1969). For the present study access pipes of aluminum, PVC, GI (thick gaze) and GI (thin gaze) were installed.

Bottom ends of the access pipes were closed with suitably tappered wooden plugs. Top ends were kept covered with a polythene cap to avoid entry of rain water.

The following steps were followed for the access pipe installation.

* Access pipes were placed on the site selected for installation of the access pipes.
* 12-15 cm. was drilled with hand auger and auger is withdrawn. Then a GI guiding tube inserted to the depth the auger had reached and was placed vertically.
* With the hand auger again 12-15 cm depth was drilled and auger was withdrawn. Then the guiding tube was hammer down to the bottom of deepened hole.
* Loose soils were taken out with the auger through the guide tube.
* This process was continued till the required depth was reached.
* After the guiding tube reached the required depth, it was with-drawn with care so as to prevent widening of the auger hole.
* Then the access pipe was inserted by pressing gently into the hole dug in the soil as already

described in to the depth of 90 cm for aluminum and GI (thick gaze) and 60 cm for PVC and GI (thin gaze) pipes.

* The pipes so installed remained 20-30 cm. above the ground level in this manner access pipes of aluminium, PVC, GI (thick) and GI (thin) gaze were installed in the middle plot.

Hg-H_2O tensio-meters wer installed in duplicate at 15, 30, 50, 65, 90 and 105 cm depth in the middle plot. On these 3 plots, water was ponded for 3 consecutive days till all the tensiometes reaching different depths registered time invariant Hg rise values in the manometers. Soon after wards, the neutron hydroprobe readings were taken to begin with, mounting neutron hydroprobe as such on a pipe, 3 consecutive readings were taken. Average of the three readings was taken as the standard count. Then the neutron hydroprobe readings were taken at 15 cm., 30 cm, 60 cm, 90 cm. These counts represented the soil layers of 7.5-22.5 cm., 22.5-37.5 cm, 52.5-67.5 cm, 82.5-97.5 cm respectively.

Three neutron counts were taken at each of the 15, 30, 60, 90 cm soil depth (average of the 3 is observed count) and it was considered that these counts stemmed from scattering of neutrons from a soil sphere of radius 7.5 cm. at each of the depths. While taking the neutron gaze counts, soil samples from 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, layers were collected for the determination of water contents. Soil samples were collected one each from both the plot from the above said depths and were homogenised before oven drying for water content determination by gravimetric method.

Together with neutron hydroprobe readings for different access pipes, tensiometer readings were recorded at 0, 15, 30, 50, 65, 90 and 105 cm after the start of the experiment. Volumetric water content θ (cm^3/cm^3) for different depths with time were calculated based on the relationship.

$\theta = D_b \times W$ .... (20)

$W = W_2 - W_3 / W_3 - W_1$ where W_1 is weight of moistur box, W_2 is weight of moisture box + Weight of soil, W_3 is weight of moisture box + oven dry soil and D_b is the bulk density (gm/cm^3) W is the gravimetric water content (gm/gm). D_b values were taken from Patro (1983) Ph.D Thesis. Utkal Univesity, Vanivihar, Bhubaneswar.

Count ratio (C.R) was calculated from the observed neutron moisture meter readings C.R = observed counts/ standard counts.

The count ratio for different access pipes were derived from different θ at selected times after saturation. Values of C.R. was plotted against the volumetric water content (θ) for different depths and different access pipes and the linear regression between the two variables was expressed in the form :

$Y = a + bx$

Where Y is C.R., X is θ

The neutron hydro - meter was calibrated for different access pipes and regression equations derived for different depth.

3.2.3. Insitu measurement of hydrological properties :

3.2.3.1. Insitu soil water characterists θ (h) :

Volumetric water content (θ) inferred from smooth calibration curve was plotted versus the pressure head (h) concunrently recorded with the help of tensiometers for different soil depths and field soil water characteristics for different soil depths were obtained.

Taking the mean values of both θ and h for these different depths, a soil water characteristic curve was formulated for the entire profile. An exponential equation

(θ = a exp (-bh) was fitted to describe the over all mean water characteristic curve.

3.2.3.2. Insitu hydraulic conductivity, K(θ)

Hydraulic onductivity of the soil layer in the field was measured using evaporating profile method (Richards et al., 1956), (Arya et al., 1975a).

For this purpose the adjacent 3 plots selected earlier were utilised at the same time during which neutron readings were taken. The experiment was started with a near saturated profile. The soil surface was left uncovered in the middle plot. Tensiometers in duplicate reacing 15, 30, 50, 65, 90 and 105 cm soil depth (3.2.2.) was selected for this purpose. Water content (θ) was determined and expressed on oven dry basis taking samples from both the adjacent plots, so as not to disturb the middle plot where tensiometers had been installed. The rise of Hg in the Hg-H_2O manometers and θ cm^3/cm^3 obtained from gravematric measurement were recorded for different depths with time.

In a evaporating profile with evaporation and drainage occuring simultaneously, zones of upward and down ward flow of water are separated by a "Zero flux plane." Across this plane, water does not move either upward or down ward direction (Arya et al., 1975a) the zero flux boundary tends to move down ward with time depending upon the evaporative demand of the soil surface.

"Zero flux plane" at any depth is obtained by plotting hydraulic gradient (dH/dZ) in y axis and time of observation (hrs) in X axis. (Fig. 8).

Hydraulic conductivity at the desired depth (90 cm) at any time can be calculated by monitoring the position of "zero flux plane".

Assuming zo to be the depth of the "Zero flux Plane" (Fig. 8) and zd is the desired depth.

$$K\ (\bar{\theta}) = \left[\int_{-z_o}^{-z_d} \frac{\partial \bar{\theta}}{\partial t}\, dz \right] \left[\frac{dH}{dz} \right]^{-1}_{z = z_d} \quad \text{- - - - - (18)}$$

Where the integral in the right hand side is the soil water flux in the evaporating zone, Zo < Z < Zd.

K (θ) is the hydraulic conductivity as a function of mean soil watercontent at Zd. $\frac{dH}{dZ}$ is the hydraulic gradiant at Zd, which is unity in a internal draining profile.

Soil water content (θ) change :

Soil water content values for different soil depths were taken gravimetrically from which calibration curve was prepred for different access pipes. It was seen that soil water content decreases with time and increases with depth. A graph was plotted taking θ (cm^3 cm^3) in X axis and depth (Z) in Y axis.

3.2.3.3. Soil water flux :

Soil water flux (cm/d) below the rootzone (90 cm) is either the soil water loss by percolation on the gain by rechrge computed using Darcy's law.

$$p = q = -K(\theta)\frac{dH}{dZ} \quad .... \quad \text{(ii)}$$

P > 0 : recharge

P < 0 : Percolation down ward

Hydraulic head gradiant (dH/dZ) was calculated from the graph plotting H (h + z) against soil depth (z). This dH/dz was utilised for calculation of hydraulic conductivity (θ) based on eq. (11) computing "soil water flux" from the area of the graph plotting θ against depth (z).

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1. Soil Characterisation :

The basic physicochemical properties of the experimental site has been presented in Table 1. The soil was sandy loam in textur upto 60 cm depth and sandy clay from 60-105 cm depth. The bulk density decreased from 1.68 gm/cm^3 to 1.46 gm/cm^3 between 0-75 cm. depth and there after remained constant upto 105 cm. depth. But particle density remaiend almost constant through out the profile. The mean bulk density and mean particle density, considering the entire profile, happened to be 1.53 gm/cm^3 and 2.66 gm/cm^3 respectively. Thus the over all porosity works out to be 42.5%. The soil was strongly acidic in reaction (pH=5.1) with low organic carbon content ranging from 0.38% to 0.54%. The cation exchange capacity varied from 3.5 - 4.3 c.mol (p^+)/kg of soil indicating the dominance of Kaolinite and hydroxide intergrades.

4.2. Neutron hydroprobe calibration in bare field profile:

The ratio of mean (n=3) measured count to mean (n=3) standard count plotted against the mean (n=2) volumetric water content, θ for differnt depths, yields the calibration

Table 1.

Physical and Chemical properties of the Layes of Bhubaneswar lateritic soil profile

Soil Layers (cm)	Mechanical Composition			Textural class	B.D. (g/cm^3)	P.D. (g/cm^3)	Steady State		pHw	OC%	CEC C mol(p+)kg^{-1}
	Sand (%)	Silt (%)	Clay (%)				θs cm^3/cm^3	Ks cm^3/cm^3			
0 - 15	74.30	17.70	8.00	Sl	1.68	3.60	0.32	1.40	5.0	0.41	3.8
15 - 30	71.20	17.50	11.30	Sl	1.65	2.62	0.32	0.78	5.1	0.54	4.2
30 - 45	67.00	15.90	17.10	Sl	1.56	2.68	0.32	1.00	5.1	0.41	3.5
45 - 60	65.30	18.70	16.00	Sl	1.51	2.66	0.32	0.82	5.1	0.39	3.9
60 - 75	62.00	15.00	23.00	Sl	1.46	2.70	0.33	2.55	5.1	0.39	4.3
75 - 90	62.20	14.80	23.00	Scl	1.47	2.68	0.34	0.75	5.1	0.39	4.2
90 - 105	62.20	14.80	23.00	Scl	1.46	2.67	0.34	1.40	5.1	0.38	4.3

Source : Ph.D. Thesis, Jena (1985)

curve for the instrument. Such curves have been obtained using four different kinds of access pipes viz. aluminum, thick gauge galvanised iron, thin gauge galvanised iron and PVC pipes and have been presented in Fig.3(a) to 3(d).

4.2.1. Calibration curves for test access pipes :

Table 2 presents the values of (mean) count ratio (C.R.) and (mean) θ for different depths and time for the access pipe made up of aluminum. The resulting calibration curves have been shown in Fig. 3(a) and were represented by the following linear relationships :

Soil layer :

7.5 - 22.5 cm; C.R. = 0.28 + 7.91 θ; r = 0.94^{**} (n=12)

22.5 - 37.5 cm; C.R. = 0.32 + 5.30 θ; r = 0.90^{**} (n=12)

52.5 - 67.5 cm; C.R. = 0.24 + 5.57 θ; r = 0.83^{**} (n=12)

82.5 - 97.5 cm; C.R. = 0.06 + 6.76 θ; r = 0.89^{**} (n=12)

Lowest 'r' value of 0.83 was observed to be at 52.5-67.5 cm. soil layer indicating comparatively less uniform neutron scattering. It might be due to higher Fe content in the lower soil layers. As such, the overall relationship worked out, based on pooled data, to be :

C.R. = 0.01 + 6.58 θ; r = 0.92^{**}, (n=48)

Table 3 presents the values of mean C.R. and mean θ

Table 2.

Count ratio measured using aluminum access pipe in relation to volumetric water content in the soil layers

Time after saturation(h)	SOIL LAYER							
	7.5 - 22.5 cm.		22.5 - 37.5 cm		52.5 - 67.5 cm.		82.5 - 97.5 cm	
	θ	CR	θ	CR	θ	CR	θ	CR
0	0.24	1.84	0.27	1.95	0.27	1.90	2.27	1.86
15	0.24	1.53	0.26	1.63	0.25	1.60	0.25	1.58
24	0.23	1.50	0.24	1.65	0.23	1.61	0.24	1.62
39	0.20	1.40	0.23	1.55	0.22	1.55	0.23	1.54
48	0.22	1.41	0.23	1.54	0.26	1.55	0.25	1.55
96	0.20	1.31	0.22	1.46	0.24	1.51	0.24	1.50
136	0.19	1.22	0.23	1.43	0.23	1.46	0.23	1.47
216	0.18	1.09	0.21	1.39	0.21	1.46	0.22	1.46
297	0.16	1.01	0.21	1.38	0.22	1.44	0.23	1.48
417	0.18	1.05	0.20	1.33	0.21	1.39	0.23	1.44
490	0.16	0.91	0.18	1.30	0.21	1.38	0.22	1.45
725	0.13	0.87	0.15	1.23	0.20	1.36	0.21	1.39

Fig.3(a) Count ratio and volumetric water content using alumium pipes

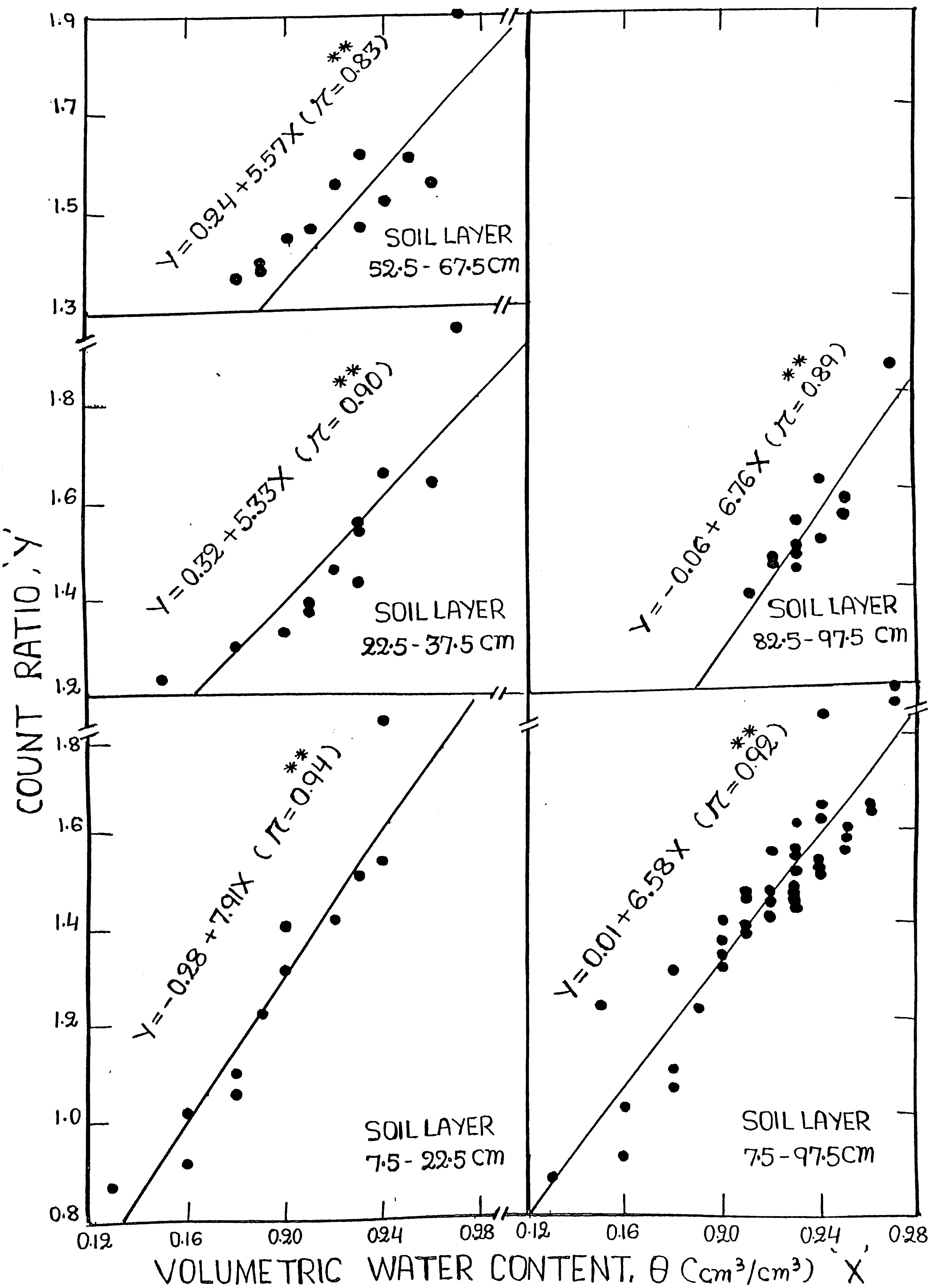


Table 3.

Count ratio measured using galvanised iron (thick gauge) access Pipe in relation to volumetric water content in the soil layers

Time(h)	SOIL LAYER							
	7.5 - 22.5 cm.		22.5 - 37.5 cm.		52.5 - 67.5 cm.		82.5 - 97.5 cm.	
	θ	CR	θ	CR	θ	CR	θ	CR
0	0.24	1.50	0.27	1.53	0.27	1.47	0.27	1.62
15	0.24	1.16	0.26	1.34	0.25	1.40	0.25	1.40
24	0.23	1.10	0.24	1.36	0.23	1.41	0.24	1.41
39	0.20	1.08	0.23	1.30	0.22	1.37	0.23	1.36
48	0.22	1.09	0.23	1.31	0.26	1.38	0.25	1.35
72	0.23	1.05	0.23	1.33	0.24	1.37	0.23	1.32
96	0.20	1.02	0.22	1.26	0.24	1.33	0.24	1.34
136	0.19	0.97	0.23	1.23	0.23	1.29	0.23	1.29
216	0.18	0.91	0.21	1.19	0.21	1.28	0.22	1.29
297	0.16	0.85	0.21	1.19	0.22	1.27	0.23	1.29
417	0.18	0.91	0.20	1.04	0.21	1.22	0.23	1.29
490	0.16	0.80	0.18	1.11	0.21	1.21	0.22	1.42
725	0.13	0.87	0.15	1.10	0.20	1.18	0.21	1.26

Fig.3(c) Count ratio vrs volumetric water content using GI thick gage pipe

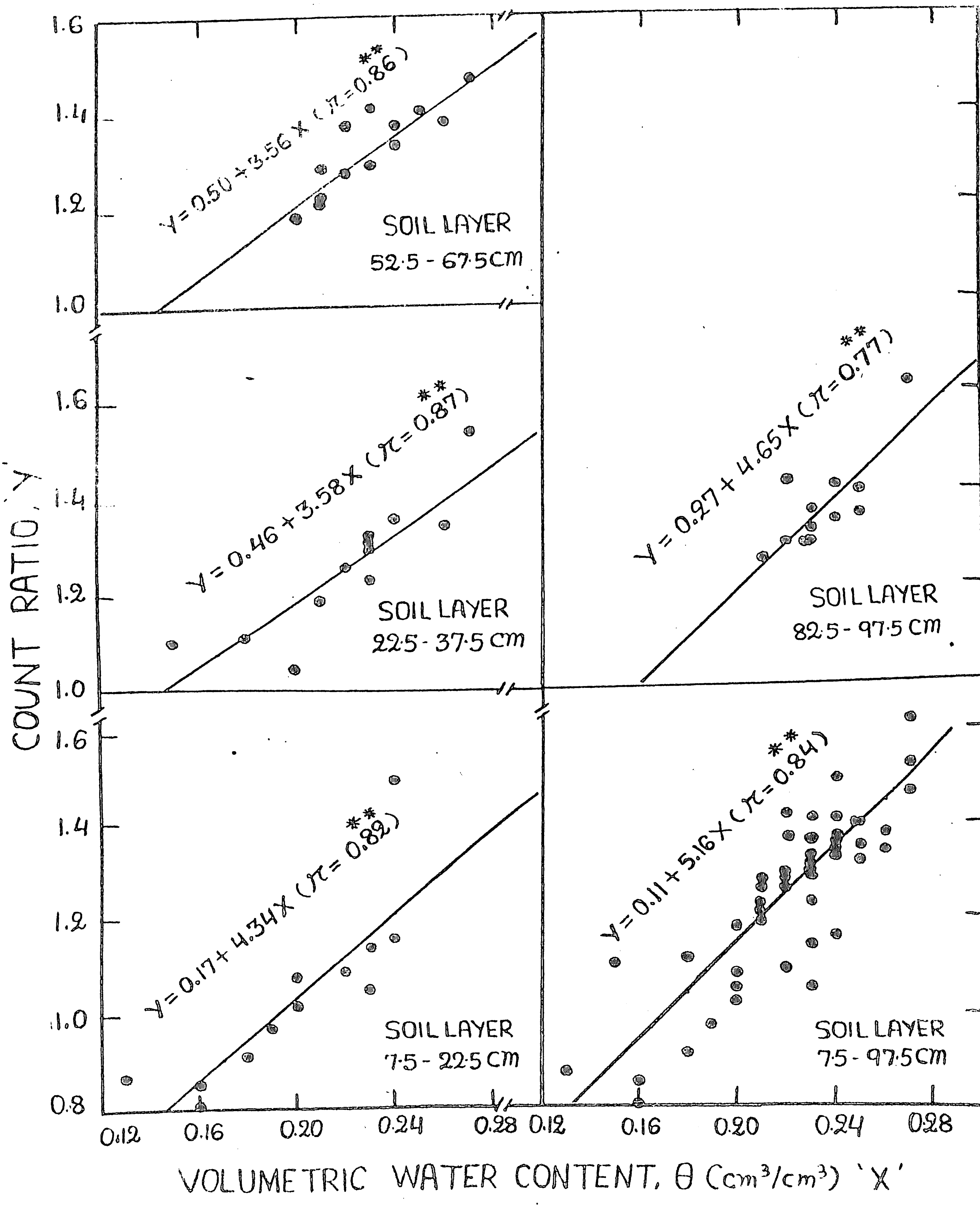
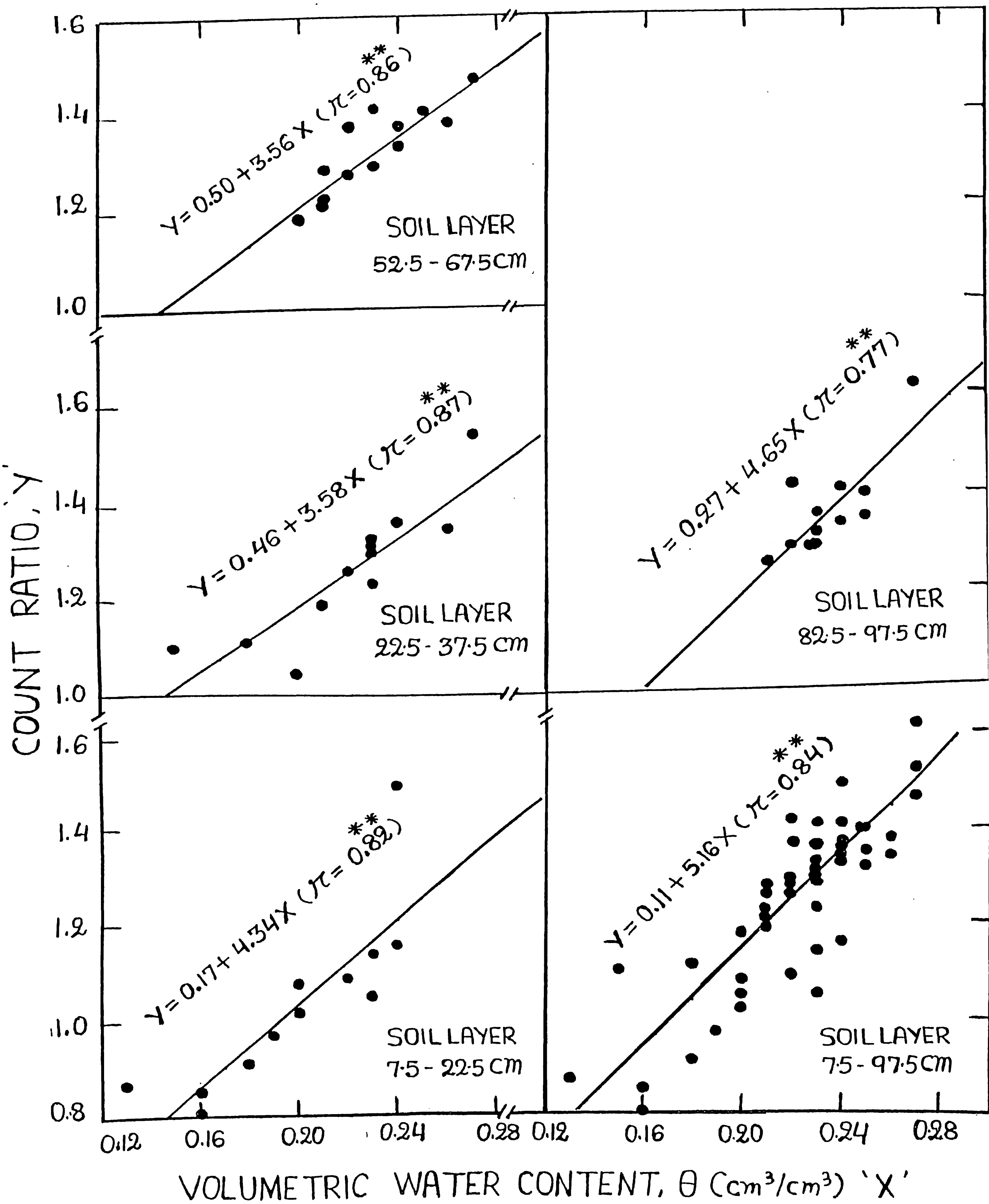


Fig.3(c) Count ratio vrs volumetric water content using GI thick gage pipe



for the thick gauge galvanised iron pipe with the corresponding calibration curves shown in Fig. 3(b). The following linear relationship were worked out to represent the calibration curves :

7.5 - 22.5 cm.; $CR = 0.17 + 4.34\ \theta;\ r = 0.82^{**}$ (n=13)

22.5 - 37.5 cm.; $CR = 0.46 + 3.58\ \theta;\ r = 0.87^{**}$ (n=13)

52.5 - 67.5 cm.; $CR = 0.50 + 3.56\ \theta;\ r = 0.86^{**}$ (n=13)

82.5 - 97.5 cm.; $CR = 0.27 + 4.65\ \theta;\ r = 0.77^{**}$ (n=13)

The lowest value of r (0.77) has been observed for 82.5-92.5 cm. soil layer. The overall equation for the pooled data happened to be :

$C.R. = 0.11 + 5.16\ \theta;\ r = 0.84^{**}$ (n = 52) Th 2054

The results of calibration stemming from the thin gauge galvanised iron pipe have been presented in Table 4 with the corresponding calibration curves shown in Fig.3(a). The following linear relationship were obtained to represent the calibration curves :

7.5 - 22.5 cm.; $CR = 0.12 + 4.88\ \theta;\ r = 0.88^{**}$ (n=13)

22.5 - 37.5 cm.; $CR = 0.45 + 3.44\ \theta;\ r = 0.88^{**}$ (n=13)

52.5 - 67.5 cm.; $CR = 0.29 + 3.93\ \theta;\ r = 0.86^{**}$ (n=13)

There was little variation in the value of r and the overall equation was -

Fig.3(d) C.R. Vrs θ using GI thin gage pipes

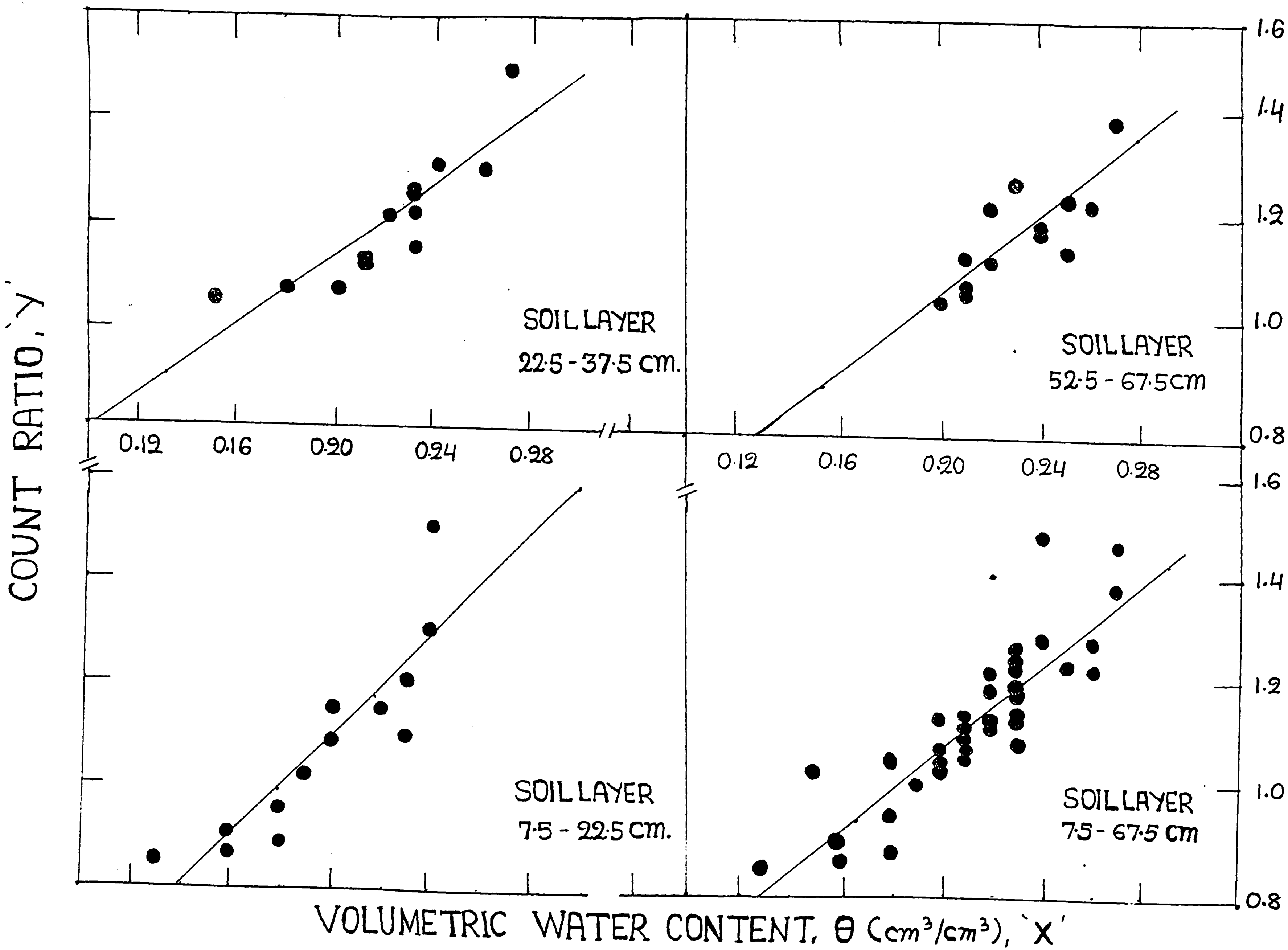


Table 4.

Count ratio measured using galvanised iron (thin gauge) access pipe in reflation to volumetric water content in the soil layers

Time(h)	SOIL LAYERS					
	7.5 - 22.5 cm.		22.5 - 37.5 cm.		52.5 - 67.5 cm.	
	θ	CR	θ	CR	θ	CR
0	0.24	1.51	0.27	1.49	0.27	1.41
15	0.24	1.31	0.26	1.30	0.25	1.26
24	0.23	1.21	0.24	1.31	0.23	1.29
39	0.20	1.15	0.23	1.25	0.22	1.24
48	0.22	1.15	0.23	1.26	2.26	1.25
72	2.23	1.10	0.23	1.22	0.24	1.21
96	0.20	1.09	0.22	1.21	0.24	1.20
136	0.19	1.02	0.23	1.15	0.23	1.16
216	0.18	0.96	0.21	1.13	0.21	1.15
297	0.16	0.91	0.21	1.12	0.22	1.14
417	0.18	0.89	0.20	1.07	0.21	1.09
490	0.16	0.87	0.18	1.07	0.21	1.08
725	0.13	0.86	0.15	1.05	0.20	1.06

$C.R. = 0.27 + 4.11\ \theta;\ r = 0.88^{**}\ (n = 39)$

Two PVC pipes were used to test their suitability as access pipes. The results of calibration obtained have been presented in Table 5 with the corresponding calibration curves shown in Fig. 3(d). The following relationships have been worked out for the data.

7.5 - 22.5 cm.; $CR = 0.17 + 3.45\ \theta;\ r = 0.93^{**}\ (n=13)$

22.5 - 37.5 cm.; $CR = 0.34 + 2.63\ \theta;\ r = 0.94^{**}\ (n=13)$

52.5 - 67.5 cm.; $CR = 0.36 + 2.67\ \theta;\ r = 0.83^{**}\ (n=13)$

The lowest value of $r = 0.83^{**}$ was deserved for 52.5 - 67.5 cm. soil layer with the over all equation being.

$CR = 0.25 + 3.09\ \theta;\ r = 0.92^{**},\ (n=13)$

It was observed that higher the slope, the lower was the intercept for all access pipes, for all depth except those for 82.5 - 97.5 cm. layer in thick gauge GI pipe, with the lowest correlation coefficients observed when compared with the relationship for 7.5 - 22.5 cm. layer. Such slope intercept relationship is in close agreement with that observed by Jena (1985).

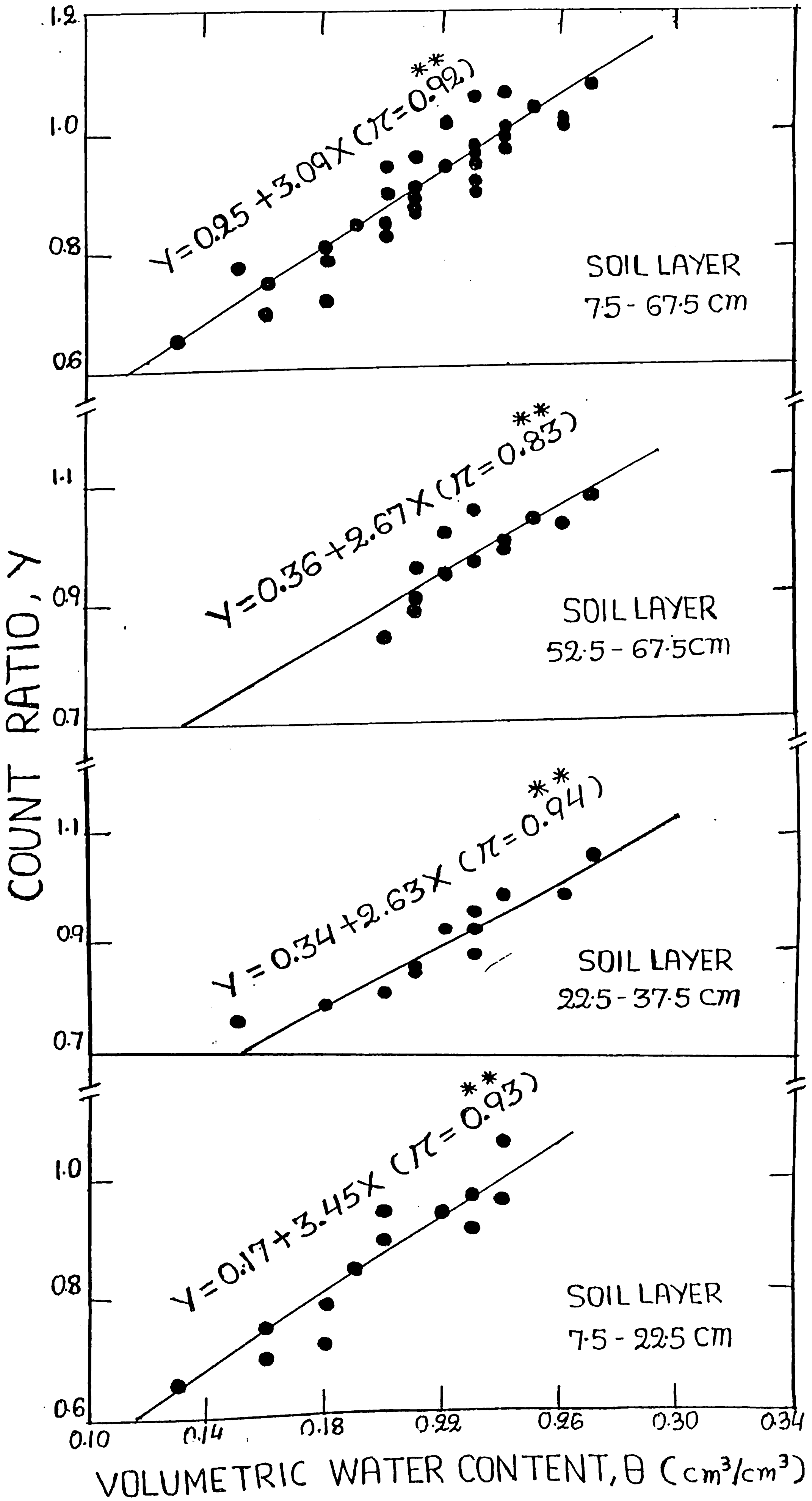
In general the regression coefficient were observed to be in the decreasing order :

Table 5.

Count ratio measurd using PVC access pipe in relation to volumetric water content in the soil layers

Time (h)	SOIL LAYER 7.5 - 22.5 cm.		22.5 - 37.5 cm.		52.5 - 67.5 cm	
	θ	CR	θ	CR	θ	CR
0	0.24	1.06	2.27	1.07	0.27	1.07
15	0.24	0.96	0.26	1.00	0.25	1.03
24	0.23	0.97	0.24	1.00	0.23	1.05
39	0.20	0.94	0.23	0.97	0.22	1.01
48	0.22	0.94	0.23	0.97	0.26	1.02
72	0.23	0.91	0.23	0.94	0.24	0.99
96	0.20	0.89	0.22	0.94	0.24	0.98
136	0.19	0.84	0.23	0.89	0.23	0.96
216	0.18	0.78	0.21	0.87	0.21	0.95
297	0.16	0.74	0.21	0.86	0.22	0.94
417	0.18	0.71	0.20	0.82	0.21	0.90
490	0.16	0.69	0.18	0.80	0.21	0.88
725	0.13	0.65	0.15	0.77	0.20	0.84

Fig.3(b) Count ratic vrs volumetric water content using PVC Pipes



Aluminium Pipe > Thick gauge G.I. Pipe > Thin gauge G.I.Pipe > P.V.C. pipe considerisng all the depths. However, the overall regression coefficient was the highest for aluminum access pipe and the lowest for PVC pipe suggesting that aluminum was the best filter for neutrons. Ealeas (1969) had also reported such observation. Hence for a given water content the neutron-probe register higher count with an aluminum access pipe than that in iron as well as PVC access pipes. The correlation coefficient, on the other hand, are higher for both aluminum and PVC access pipes than those for G.I. pipes (Both thick and thin gauges). Hence PVC pipes can well substitute the aluminum pipes on account of their durability and lower cost. Indeed, aluminum pipes remaining embeded in the soil were observed to have been damaged due to the combined action of water and iron compound present in the soil.

4.2.2. Volumetric watercontent inferred based on calibration equation in relation to that measured in the rhizosphere :

Jena (1985) had observed a 50% reduction in the value of correlation coefficient (obtained for bare field condition) when calibration was redone by him under cropped situation. The presence and continual increase of root biomass was assumed to be responsible for such observations. To appreciate and confirm this result, attempts were made in course of this study to infer the soil water content using the calibration curves obtained under bare field situation. Table 6 & Fig.4 presents the soil water content measured gravimetrically and that inferred by calibration equations obtained with aluminum access pipes in different soil layers and growth stages of the crops. In active stage of growth the inferred θ values have been observed to be in general, higher than the measured θ values at 15 and 30 cm depths, whereas there is close match between inferred and measured θ values beyond 30 cm depth for all the cropping systems. But towards the senescent stage the inferred θ values are definitely higher for all the cropping systems except for the rice root zone. In the case of rice there is close agreement between measured and inferred θ values only below 30cm depth, presumably because of the shallow root system. Hence it is, the presene of structural hydrogen in both active and dead organic tissue (in the rhizosphere) that augments the thermalisation process resultidng in higher count ratio and leading to an apparent higher water contents for the soil layer with higher concentration of root biomass.

4.3. Insitu measured hydrological properties of the soil :

Soil hydrological properties viz. $\theta(z,t)$, $\theta(h)$, $h(z,t)$, q (soil water flux) and $K(\theta)$ (hydraulic conductivity) measured during the course of this

Table 6.

Soil Watercontent (cm^3 /cm^3) at selected growth stages measured and inferred by CPN hydroprobe

Crop : Rice + Pigeonpea (3:1)

Growth Stage	Date	SOIL DEPTH 15 cm, Measured	15 cm, infered	30 cm. measured	30 cm. infered	60 cm, measured	60 cm, infered	90 cm. measured	90 cm. infered
Active	9.9.91	0.16	0.18	0.19	0.23	0.23	0.22	0.23	0.22
Growth	27.9.91	0.15	0.17	0.18	0.20	-	-	0.22	0.22
Stage	2.10.91	0.08	0.13	0.16	0.20	0.20	0.20	0.19	0.21
Senesc-	29.11.91	0.08	0.13	0.11	0.17	0.17	0.19	0.18	0.20
ent	4.12.91	0.07	0.11	0.10	0.14	0.14	0.19	0.16	0.19
Stage									
RICE									
Active	9.9.91	0.19	0.18	0.20	0.23	0.22	0.24	0.24	0.25
Growth	27.9.91	0.19	0.19	0.21	0.23	0.24	0.23	0.28	0.25
Stage	2.10.91	-	-	0.13	0.22	0.23	0.22	0.25	0.24
Senesc-	29.11.91	0.08	0.15	0.13	0.21	0.23	0.22	0.25	0.24
ent	4.12.91	0.09	0.13	0.09	0.21	0.22	0.21	0.18	0.23
Stage									

Contd.......

Rice + Pigeonpea (5:2)

Growth Stage	Date	SOIL DEPTH 15 cm. Measured	15 cm. infered	30 cm. Measured	30 cm. infered	60 cm., measured	60 cm., infered	90 cm. measured	90 cm. infered
Active Veg.	9.9.91	0.19	0.19	0.24	0.24	0.23	0.24	0.22	0.24
Senescent	27.9.91	0.23	0.19	0.20	0.15	0.23	0.23	0.21	0.22
	4.12.91	0.05	0.12	0.13	0.17	0.09	0.17	0.14	0.17

Rice : Pigeonpea (2:1)

Growth Stage	Date	15 cm. Measured	15 cm. infered	30 cm. Measured	30 cm. infered	60 cm., measured	60 cm., infered	90 cm. measured	90 cm. infered
Active Veg.	9.9.91	0.21	0.16	0.21	0.21	0.22	0.23	0.24	0.24
	27.9.91	0.19	0.16	0.22	0.21	0.23	0.22	0.24	0.23
Senescent stage	2.10.91	0.10	0.12	0.16	0.18	0.21	0.20	0.21	0.21
	29.11.91	0.12	0.16	0.16	0.21	0.16	0.21	0.17	0.20
	4.12.91	0.09	0.10	0.09	0.14	0.11	0.16	0.11	0.16

Pigeonpea

Growth Stage	Date	15 cm. Measured	15 cm. infered	30 cm. Measured	30 cm. infered	60 cm., measured	60 cm., infered	90 cm. measured	90 cm. infered
Active Veg.	9.9.91	0.19	0.17	0.19	0.21	0.22	0.24	0.23	0.25
Senescent stage	2.10.91	0.08	0.14	0.15	0.19	0.18	0.19	0.21	0.21
	29.11.91	0.09	0.10	0.09	0.14	0.10	0.18	-	-
	4.12.91	0.08	0.11	0.09	0.15	0.15	0.16	0.16	0.16

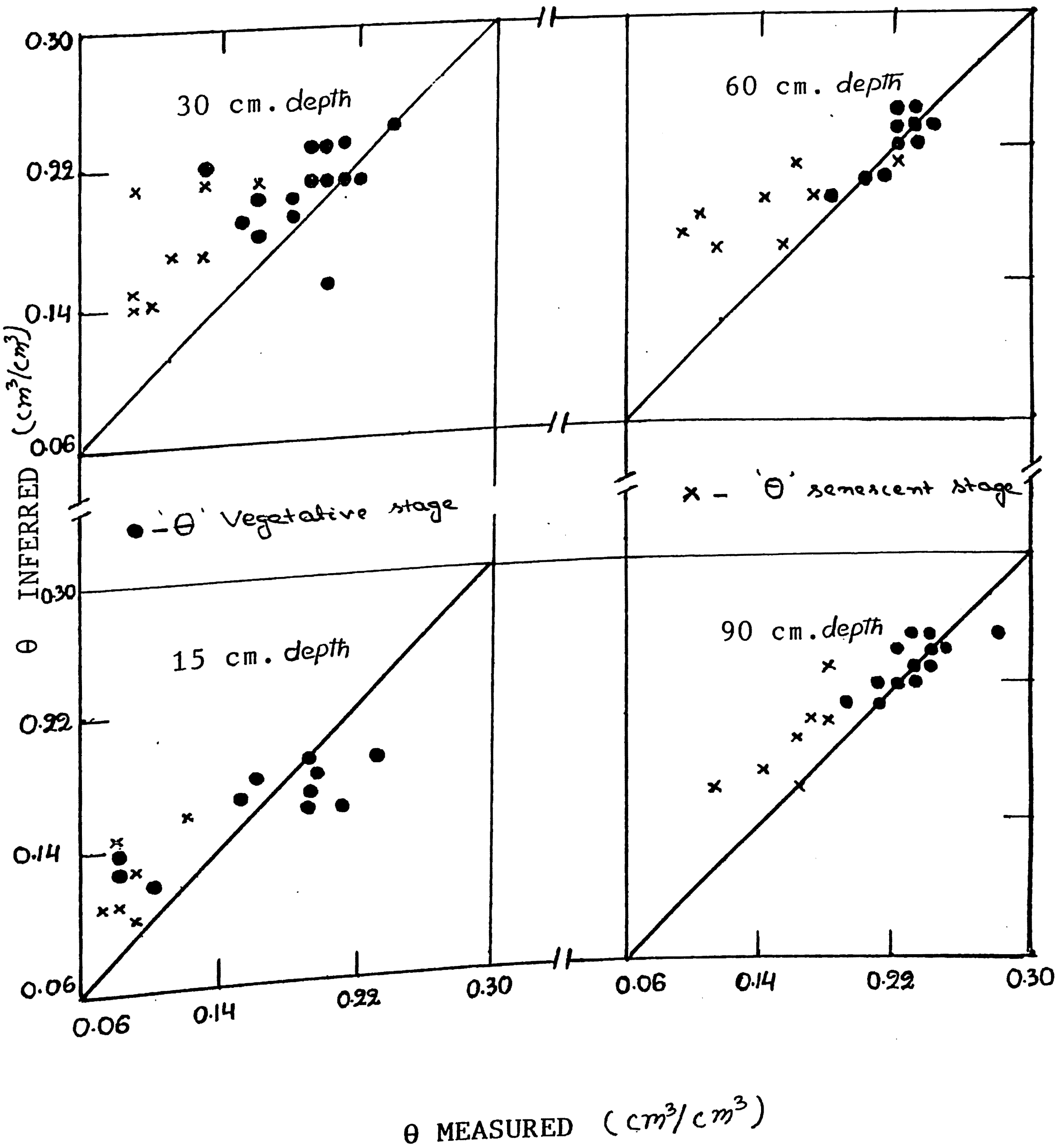


Fig.4 Soil water content (cm^3/cm^3) measured and inferred at different depth of the profile

investigation are presented in the following sections.

4.3.1. Insitu measured θ (z, t) :

Soil samples for gravimetric determination of water content were collected periodically from two adjacent plots flanking the experimental site (having the access pipes) after a steady state infiltration was reached. The mean volumetric water content values (n=2) thus obtained have been presented in Table 7 for different depths and over a period of 490 hours. The θ (z,t) data have been presented Fig.6. These curves were extrapolated to z = 0 in order to help estimate the depletion of waterfrom 0-15 cm soil layer. The volumetric water content was observed to ranges between 0.23 - 0.11 cm^3/cm^3 at 15 cm depth and 0.27-0.21 cm^3/cm^3 at 90 cm depth between 0 and 490 hours, unlike the corresponding range of 0.32 - 0.15 cm^3/cm^3 and 0.34 - 0.20 cm^3/cm^3 between 0th and 374th hour reported by Jena (1985). Further the mean steady state water content for the entire profile (0-90 cm) was found to be 0.27 cm^3/cm^3 unlike that of 0.33 cm^3/cm^3 obtained by Jena (1985) on the same place of experimentation. θ (z, t) data reported earlier by Patra (1983) were in agreement with that of Jena (1985) possibly because both had conducted the experiment during April-May on the same site. Lower values of θ (z, t) obtained during the present investigation may have been due to the fact that

Table 7.

Insitu measured θ (z,t) for different depths after cessation of steady state infiltration

	SOIL DEPTH (cm)					
Time after steady state infiltration (h)	0	15	30	60	90	Remarks
0	0.23	0.25	0.27	0.28	0.27	Mean steady state water content for the entire profile (0-90cm)is 0.27 cm^3/cm^3)
15	0.22	0.24	0.24	0.27	0.25	
39	0.20	0.21	0.22	0.23	0.24	
136	0.16	0.18	0.20	0.22	0.23	
216	0.14	0.17	0.19	0.21	0.22	
490	0.11	0.14	0.17	0.20	0.21	

these experiments were conducted in the month of November and in a different site. The profile having been initially much wetter during November as compared to that during April-May also appeared to hinder the soil saturation process.

As time passes the θ values invariably decreases in all depths. However, the magnitude of decrease was greater in the shallower depth as expected.

The area $\int_{-z_1}^{0} \int_{\theta_1(t_1)}^{\theta_2(t_2)} d\theta . dz$ enclosed between θ(z) profile for two consecutive time intervals and $z = - z_1$ and $z = 0$ represents the amount of sol water that drais across $z = z_1$ during the time $t = t_2 - t_1$.

4.3.2. Insitu soil moisture characteristic curve, O(h) :

In order to avoid the anomalis in the gravimetrically estimted volumetric water content, θ values were inferred by using the nutron hydroprobe readings. Such values for the entire profile plotted against soil water pressure head, h values (given by the tensiometer readings to obtain the soil moisture characteristic curve) were presented in Fig.5. Table 8 depicts the θ values with the corresponding soil water pressure head values. It was seen from the figure that the soil water content decreases with decrease in soil water

Table 8.

Mean insitu measured soil water pressure head,h(-cm) values against the corresponding soil water content, θ (cm^3/cm^3) for different soil depths after cessation of steady state infiltration

	15 c.		30 c.		50 cm.		65 cm.		90 cm.	
Time	h	θ	h	θ	h	θ	h	θ	h	θ
0	37	0.28	37	0.30	53	0.30	66	0.29	52	0.28
15	81	0.23	84	0.25	83	0.25	81	0.24	78	0.24
24	92	0.23	96	0.25	98	0.25	91	0.24	86	0.24
39	102	0.21	103	0.24	100	0.24	94	0.23	90	0.23
48	111	0.21	110	0.23	107	0.23	100	0.23	-	0.23
96	135	0.20	131	0.22	124	0.23	115	0.23	103	0.23
136	156	0.18	143	0.22	124	0.22	115	0.22	107	0.22
216	187	0.16	178	0.21	138	0.22	119	0.22	117	0.22
297	222	0.15	198	0.21	149	0.22	130	0.22	130	0.22
490	347	0.14	2.72	0.20	176	0.21	166	0.21	157	0.22

θ values in this table have been inferred from the smooth calibration curve using the observed neutron counts.

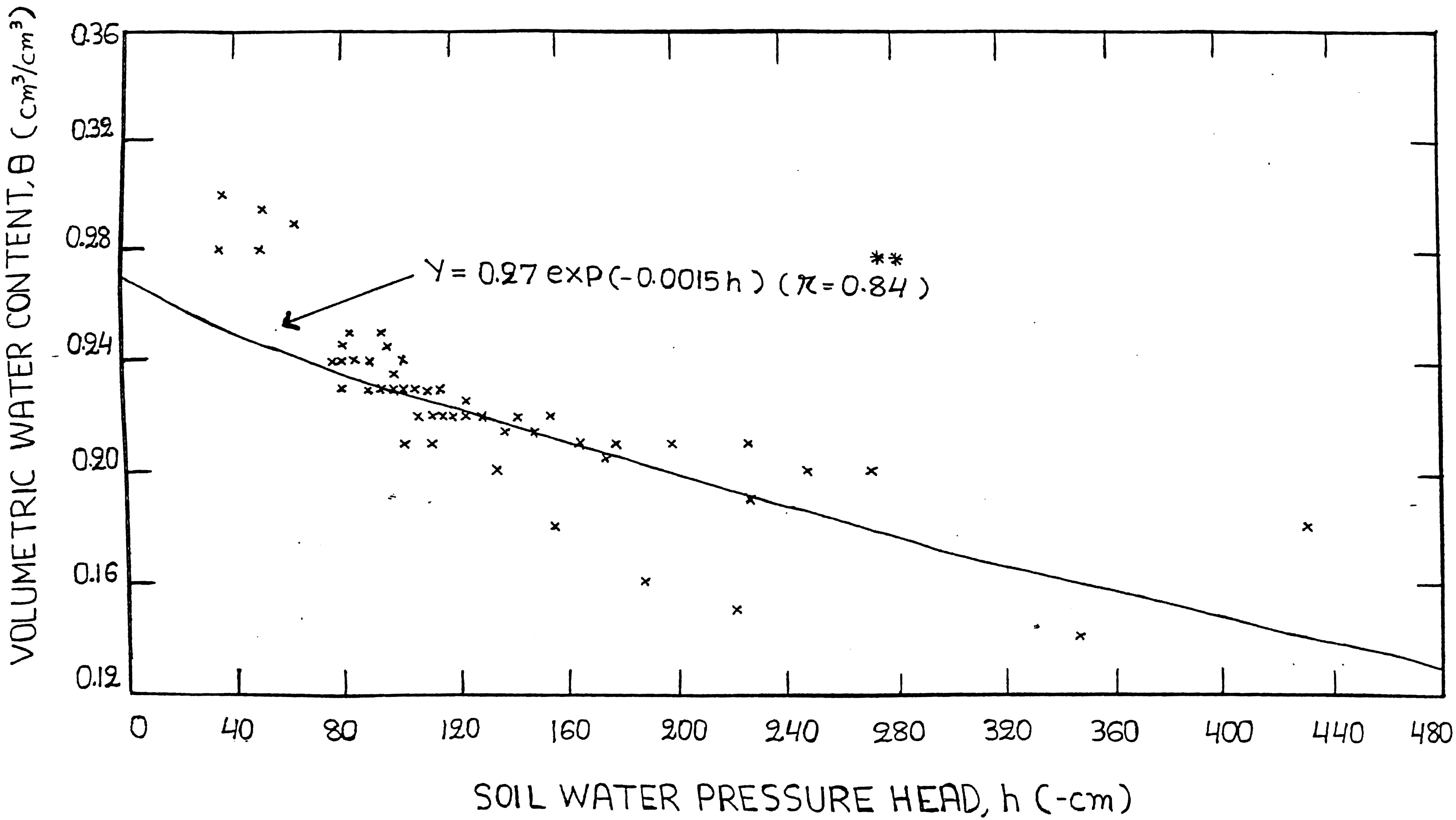


Fig.5 Insitu soil water characteristic curve for the soil profile (0 - 90 cm)

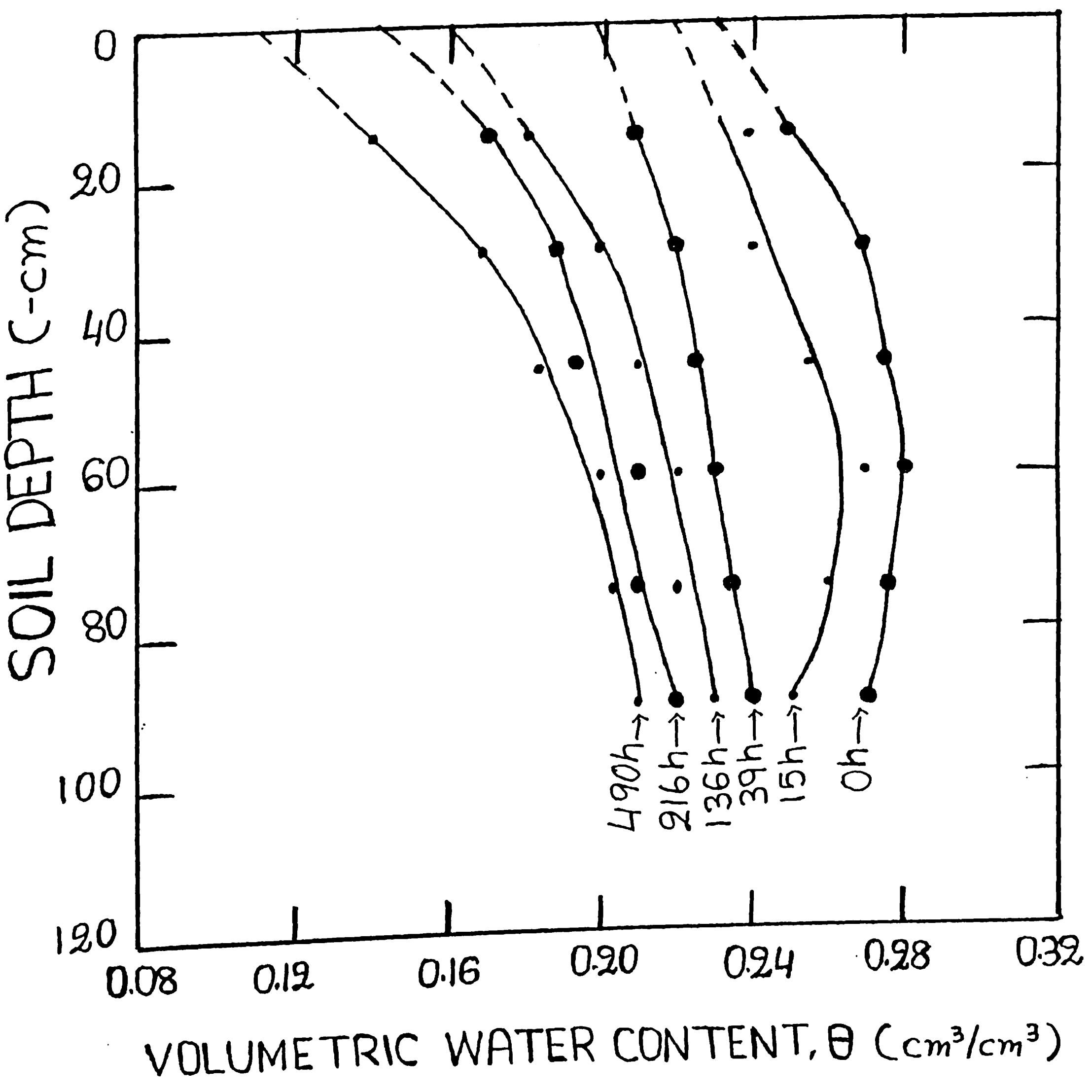


Fig.6 Soil water content distribution with depth and time after steady state infiltration was attained

pressure head as was to be expected. The exponential relationship between θ and h is given by -

$\theta = 0.27 \exp(-0.0015\ h)$ $r = 0.84^{**}$ $(n = 65)$ The magnitude of the constant (b = 0.0015) has been observed to be lower than that (0.004) reported by Jena (1985).

4.3.3 Insitu H (z, t) :

Table 9 depicts the mean measured soil water pressure head, h (-cm) values for different soil depths over 490 h after the steady state infiltration was attained. It was observed that initially the near saturated profile registered a mean soil water pressure head (h) of - 50 cm. Subsequently the pressure head decreased over time and soil depth, the decrease being higher in the shallower depth as that compared with the deeper ones. Over 490 h period the soil water pressure head decreased from - 37 cm. to-347 cm. at 15 cm depth as compared with -52 cm to -141 cm at 105 cm depth. similar results were obtained by Jena (1985).

The soil water pressure head combined with gravitational head yields soil hydraulic head (H). Fig.7 presents the relationship between hydraulic head (H) values with depth and time. The graphs have been extrapolated to z = 0 in order to help estimate the hydraulic gradient

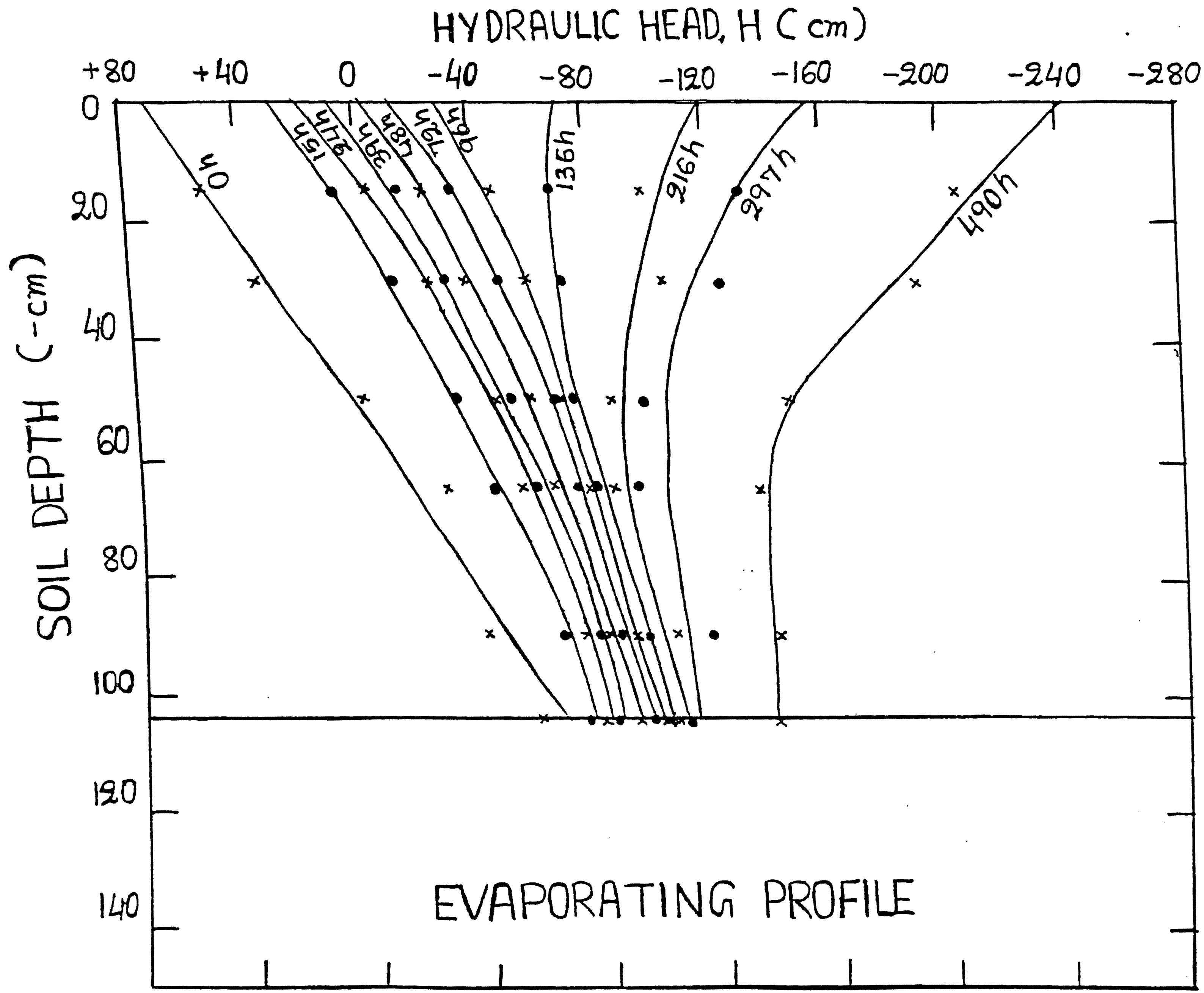


Fig.7 Hydraulic head distribution with depth and time.

Table 9.

Hydraulic head gradient dH/dz values for different soil depths following cessation of steady state infiltration

Soil despth (cm)	HYDRAULIC HEAD GRADIENT (cm/cm) TIME (H) 0	15	24	39	48	72	96	136	216	297	490
15	1.27	1.33	1.53	1.47	1.33	1.40	1.06	-0.27	-1.07	-1.73	-1.87
30	1.33	1.07	1.27	1.07	0.93	0.87	0.80	0.00	-0.60	-1.07	-2.13
50	1.30	1.00	0.95	1.00	0.90	0.80	0.50	0.30	-0.35	-0.60	-1.40
65	1.27	0.93	0.80	0.80	0.60	0.53	0.47	0.40	0.53	-0.13	-0.73
90	1.28	0.84	0.80	0.64	0.68	0.56	0.52	0.56	0.48	0.28	0.16
105	1.33	0.67	0.40	0.53	0.53	0.53	0.60	0.53	0.53	0.20	0.00

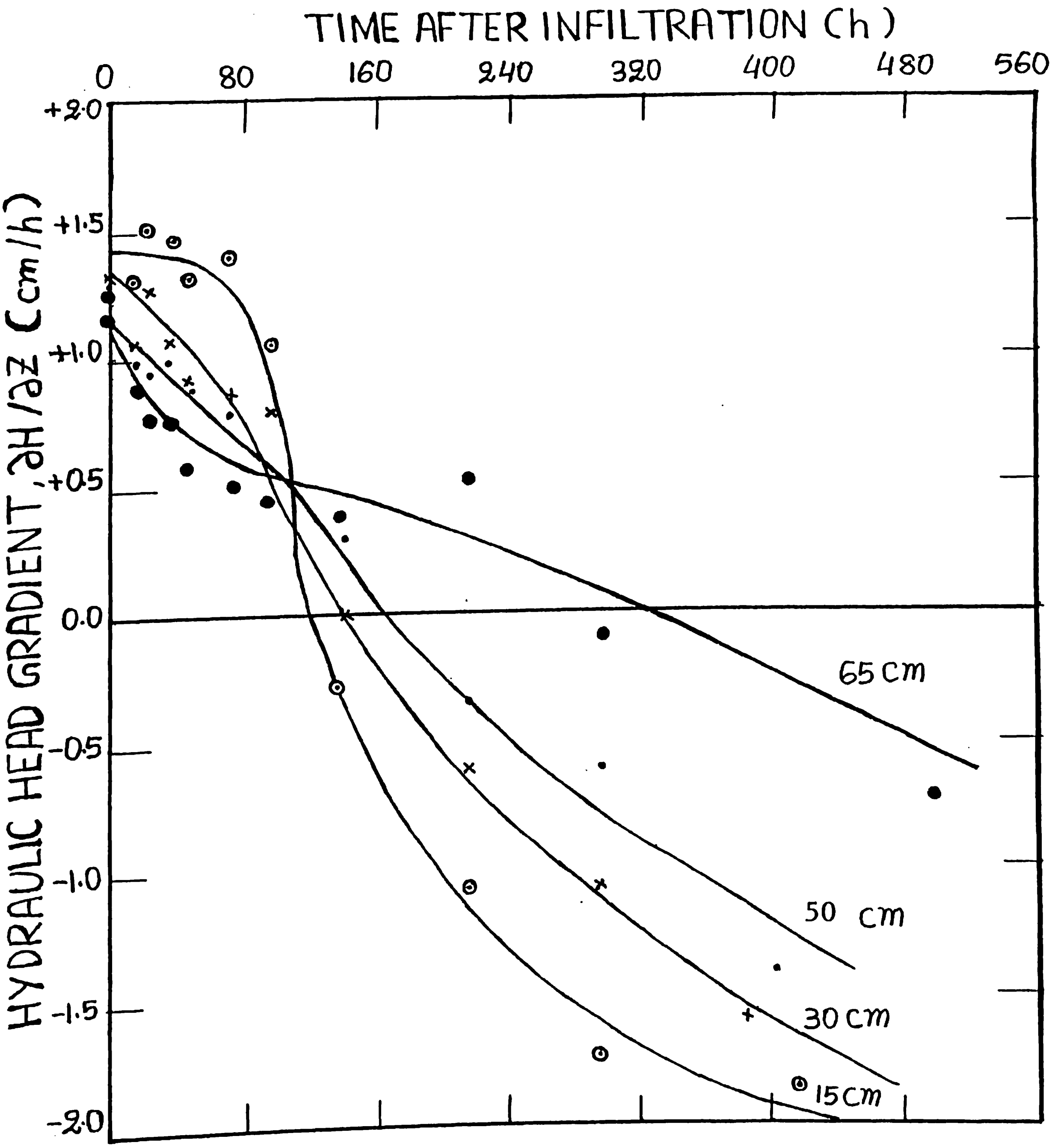


Fig.8. Hydraulic head gradient distribution with soil depth and time for 15, 30, 50 and 65 cm. soil depth.

(dH/dz) for the 0 - 15 cm soil layer. The dH/dz (z) values have been computed by taking finite difference of the coordinates for each depth and each time (t) and were presented in Table 9. On the '0'th hour the entire profile was draining downward with nearly a unit gradient (1.30). Although surface evaporation has been allowed to occur, the direction of flow was observed to be downward in 0-15 cm depth upto 120 h (unlike 75 h observed by Jena , 1985) in as much as the gradient values were positive. According to Darcy's law $q = -K \nabla H$ with z defined to be negetive into the soil (from surfae downwards), the flux, q was upward when the graient < 0. After the passage of 120 h and 140 h for 15 and 30 cm soil depth, respectively, the dH/dz values became negetive indicating that the water was lost by evaporation at the soil surface. The observations made by Patro (1983) and Jena (1985) in this soil had revealed that negetive flux values were obtained much earlier i.e. 57, and 64 h and 75, and 105 h, respectively. The difference could have been due to differing atmospheric condition during the month of May 1979, April 1981 for the previous authors and November 1991 for the present study. It has also been observed that the water continues to move downward below 90 cm depth even after 490 h unlike in the case of Jena (1985). However, as had been observed earlier by Patro (1983) and Jena (1985), the gradients decrease, by and large, with advance of time in all the soil layers.

In an initially saturated soil profile in which evaporation and drainage were allowed to occur simultaneously, the zone of upward and downward flow of water should be distinct as has been claimed by several investigators (Arya et al. 1975, Jena, 1985) and a "zeroflux plane" accross which no flow of water could occur should be observed. Fig.8 is the plot of dH/dz versus time following the steady state infiltration at 15, 30, 50 and 65 cm soil layers. It may be seen that the graph crossed the absciassa, dH/dz = 0, (i.e. dH/dz changes sign from positive to negative indicating the change in flow direction) at 15 cm. depth after 120 h. Under the condition of simultaneous evaporation and drainage, "the zero flux plane" moved downward with time. As such the graph in the Fig.8 revealed that it took about 320 h for the "zero flux plane" to reach 65 cm depth.

4.3.4. Insitu K (θ) :

The drainage flux values were derived from the depletion amount presented in Fig.5 inferred with the help of Fig. 7 and Fig. 8. Using (Eq.11), K (θ) values at different time were calculated for the soil depth of 90 cm and represented in Fig. 9. From Fig. 8 it was observed that "zero flux plane" reached the 15 cm., 30 cm., 50 cm. and

65 cm. soil depth at around 120 h, 140 h, 160 h and 320 h. Assuming that "zero flux plane" took equal time to pass through unit distance during 15, 39, 136, 216 and 490 h, the depth of drainage was calculated to be 88, 85, 63, 40 and 25 cm, respectively. This means by 15 hours, the drainage is supposed to occur from the soil layer of 2 - 90 cm and so on. Taking these values of depth of drainage into account, flux values were derived and presented in Table 10 following cessation of steady state infiltration . It is seen that with passage of time q, decreases from 0.10 (-cm/h) at 15 h to 0.0005 (-cm/h) at 490 h. Higher values of q has been reported by Jena (1985) for this soil possibly owing to effect of the season and attainment of higher degree of soil saturation. K (θ) values calculated by tensiometric method were presented in Table 10 and Fig.9. Like q, K (θ) also decreased with passage of time which was also observed earlier by Patro (1981) and Jena (1985). K (θ) value was observed to be the highest at 15 h (0.12 cm/h) and lowest at 490 h (0.0063 cm/h) during present study. Using Eq 20 and taking $\theta o = 0.27\ cm^3/cm^3$, the value of Ko was calculated to be 0.55 cm/h and the corrosponding α value, 72.9. These values of Ko and α do not agree with the values observed by Patro (1983) and Jena (1985), who had observed lower values of both Ko and α for the same soil in comparision to the present study. The higher α value indicated slower passage of water through 90 cm. depth.

Table 10.

Measured soil water flux and hydraulic conductivity K (θ) for different water content and time (15 h to 490 h)

Time	Volu-metric water content (cm^3/cm^3)	Soil water flux (q)(-cm/h)	Hydraulic gradient (dH/dz)	Hydraulic conductivity: Tensio-metric (q/dH/dz)	Hydraulic conductivity: Libardi et al.'s method ($-z\frac{d\theta}{dt}$)	Remarks
15	0.25	0.102	0.84	0.12	0.11	Model used : $K = Ko \exp \alpha (\theta - \theta_o)$ In tensiometric method $K = 0.55 \exp 72.9 (\theta - 0.27)$ In Libard et al.'s method : $K = 1.23 \exp 119.9 (\theta - 0.27)$
39	0.24	0.089	0.64	0.11	0.04	
136	0.23	0.008	0.56	0.014	0.008	
216	0.22	0.0065	0.48	0.0135	0.003	
490	0.21	0.0005	0.08	0.0063	0.001	

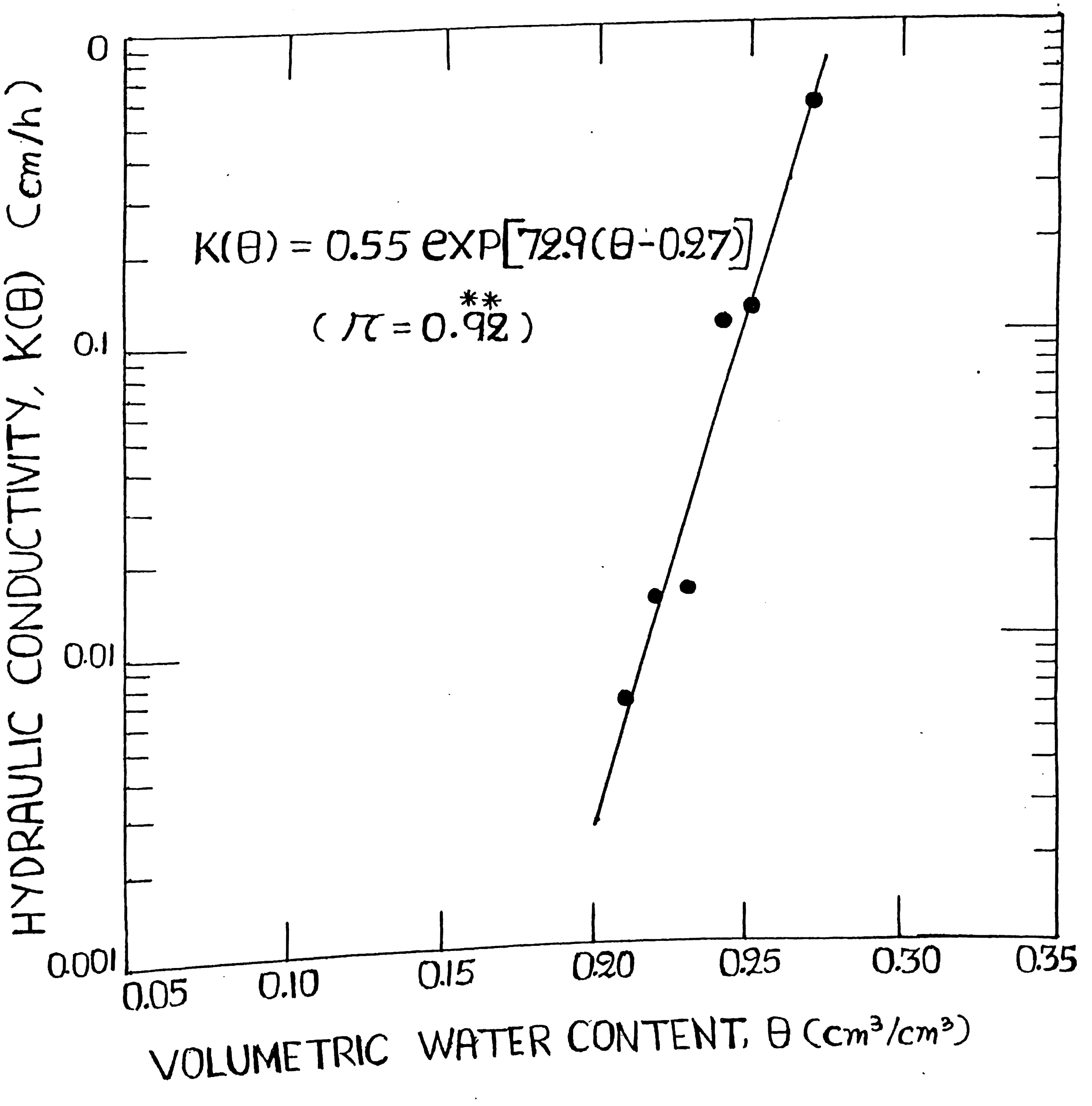


Fig.9 Hydraulic conductivity as a function of mean soil water content for the 0 - 90 cm. profile

In the present study K (θ) values were also calculated for the same depth and time using Libardi *et al*.'s field method of determining K (θ), the values of K (θ) and α calculted have been presented in Table 10. Unlike the results presented by Misra (1990) the Ko observed using Libardi *et al*.'s model in the present study was higher (1.23 cm/h) than that in tensiometric method (0.55 cm/h). Similarly α value was also higher (α = 119.9) in this method to tensiometric method (α = 72.9). This result was due to the fact that $0 < dH/dz < 1$ in the present sudy in all the soil layers.

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY, CONCLUSION AND SUGGESTED FUTURE RESEARCH

5.1. Objective :

The aim of the present investigation was to calibrate a CPN make neutron moisture meter using different access pipes under bare land situation and to study some hydrological properties of the lateritic soil of Bhubaneswar, employing tensiometers and the neutron hydroprobe measurements.

5.2. General soil characteristics of the experimental site:

The field experiments were conducted at the upland site of the Central Research Station, Orissa University of Agriculture and Technology, Bhubaneswar, (Latitude : 20°15'N, Longitude : 85° 50'E and altitude : 26 m) Orissa. The soil is classified as an ultisol occuring widely in the coastal districts and elsewhere in Orissa. The land surface slope is nearly 1% in the east-west direction. The surface soil is sandy-loam in texture and clay content increases with depth up to nearly 105 cm. The soil is strongly acidic in reaction (pHw 5.1) and poor in base and plant nutrient content.

5.3. Calibration of CPN neutron hydroprobe :

The neutron hydroprobe was calibrated under bare land situation using different types of access pipes viz. aluminum, PVC, GI (thick gauge) and GI (thin gauge). Three small (4x3 m) adjacent field plots were separated by 15 cm. bunds in order to prevent run off. A pair of access pipes of each kind was installed in the middle plot. Aluminum, PVC, GI (thick gauge) and GI (thin gauge) reached > 60 and ≤ 90 cm. depth. Hg-H_2O tensiometers were also installed in duplicate with their cups reaching 15, 30, 50, 65, 90 and 105 cm. depths in the middle plot. On these plots water was ponded continuously for 3 consecutive days to bring the field near saturation and attain steady state infiltration. There after neutron hydroprobe readings, tensiometer readings were recorded and soil samples were collected from 0-15, 15-30, 45-60 and 75-90 cm. soil layers for determining their water content by gravimetric method at different time intervals until 490 h. Volumetric water content was determined based on the known bulk density and gravimetric water content data. Calibration curves were prepared for different access pipes by ploting the count ratio values against the volumetric water content for different soil layers under bare field condition. Under cropped condition 'θ' values, both measured and inferred from calibration curve werecompared against each other.

5.4. Insitu methods for the measurement of hydrological properties :

5.4.1. Field soil water characteristics θ (h) :

Field soil water characteristics for different soil layers were derived by plotting the volumetric water content, θ, inferred from the calibration curve using aluminum access pipe versus the suction head, h, recorded with the help of tensiometers for the differnt depths. The θ (h) relationship was observed to be $\theta = 0.27 \exp(-0.0015\ h)$

5.4.2. Hydraulic conductivity, K (θ) :

Hydraulic conductivity, K (θ) for the same plot where calibration of the neutron hydroprobe was performed, was determined based on measured soil water flux through 90 cm. depth at 15, 39, 136, 216 and 490 h following steady state infiltration in the evaporating profile employing both the tensiometric and Libardi et al.'s method. The hydraulic gradiet values were derived from the tensiometer readings and θ values inferred from neutron hydroprobe calibration curve for different depths and times. Soil water flux values weremeasured based on $\int_{z_0}^{z} d\theta/dt\ dz$ by monitoring the position of the "Zero flux plane". K (θ) was calculated from a knowledge of the measured hydraulic gradient and the soil water flux values based on Darcy's law.

5.5. Important Results :

The mean volumetric water content, θ, for the entire profile (0-90)cm at steady state infiltration was 0.27 cm^3/cm^3. The over all calibration equation using different access pipes were as follows :

Alluminum : for soil layer 7.5 - 97.5 cm.

$CR = 0.01 + 6.58\ \theta;\ r = 0.92^{**}$ (n=48)

GI (thick gauge) : For soil layer 7.5 - 97.5 cm.

$CR = 0.11 + 5.16\ \theta;\ r = 0.84^{**}$ (n=52)

PVC : For soil layer 7.5 - 67.5 cm.

$CR = 0.25 + 3.09\ \theta,\ r = 0.92^{**}$ (n=39)

GI (thin gauge) : For soil layer 7.5 - 67.5 cm

$CR = 0.27 + 4.11\ \theta;\ r = 0.88^{**}$ (n=39)

Stemming from the θ inferred from calibration curve and tensiometer readings (h), the soil water characteristic curve for the entire profile (0-90 cm) was given by :
$0 = 0.27 \exp(-0.0015\ h);\ r = 0.84^{**}$.

The value of soil water flux through 90 cm depth at steady state infiltration was 0.715 cm/h (t = 0) and with increase in time it decreased to 0.0005 cm/h (t = 490 h).

The hydraulic conductivity for the 90 cm. depth based on Libardi et al.'s (1980) method could be formulated as $K(\theta) = 1.23 \exp[120(\theta - 0.27)]$ and that based on the tensiometric method as :

$K(\theta) = 0.55 \exp[73(\theta - 0.27)]$.

5.6. Conclusion :

Based on the results of the present experiment carried out during 1991, the following conclusions may be drawn.

* Neutron hydroprobe is a useful tool for determining soil water content non destructively, at desired depth and time based on a predetermined insitu calibration relation.

* Calibration relation for bare land situations may over predict θ from cropped situations possibly due to the presence of living growing roots and dead biomass.

* Among the four access pipes aluminum is the most transparent material for thermalising fast neutrons thus giving high count readings as well as highly significant correlation coefficient values. But on the other hand, although PVC pipes may give lower count readings as compared to that with aluminum, it

is preferred (to aluminum) under field conditions due to its durability and comparable magnitude of correlation coefficient as aluminum.

* Neutron hydroprobe along with Hg-H_2O tensiometes can be used with advantages for insitu measurement of hydrological properties.

* Tensiometric method of determination of K (θ) is more reliable than Libardi et al.'s method, that assumes the prevalence of unit gradient which is not necessarily obtained in practice.

5.7. Suggested future research needs :

Further research is required to understand if K (θ) temporarily variable i.e. dependent on the season of the year. Also it is necessary to study if calibration relation ought to be performed for different cropping systems.

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