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STUDY OF SOIL MOISTURE USING NEUTRON PROBE

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ABSTRACT

Soil moisture studies provide potential information in the field of agriculture,meteorology and hydrology. In the field of agriculture, information on soil moisture is needed for many diverse applications including improved yield forecasting and irrigation scheduling. In meteorology, the knowledge of soil moisture is required for understanding radiation components while in the field of hydrology, the soil moisture content is important for understanding the component of infiltration due to precipitation and irrigation. in such processes of hydrological balance, the moisture content of the surface layers control upward and downward flow and storage of water in the unsaturated zone.

In this report, investigations on the soil moisture content and its redistribution along a soil profile in the unsaturated zone using neutron probe are presented. Various methods for in-situ soil moisture measurements are touched upon. Basic principle, theory of neutronic method, design features, calibration procedure, merits and limitations of the probe are briefly discussed. Applications of neutron probe for the measurement of soil water storage, soil water reservoir characteristics and recharge etc. are given.

Studies carried out at the campus of National Institute of Hydrology clearly show the capabilities of neutron moisture probe, for accurate measurements of soil moisture changes, in-situ, in undisturbed soil in the natural state.

Some typical soil moisture profiles were plotted showing depletion in moisture content and water gained. It is seen that there is not much variation in the moisture content below 120 cm depth. Soil returned

to an almost identical moisture level within two-three days after a rain storm. Evaporation for the period 22nd April to 22nd May and 22nd May to 21st June 1985 was estimated as 5 cm and 1.91 cm respectively.

INTRODUCTION

Soil moisture studies provide necessary information in determining the optimum irrigation regime. Essentially, there are two main problems, firstly, what are the water requirement, of the crop for maximum yield and secondly, what is the optimum way in terms of irrigation rate, frequency and method by which water can be made available to the plant, utilising the natural storage of the soil. On the other hand, tendency of farmers to use as much water as they can get for irrigation without understanding the soil moisture storage create serious problems as over irrigation can cause water logging and thereby reducing its productivity. As water resources are becoming increasingly scare and more expensive to develop, wastage must be reduced and more precise information of soil moisture storage and movement in the unsaturated zone is required.

The first problem, that of determining the consumptive use of the crop can be studied from a soil moisture approach by meeting certain boundary condition. The second problem, that of making water available to the plant with maximum efficiency, can be studied effectively only through investigation of the soil water regime. Continual accurate measurements of soil moisture are thus essential. In addition, measurement of the soil moisture hydraulic potential profiles is necessary for a full understanding of the movement of water in the soil. Nevertheless, in some situations, crude but useful information can be provided by soil moisture measurements alone.

Soil water exists in three different conditions, (i) Gravity water, the water present in the large pores of the soil and move under gravity, (ii) Capillary water, the water held in the small pores by capillarity against the force of gravity, and (iii) the hygroscopic water, which is the water retained by individual soil particles due to molecular attraction. The movement of soil moisture in the unsaturated zone is not well understood. As per Zimmermann (1967), the soil moisture moves downwards in discrete layers. The traditional methods of soil moisture measurements are clearly time consuming, destructive and not repeatable at the same site, while the neutron probe is capable of giving precise measurements of soil moisture. Repeated measurements at the same site provide valuable information on changes in soil moisture content at various depths. Measurements are rapid, in-situ in undisturbed soil and may be repeated as frequently as necessary in the same profile which remains unchanged except for moisture content. This is a considerable advanced approach in comparison the traditional gravimetric methods with their disadvantage of disturbance of the soil profile and practical limitations of time and effort required.

The Troxler depth moisture gauge 3320 series developed and manufactured by Troxler Electronic Laboratories, U.S.A. has been used at the NIH campus for measuring in-situ the volumetric water content of the soil. This field instrument is shown in Fig.1. The gauge measures the moisture content of soils, aggregates, or other similar materials and work on the principle of neutron thermalization. Fast neutrons emitted by an Americium 241: Beryllium radioactive source are thermalized by hydrogen molecules in the soil. These slowed neutrons are detected and counts are displayed in direct proportion to the water content of the soil sample. The measurements of soil moisture content are made by lowering the probe into an access tube installed vertically in the soil profile. Soil moisture is determined at specific depths to provide a 'Soil moisture profile'. Measurements were taken upto 2.5 metre depth only. This is limited because of available length of the cable and the access tubes supplied by the manufacturer. Instrument contains a microprocessor which allows the unit to compute and display the moisture content directly. The front panel of the gauge is shown in Fig.2. The display is in the units of kilograms per cubic metre, pounds per cubic foot, volume percent, count ratio, inches per foot, millimeters per meter or centimeters per meter. There is provision to alter the calibration to account for hydrogen other than that in free water and also to change the slope to account for materials absorbing thermal neutrons. The probe is found very useful for studying movement of soil moisture content in the unsaturated zone, and some of the findings are discussed in this report. An attempt has also been made to review the status and potentialities of the neutron probe.

1.1 Moisture Movement in the Unsaturated Zone

Information on the movement of water in the unsaturated zone is needed whenever one tries to set up a water balance either for the unsaturated zone itself or for the groundwater in the saturated zone beneath it. The knowledge of spatial distribution of soil moisture may yield information on the water movement as well. However , the relation between potential gradient and flow rate known as Darcy's law is more complicated in unsaturated than in saturated flow. In the saturated zone, the hydraulic conductivity is usually constant with time and even if its numerical value is unknown, relative changes in flow are strictly proportional to the corresponding changes of the hydraulic gradient. In the unsaturated zone, however, conductivity is a variable dependent on moisture content. Moreover, the relation between moisture potential and moisture content is a complicated one.

Zimmermann et al (1967 b), Munnich (1968 a) studied the moisture movement in the unsaturated zone by Tritium tagging method. The concept

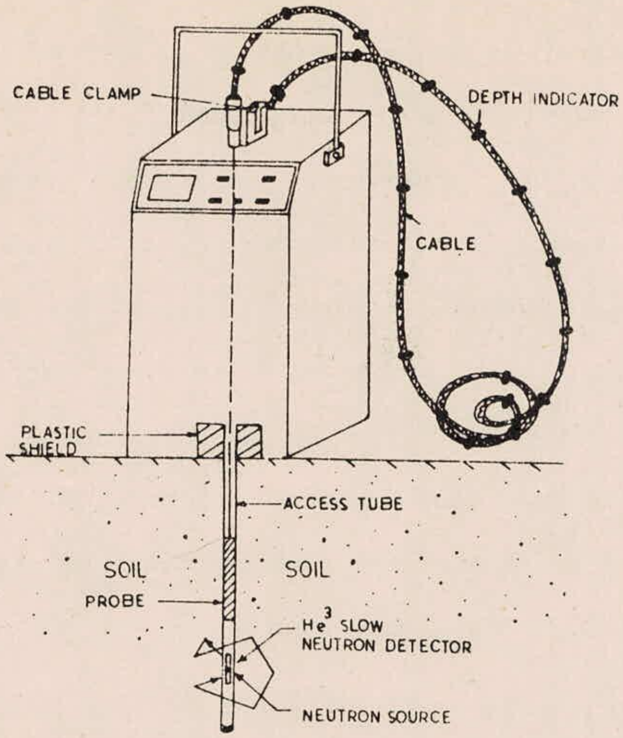

FIG. 1 - DIAGRAM OF NEUTRON PROBE EMPLACED ON ACCESS TUBE ; PROBE LOWERED INTO SOIL PROFILE

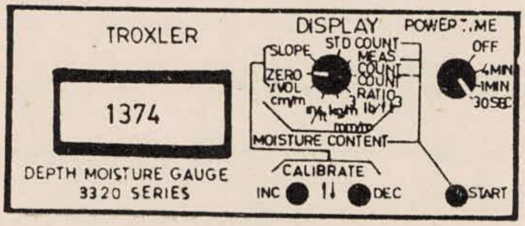

FIG. 2 - FRONT PANEL OF THE NEUTRON PROBE.

of water movement through soils, termed the piston flow model was developed. The studies employed the basic assumption that soil moisture moves downwards in discrete layers. Any fresh layer of water added on the surface, due to precipitation or irrigation, would percolate by pushing an equal amount of water beneath it further down, and so on, such that the moisture of the last layer in the unsaturated zone is added to the water table. Datta et al (1973) and Athavale et al (1980 & 1983) used the tritium tagging technique to understand the soil moisture movement and estimated recharge to ground water. This assumption of piston flow model was used by many others subsequently. Under this assumption, soil water or infiltrated water can not bypass or short cut the moisture of underlying layers in either direction and leads to a downward displacement of it like a moving piston.

Thus, the water flow in the unsaturated zone corresponds to that of mass flow in any chromatographic process and movement of soil moisture can be simulated by a simple one dimentional multibox model. Model may be used to describe the unsaturated zone as a series of soil layers with internally well mixed soil water. Lot of work has been done to understand the flow mechanism by tritium technique and by modelling. The use of neutron probe is still limited particularly in India. The probe if used regularily may provide valuable data which if properly computed and analysed may fill the existing gap in understanding the kinetics of the redistribution. In the present study, attempts have been made to understand the mechanism of soil moisture movement. Observations were taken at few access tubes daily at 0.10 metre interval from the depth 0.20 metre below the surface down to the bottom of the tube i.e. 2.5 metre. The method of tritium tagging of soil moisture has also been used for observing moisture movement and for estimating local ground water recharge. The accuracy obtainable depends upon the velocity of moisture movement, which is proportional to the groundwater recharge rate and inversely proportional to the field capacity of the soil.

1.2 Methods of Measuring Soil Moisture Content

The water content of soil can be measured by direct or indirect methods. Direct methods require a separate sample for each measurement, which precludes repeated measurements at the same point. Direct methods are preferred only when one time data is needed. Indirect methods require calibration to relate measurement to water content. Once the relationship is established frequent measurements are possible. These measurements are of non destructive nature and usually require little time.

DIRECT METHODS:

Direct measurements of water content remove water from a soil sample. Two recommended direct methods are oven drying and drying with burning alcohal. Oven drying is the oldest and most widely used direct method of measuring soil moisture content. The procedure involves weighing the sample before and after drying it at about 105°C and then calculating its original water content per unit mass of oven-dry soil. The drying of soil by burning alcohal is a rapid field method requiring minimal equipment. Soil drying is speeded up considerably by removing part of the water from soil sample using ethyl, methyl or propyl alcohal, then by evaporating water by burning the alcohal. This method can remove as much water as by oven drying, if the burning process is repeated several time.

INDIRECT METHODS:

Indirect methods of measuring soil water content include neutron scattering, gamma ray attenuation,gas pressure, soil water retention curves, electrical and thermal conductivity, and also velocity of sound. The gamma ray attenuation method is essentially a corelogging technique in which gamma rays are emitted from a radioactive source. The rays that are not attenuated when they pass through the soil core are counted by a detector. It has been a very effective lab method and can be adopted to field studies. In the gas pressure method, water content is determined by measuring the pressure temperature increase of the acetylene gas that is produced when calcium carbide is mixed with soil in a small closed containner. It is a rapid field method for estimating the water content of the soil.

Measurements based on electrical and thermal conductivity, and velocity of sound have not resulted in unique correlation with water content and thus have not come into common use. Neutron scattering is a single probe, borehole logging technique in which fast moving neutrons are emitted from a radioactive source. The neutrons collide with hydrogen atoms present in the surrounding soil and slowed down and can be counted by a slow neutron detector. It is very reliable field method for measuring soil water content. However, a limitation of this method is the difficulty in installing access tubes in hard soil. The merits and limitations are discussed in subsequent sections of this report.

2.0 REVIEW

The principle of measuring soil water content by counting thermalized neutrons was first proposed in the late 1940's and the instruments required for carrying out field studies were developed. The great advances in the electronics field since then have led to the development of highly reliable and stable systems. The use of neutron probe came into existence and it was properly understood for measuring changes in soil moisture in-situ to a precision obtainable in no other way. The effect of variation of a number of parameters such as changes in the density, the absorption cross section and the content of hydrogen, and organic matter in the dry soil are important factors to be considered for obtaining count rate. Concept of 'sphere of importance' was introduced, which is a measure of the volume around the source in which practically all thermal neutrons are found. This concept was given by Bavel et.al. (1956), stating that sphere of influence is the sphere around the source which contains 95% of thermal neutrons. For pure water, it was estimated as 15 cm. For other media, it was assumed that the sphere of influence is the sphere which contains the same amount of water as a sphere of pure water with a radius of 15 cm. Radius of the sphere of influence can be calculated by using the following formula

$$\underset{\text{(in cm)}}{R} = 15\sqrt[3]{100/V_w}$$

where,

R = radius of the sphere of influence, and

V_w = water volume percent

Soil moisture studies were carried out by Reginato et al (1964) by using gamma attenuation method. Hewlett et al. (1964) used neutron scattering method for studying soil moisture variance. Ølgaard (1965) carried out theoretical investigations of measuring soil moisture content by neutronic method. Various formulas were derived for determining nuclear constants of the soil. Numerical calculations for typical Danish soil types were performed. Soil moisture measurements of the surface layers were carried out by Pierpoint (1966) using neutron depth probe and a surface shield. Boodt et.al. (1967) determined soil moisture characteristics for irrigation by using neutron moisture meter and air-purged tensiometers.

Measurements of soil water storage changes for water balance purposes were taken up by Bell and McCulloch (1969). They carried out studies of soil moisture estimation in Britain by using neutron method. Studies were reviewed by Visvalingam and Tandy (1972). The application of neutron probe techniques were applied to irrigation research & management in Jamaica by Holdsworth (1974). Project was taken up by the Institute of hydrology, Wallingford with specific purpose for the improvement of the efficiency of irrigation of Bananas and Sugarcane at two experimental sites. This made it possible to gain useful information in a very short duration on the consumptive requirement of both the crops. Grant (1975) measured the soil moisture content near the surface by using a neutron moisture meter. Visvalingam (1975) investigated the effectiveness of the neutron moisture meter in studying saturated soil conditions. In the boulder clay experimental site, a perched water table observed during winter months was indicated by the neutron method and a gross moisture movement in the soil profile was observed.

Bell (1976) applied neutron probe particularly in the context of irrigation and water resources studies. Main uses were summarised as follows:

	APPLICATIONS	CONTEXT
1.	Measurement of soil water storage for water balance	.Catchment and plot studies for various hydrological purposes.
2.	Determination of soil water reservoir characteristics	.Process studies. .Land use capability studies. .Agricultural research. Planning irrigation regimes.
3.	Measurement of crop water studies use and drainage	.Feasibility studies for irrigation schemes. .Optimisation of irrigation water use. .Soil salinity control. .Groundwater recharge measurements. .Infiltration and drainage studies. .Studies of chemical pollution of the unsaturated zone.

Neutron probe was used to measure soil moisture storage for computing water balance and in-situ soil characteristics such as field capacity, drainage capacity, the drainage time constant, the saturation profile, the abstraction limit profile etc. Information obtained was used for many purposes in agricultural research, catchment modelling, soil surveys and studies of soil and water interaction.

Rao (1978) reviewed the application of radiation sources to measure water and soil characteristics. Neutron moisture probe was being put to use in India by the Scientists of Bhabha Atomic Research Centre, Bombay, Nuclear Research Laboratory, Delhi and Physics Department, University of Roorkee, Roorkee. Neutron moisture gauges were preferred over the conventional methods for monitoring moisture in the unsaturated zone. Shankar et.al.(1979) analysed variation of soil moisture at various depths by Ra- Be neutron scattering probe under ponding conditions. Experiments were conducted on a test plot by filling water in the enclosure to a certain height to study the mechanism of redistribution of infiltrated water under controlled conditions. Soil moisture studies were taken up in the Betwa Catchment by Hodnett et.al. (1981). The regional and annual variations of soil moisture were studied on the black cotton soils of Betwa Catchment (Central India) under Indo-British ground water project. Neutron probe was used to measure variation in soil moisture content and soil water flow mechanism. Bhatti (1983) used the neutron moisture probe for determining distribution of water in furrow irrigation. Soil moisture distribution measurements due to lateral spread of water were taken to analyse distribution uniformity precisely. Singh (1984) discussed special features of isotope techniques and studied moisture movement in controlled conditions in the laboratory and field. An eight years run of detailed soil moisture data was incorporated into simple water balance calculations by Pegg (1985), in an attempt to estimate actual evapotranspiration.

Ramesh Chand (1986) conducted some soil moisture studies at the National Institute of Hydrology, Roorkee using Troxler depth moisture gauge model 3321. Main objectives of these studies included the following:

1. To access the variability of soil moisture storage.
2. To provide regular measurements of the changes in soil moisture storage for the surface water balance.

3. To provide semiquantitative information concerning evaporation rate and recharge through the soil.

As the advantage of measuring soil parameters in-situ are numerous, the use of neutron probes is now being taken up by many institutions in India. Shortcomings of the sphere of influence concept are still to be overcomed. Error is involved in calculating 'R' the radius of the sphere of influence by trial and error method and neglecting of the existence of dry soil, which have a significant influence on the distance the neutron will move away from the source. As per the definition, it is not very appropriate to define the sphere of influence as the sphere around the source which contains 95% of all thermal neutrons. For hydrogeneous media the neutrons in the outerparts of the sphere will have little chance to get to the counter in case the later is situated near or at the source. For this reason, a different concept of the sphere of importance has been introduced, which applies in particular to cases where the detector is situated close to the source. The 'sphere of importance' was defined as the sphere around the source, situated in a moderating medium, which if all soil and water outside the sphere is removed, will yield a neutron flux at the source that is 95% of the flux obtained if the medium is infinite. A simplified expression for quick assessment of the radius of the sphere of importance (R_I) in the cases where the properties of the dry soil are not known may be derived for range of V_w between 0 and 35% by using the following expression.

$$\underset{\text{(in cm)}}{R_I} = \frac{100}{1.4 + 0.1\, V_w}$$

Practically, all the neutrons which determine the count rate of the detector will always remain inside the sphere of importance. Bell

(1976) gave the values of effective radius about 15 cm in Wet soil and upto 30 cm in very dry soils. The optimum spacing of observations should therefore be kept 10 to 15 cm and no greater resolution can be gained by decreasing this figure.

Recent studies have indicated that measurement of soil moisture content is not only important in the field of agriculture for planning irrigation regimes but also in the field of hydrology for infiltration and drainage studies, groundwater recharge measurements and water balance studies. The advantages of using neutron probe for measuring changes in soil moisture content are numerous. The most important one is that disturbances are nearly completely avoided and no artificial conditions are imposed.

3.0 PROBLEM DEFINITION

The moisture content in the surface layers of the soil is of great importance to the disciplines of agriculture, meteorology and hydrology. In hydrology, the moisture content of the surface layers is important for partitioning of rainfall into runoff and infiltration components. The soil layer considered is that which can interact with the atmosphere through evapotranspiration i.e. the soil root zone and the moisture content of this layer fluctuates in response to precipitation, irrigation and potential evapotranspiration. The thickness of this layer depends upon the type and stage of the soil's plant cover, but it is typically about 1 to 2 m. The moisture stored in this layer is called 'soil moisture'. This moisture, however, is only 0.005% of the total water on the earth's surface (Nace, 1964) but its seasonal variation accounts for 1.4 cm variation in sea level (Mather, 1974). Soil moisture exists in three different conditions, gravity water, capillary water and hygroscopic water. Capillary water can be removed from the soil only by overcoming the capillary forces, whereas hygroscopic water can be removed only by heating. Measurement of soil water involves three aspects: the volume of water, the movement of water and the energy with which the water is held in the soil. The water content of the soil and the suction or tension with which the water is held generally are inversely related. In unsaturated soil, the water potential is negative and is called 'matrix suction'. The term 'soil water tension' and 'capillary pressure' also refer to negative water potential. The rate of water movement is determined by the energy gradient and a water conductivity coefficient. In saturated soils, this coefficient is called the 'permeability' or the 'hydraulic conductivity' and in the unsaturated soils it is called 'capillary conductivity' or the 'unsaturated hydraulic conductivity'.

The movement of soil moisture towards the water table depends upon the soil properties, and amount and intensity of precipitation. High intensity rain of short duration can contribute more towards infiltration component than the long duration rains of low intensity for some soils, while reverse happens for other type of soils. It is not very easy to understand the mechanism of flow of moisture in the unsaturated zone. Various classical methods have been in use in the past which have been recently overtaken by nuclear methods. These may include the injection of radio isotopes, H^3 (tritium) or cobalticyanide etc. in the soil below the root zone and following its movement with respect to the infiltration of precipitation. The other approach, the most suitable one is the use of neutron probes. They can be used to measure water movement in the soils under different conditions, at different depths,locations and times. Field capacity and the kinematics of water redistribution can be deduced from these measurements.

4.0 METHODOLOGY

The neutron soil moisture gauge used for soil moisture studies, usually referred to more simply as the 'neutron probe', consists essentially of a probe containing a fast neutron source and a slow neutron detector adjacent to the source. The probe contains a radioactive source which emits fast neutrons into the surrounding soil. Collision of emitted neutrons with the nuclei of the soil atoms, predominantly those of hydrogen in the soil water slows down the neutrons. Neutron lose their kinetic energy and get slowed to the so called thermal energy level, and finally get absorbed in the medium by other nuclear reactions. Thus a cloud of slow neutrons is generated with in the soil around the source. The density of this cloud which is largely a function of the soil water content increases with the concentration of the hydrogen nuclei of the soil water molecule. The number of thermalized neutrons are detected by a slow neutron detector and represents the soil moisture content.

The Americium 241: Berrylium source is selected in the Troxler depth moisture gauge mainly on two grounds. First, the lower level of gamma radiation in amount and energy adds to the safe handling of the instrument by the user, secondly very long half life of the source (450 years) leads to minimisation of the losses caused by the drift in activity. A Helium-3, detector is used to detect thermalised neutrons, , these detectors are more expensive than other detectors such as boron trifluoride (BF_3), lithium glass and other scintillation detectors but He^3 detectors are preferred because of their high sensitivity and comparative simple electronics.

There is a optimum geometry for each source and detector to obtain the maximum sensitivity, and a linear calibration. Ideally, the source and detector should lie at the same point, but in practice the linearity is acceptable provided no part of the detector is more than about 6 cm away from the source. Detector used in Troxler depth moisture gauge (which has been employed for soil moisture studies at the campus of the National Institute of Hydrology, Roorkee) is a metal tube about 38.10 mm in diameter and is insensitive to fast neutrons. As such, it is not necessary in this gauge to shield the detector from the source. Generally, the counts obtained from an He^3 detector are directly proportional to hydrogen atoms present in the soil. The gauge is calibrated to get a relationship between the actual moisture content and moisture read by the neutron probe. A specific procedure is adopted for using these probes which is discussed in next section.

4.1 Procedure for using the Neutron Probe

Measurements of soil moisture are made at various depths in the soil profile by lowering the probe into access tubes. The geometry of the probe and the access tube should be similar i.e. the diameter of the probe and inner diameter of the access tube should be such that the probe moves just freely up and down in the access tube. The access tubes are installed in the field. Generally, three types of material viz. aluminium, steel and polyethelene are used for the construction of the access tubes. Aluminium absorbs very few thermal neutrons and is durable in field. But the drawback is that aluminium may corrode in highly acidic/alkaline soils or the soils having high concentration of sodium chloride. Stainless steel corrodes more slowely than aluminium, whereas iron contents in it absorb thermal neutrons. This decreases the sensitivity of the probe. However, polyethelene does not corrode but high hydrogen content in it and variation in composition reduces the sensitivity of the measurement. It is thus desirable if the tube material is low in hydrogen content and strong enough to go upto desired depth. Moreover, the variation in composition of material used in constructing the tube should be minimum. Hence, aluminium is most suitable material used for fabricating tubes for soil moisture studies by neutron probe. Aluminium tubes provide the best results whereever neutron gauges are utilized.

Tubing is used to line a hole to access a sample at a desired depth and it protects the probe from direct contact with the soil and provides facility for repeating the observations. Tubes installed at the N.I.H. Campus are of 41.25 mm out side diameter and 39.40 mm inner diameter. For installation of these aluminium tubes, holes were drilled by an auger such that diameter of the drilled hole is of the same order in size as the access tube so as to have tight fitting of the tube into ground. This is done to prevent the seepage of water along the outer surface of the tube. Moreover, the part of the tube length about 10 to 30 cm is kept out above the ground surface to check flooding of the tube. The access tube is sealed at the bottom to prevent water seepage in it. This prevents damage to the probe and from getting erroneous readings. This may be done either by a tapered plug of the same material or by putting a rubber cork. The conical shape of the end plug is preferred as it presses the projecting stones back into the side.

Placing the access tubes in the field by using suitably sized soil auger is being adopted. However this method is unsatisfactory and care should be taken in installing the access tubes. As the presence of stones can easily deflect the auger bit and where a stone is forced aside, a cavity may be made in the side of the hole. The repeated movement of the auger up and down the hole, while removing soil tends to enlarge the top of the hole, leaving room for water to rundown the outside of the access tube. This can be overcome to some extent by backfilling from the surface but this is difficult to do properly as it may result in a zone of different density and structure around the access tubes.

After installing the access tubes in the study area neutron moisture probe is kept on the tube. Observations of soil moisture content are taken by lowering the probe into the tube. Standard Counts are first taken before lowering the probe into the access tube. The thermalised neutrons are counted at various depths by lowering the probe in steps. The Troxler depth moisture gauge has a built in micro processor to compute the ratio of measured counts to standard counts and moisture content can be read in the units of pound per cubic foot, inch per foot, kilogram per cubic meter, centimeter per meter or percentage volume. The depth of the probe is read with the help of depth indicators placed on the cable. The observations can be taken upto the bottom layers, and are limited due to length of the cable and that of the access tubes.

4.2 Calibration of the Instrument

There are three basic techniques for calibrating the neutron moisture probe to read actual moisture content against the neutron count rate. Soil moisture is defined for the purpose of neutron probe calibration as the water that is or would be expelled from the soil by drying it at 105°C. This may be expressed as moisture volume fraction i.e. the volume of water per unit of soil. All the water is not expelled at 105°C, some remains as water of crystalisation or hydration of various minerals. All the hydrogen is also not present only as water. Hydrogen in organic compounds is not expelled at 105^{o}C, but affects the count rate exactly as if it were the equivalent amount of water. However, these fixed forms of hydrogen are relatively constant for a given soil, so that changes of count rate may be attributed entirely to changes in water content assuming a constant bulk density.

The three techniques used for calibration are

i) Theoretical calibration based on soil chemistry
ii) Drum calibration in the laboratory
iii) Field calibration.

i) Theoretical calibration is based on the very complete and accurate chemical analysis for soil elements. For certain elements like boron,chlorine and cadmium, the accuracy required is of the order of a few parts per million. The scattering and capture cross section of these elements are known; and hence the macroscattering and capture cross sections of soil are derived. From this information, it is possible to predict the calibration curve for any bulk density value. The prediction is not perfect as mathematical approximation of the true physical situation are involved. The count rate of a given soil is dependent upon the soil chemistry; soil bulk density and moisture content considering soil chemistry as constant for the soil, the soil bulk density and moisture content remain variable and thus the method of calibration is for most purposes of theoretical interest only.

ii) Laboratory calibrations are performed in large drums and are very accurate. However, soils which are homogenous in texture and chemistry can be repacked uniformly in the laboratory to nearly similar to their field conditions. Soils which do not change their dry bulk density with water content are also suitable. Accordingly, gravel, sand or silty soils are suitable for drum calibrations. Drum of known volume is taken. It should be water tight and at least have 2-3 m diameter and 1-2 m depth. A smaller drum may give wrong results due to escape of neutrons, particularly at the dry end of the moisture range. Few tons of soils is required to fill the drum. The soil is dug from a pit, mixed, air dried and weighed in portions into the drum, where it should be packed as uniformly as possible to the orginal field bulk density. An access tube is installed at the centre of the drum. A count rate profile is taken and plotted to confirm that the packing is uniform, this should be demonstrated by a uniform plateau in the count rate profile through the central part of the drum. The probe is set in the centre of the plateau and a large number of counts are taken and average value is determined. The mean count rate is plotted against the calculated moisture content of the drum giving the first calibration point. Water is then measured into the drum through a preplaced tube reaching to the bottom, so that air is displaced upwards as the water rises. When the profile is saturated the counting is repeated and the mean count rate is plotted against the calculated moisture content to give the second calibration point. The success of the method depends very much upon the work at all stages being performed with great experimental rigour.

iii) Field calibration is the simplest and easier method of calibration. Due to soil heterogenity and various sampling errors there is often a wide scatter in the calibration points. Many points are required to perform a linear regression, since these must span the moisture range of the soil, it usually takes a year or so to finalise the calibration. The main possibility of error lies in the introduction of a common bias in the measured moisture content, which is obtained gravimetrically from soil cores. All soil corers tend to compress the soil to some extent unless great care is taken and this results in error in the volume moisture content. To obtain each point, a temporary access tube is installed at the chosen site fairly close to a permanent tube. Precise counts are taken at various depths and few known volume soil cores are then taken from close round the tube at each depth. Dry bulk density is calculated by knowing the volume of the cores. Moisture content of the soil samples can be either determined on an Infra red balance or by oven dry method. The moisture content is plotted against the count rate to get calibration points. It is however difficult to apply this method to depths exceeding 1 m without digging a pit.

Singh (1984) determined the calibration constant for the depth moisture probe type DM 655. The moisture content was measured at various depths and soil samples were taken from the corresponding depths. Neutron count rate was plotted against the moisture content of the soil samples and the following relation was obtained.

$$M = 0.212\, M_c - 16.758$$

Where

M = Moisture Content (% Volume)

M_c = Neutron Counts per second

Calibration of theTroxler depth moisture gauge used at the N.I.H. Campus (Ramesh Chand, 1986) was done by field calibration method. Following relation was obtained

$$M = 0.367\, M_{np} + 4.68$$

Where

M_{np} is the moisture read by neutron probe and M is the moisture content (% volume).

5.0 APPLICATIONS

The main uses of neutron probe particularly in the context of water resources studies are measurement of soil water storage for water balance studies, determination of soil water reservoir characteristics and measurement of crop water use and drainage etc. The applications are numerous inspite of some limitations like inadequate depth resolutions limiting the use of neutron probe in studying evaporation, infiltration and percolations. It is difficult to make absolute measurements of moisture content. However, it has been stated (Stone et.al. 1966) that the accuracy of the neutron probe measurements exceeds that of standard techniques available.

Before the development of neutron probe for routine measurements of soil moisture storage, the usual practice in making a water balance was either to neglect this term or to choose periods for which it could be assumed that soil moisture had reached a particular state. The soil moisture term thus became a repository for the errors in all the other terms, and the very important physical role of the soil as a regulating system between the rainfall and discharge was being neglected. The general water balance equation may be written as

Runoff = Precipitation-Evaporation-Increase in soil water storage

The most indirect of the measurements of these components is evaporation. Even when meteorological data is available there is still considerable uncertainty attached to this term particularly in hilly and forested catchments. The provision of reliable measurements of Δs removes the uncertainty from the water balance.

Soil characteristics such as field capacity, drainage capacity, available water capacity, the saturation profile etc. can be measured in situ by using the neutron probe. Employing tensiometers, soil water potential can be measured. Then soil characteristics such as moisture characteristics (relating tension to water content) and the unsaturated conductivity characteristics (relating tension to conductivity) can also be measured. Information thus obtained may be used for catchment modelling, and physical studies of soil and water interaction. The advantage of determining these quantities in-situ are that the unacceptable disturbances are avoided and the values obtained are almost certainly much closer to the natural macrovalues than values derived from laboratory measurements conducted on comparatively small samples. For example, the largest component of conductivity in some soils might be due to fissures, root channels, worm holes or shrinkage cracks, none of which can be adequately reproduced in the laboratory. Artificially saturating soil profile and plotting the soil water storage decay curve, it is possible to define constants such as the drainage capacity, saturation limit, drainage time constant and field capacity.

Long term soil moisture records can be used for determining soil parameters. By plotting the changes in soil moisture at different depths with time, Field capacity and abstraction limit profiles may be derived and the moisture available can be determined. Estimation of transpiration, however crude, may be possible if the data is sufficiently precise and frequent. Soil moisture deficit is one of the easiest variable to measure and can be used for testing the validity of predicted soil moisture deficits and for short period models where changes in the soil moisture storage becomes important. In addition, neutron probe could be used for obtaining numerical values for soil constants for use in mathematical models.

The neutron probe can also be used in number of ways at different level of sophistication to estimate crop water use and drainage from the soil reservoir. During the active growth season the decay curve of the soil moisture reservoir can be used to estimate transpiration, however subject to certain reservations. The combined use of tensiometers and neutron probe provides a more sophisticated and powerful techniqaue by which it is possible to measure unsaturated fluxes of soil water in-situ. Application may include direct measurement of drainage to groundwater, direct measurement of crop water use, control of irrigation efficiency and monitoring magnitudes, and direction of movement of chemical ions i.e. pollutants in the unsaturated zone. The Penman equation is generally used to estimate evaporation and drainage. Soil physical methods referred to as the zero flux plane method and the hydraulic conductivity/potential gradient method offer a means of measuring evaporation and drainage directly. They both require essentially the same measurements and instrumentation are therefore complementary, being applicable in different seasonal conditions.

The use of neutron probe is not restricted to pure or semi applied research, it has wide applications particularly in the context of arid land irrigation. Probe may be used for assessing the soil water reservoir characteristics. The efficient use of limited water supplies is of great economic importance but some irrigation schemes fail and other waste water, in both cases due to poor management caused by lack of knowledge of the behaviour of the soil reservoir. Exact knowledge of such factors as the consumptive use of each crop, the available water capacity, the soil moisture deficit etc. make it possible to minimise losses to ground water and high direct evaporation losses. Optimum leaching rates could be determined much more efficiently in case of soil salinity or ground water salinity problems.

As stated earlier, Troxler depth moisture gauge (Model 3321) was used for soil moisture studies in NIH Campus. Access tubes were installed. Four tubes having 4.0 cm dia and 3.0 metres in length were numbered as site A, B, C and D in order from North to South. Separation between the tubes is about 2 m to 3 m and all are situated within the fenced area of NIH meteorological station. Tube 'D' is surrounded by a metal enclosure of size 2m x 2m x 1m. The tank wall penetrates into the soil to a depth of 60 cm and about 40 cm is left above the ground surface for use in studying soil moisture movement under controlled (ponding) conditions. Tube 'A' is enclosed by a mud bunding to check runoff in the vicinity of the tube. Tube 'C' is installed to achieve the natural conditions, while purpose of tube 'B' is to account for lateral flows and topographic depressions in the area. Observations were taken on these tubes more or less daily at 0.10 m depth intervals from 0.20 m below the surface down to the bottom of the tube i.e. 2.5 m.

Installation of tubes and calibration of the probe, basic principle of neutron probe and other relevant information has been given in the preceeding sections. Counting of thermalised neutrons was done for 30 to 60 seconds. The data collected and its interpretation is given in the following sections. The study clearly shows the capabilities of the neutron moisture probe in providing accurate measurements of soil moisture.

6.0 RESULTS

The moisture content measured at each access tube by using neutron probe is assumed to represent the moisture of a layer extending midway to the adjacent measuring depths. The amount of water stored in each layer in millimetres i.e. expressed as a depth, is the product of the layer depth and the volumetric moisture content. The amount of water stored in different layers are then summed to the required depth to give the total amount of water stored in the profile upto that depth. Data is presented in graphical forms either as volumetric moisture content (VMC) i.e. volume of water by volume of soil (cm^3/cm^3) or as the total profile water content. Volumetric moisture content is plotted against depth below ground level. The moisture changes both with depth and time have been analysed.

The typical soil profiles are shown in Fig.3, 4 and Fig.5 respectively. Several curves are getting superimposed on the same graph corresponding to different dates. The area under each curve represents the total moisture content on each date. Variation in moisture content with depth at the site 'A' are shown in Fig.3 for the dates 22nd April, 22nd May and 21st June 1985. Actual evaporation was computed for the period 22nd April to 22nd May and 22nd May to 21st June 1985 as 5 cm and 1.91 cm respectively. Fig.4 shows the moisture variation at depth on the dates 22nd April, 19th July, 6th August and 4th October 1985. It is seen from the figure that there is not much variation in moisture content below 120 cm depth. Profile of 19th July shows depletion in moisture content above 120 cm depth. While profile of 6th August represents the amount of water gained. Fig.5 shows moisture profiles before and after the rainstorm of 6th August 1985 for the site 'D'. Soil returns to an almost identical moisture content after few days and retains its level.

Rise in water table and increase in soil moisture storage against the precipitation of 1985 is shown in Fig.6. Data is plotted from May to December 1985. Rainfall storms are also shown in the figure. From these results, it can be seen that between around 22nd August and 30th December, the water table in the study area was less than 3.0 m below the ground level. As there is no significant variation in moisture content below 1.20 meters, soil moisture storage was computed upto this depth. Further, data is being collected for the period starting from Jan.1986 and will be collected upto May-June, 1987 and will be put to rigrous analysis. Attempts will also be made for modelling of soil moisture movement using this data.

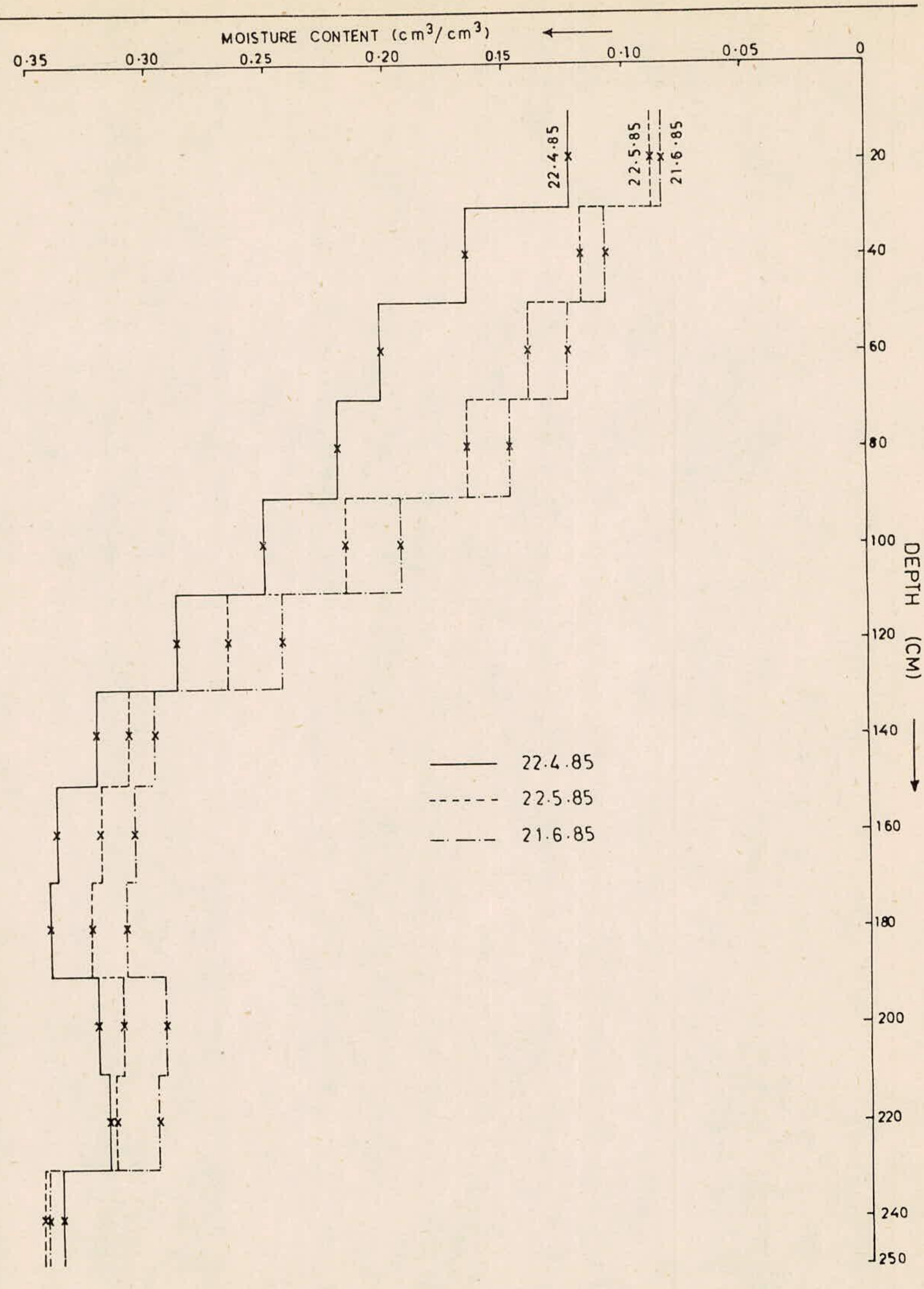

FIG. 3-MOISTURE CONTENT PROFILES FOR THE SITE 'A' DURING PREMONSOON MONTHS.

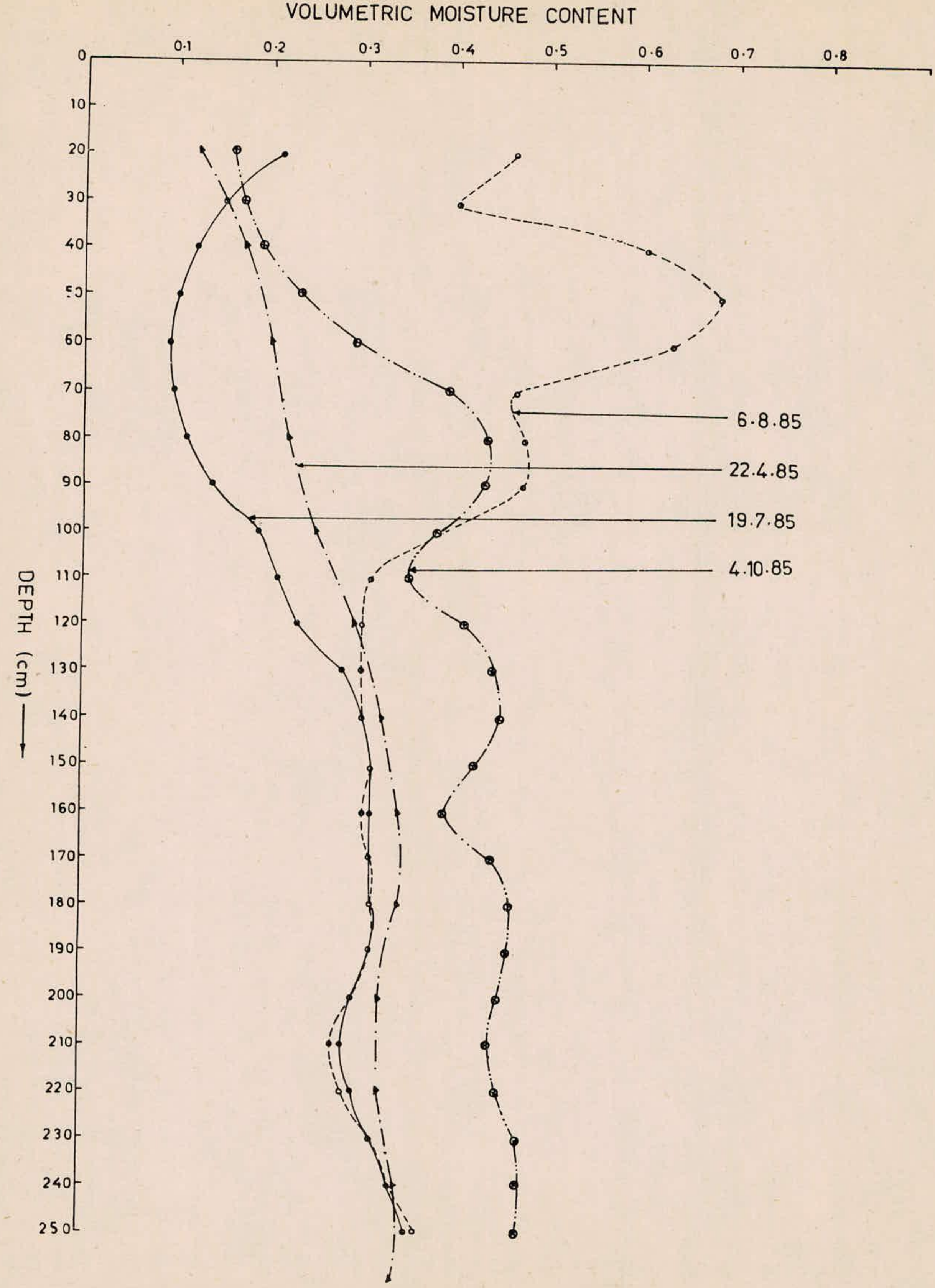

FIG. 4 - MOISTURE CONTENT PROFILE FOR THE SITE 'A' FOR 22 APR., 19 JULY, 6th AUG & 4th OCT 1985

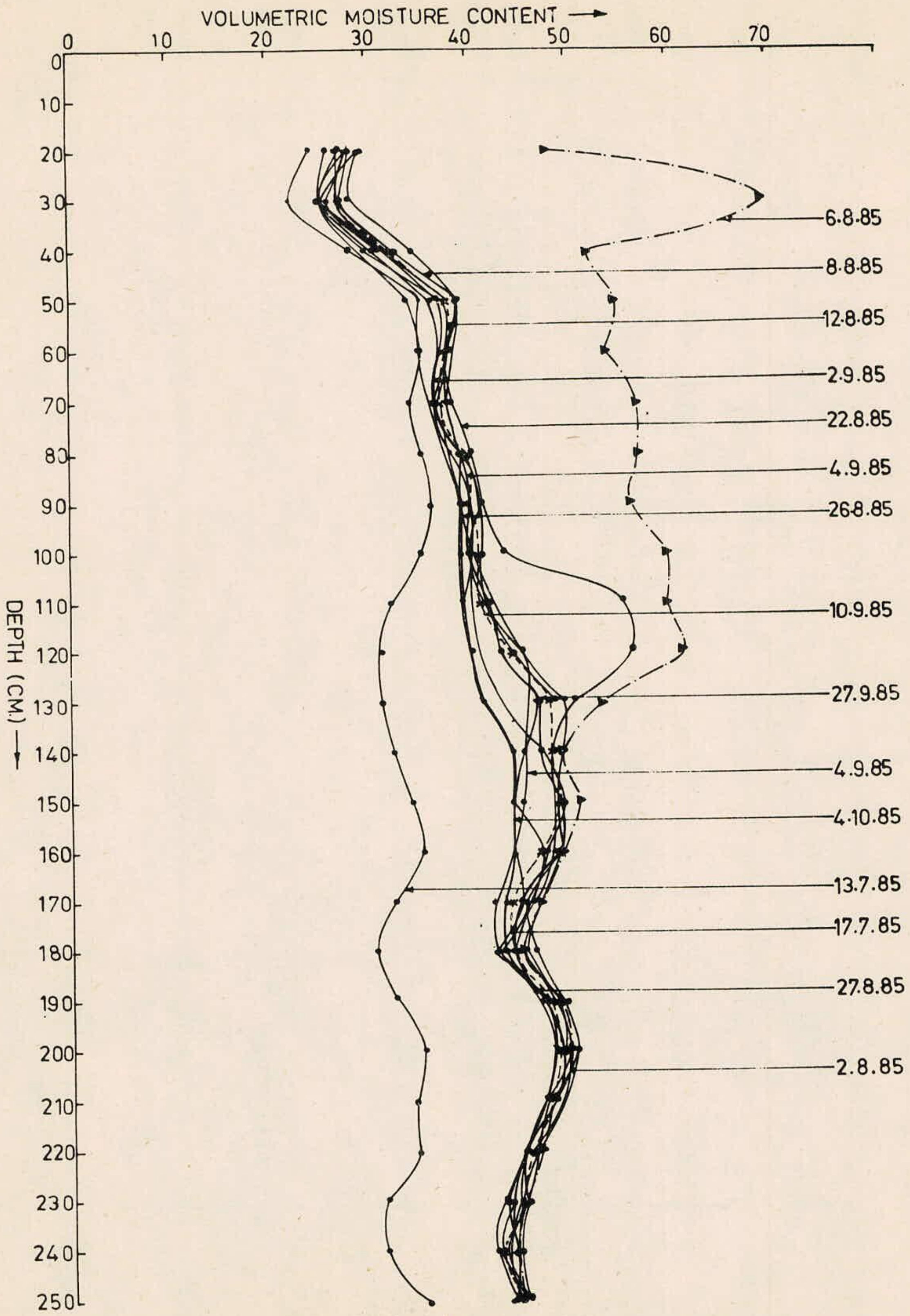

FIG. 5-MOISTURE CONTENT PROFILES FOR THE SITE 'D'

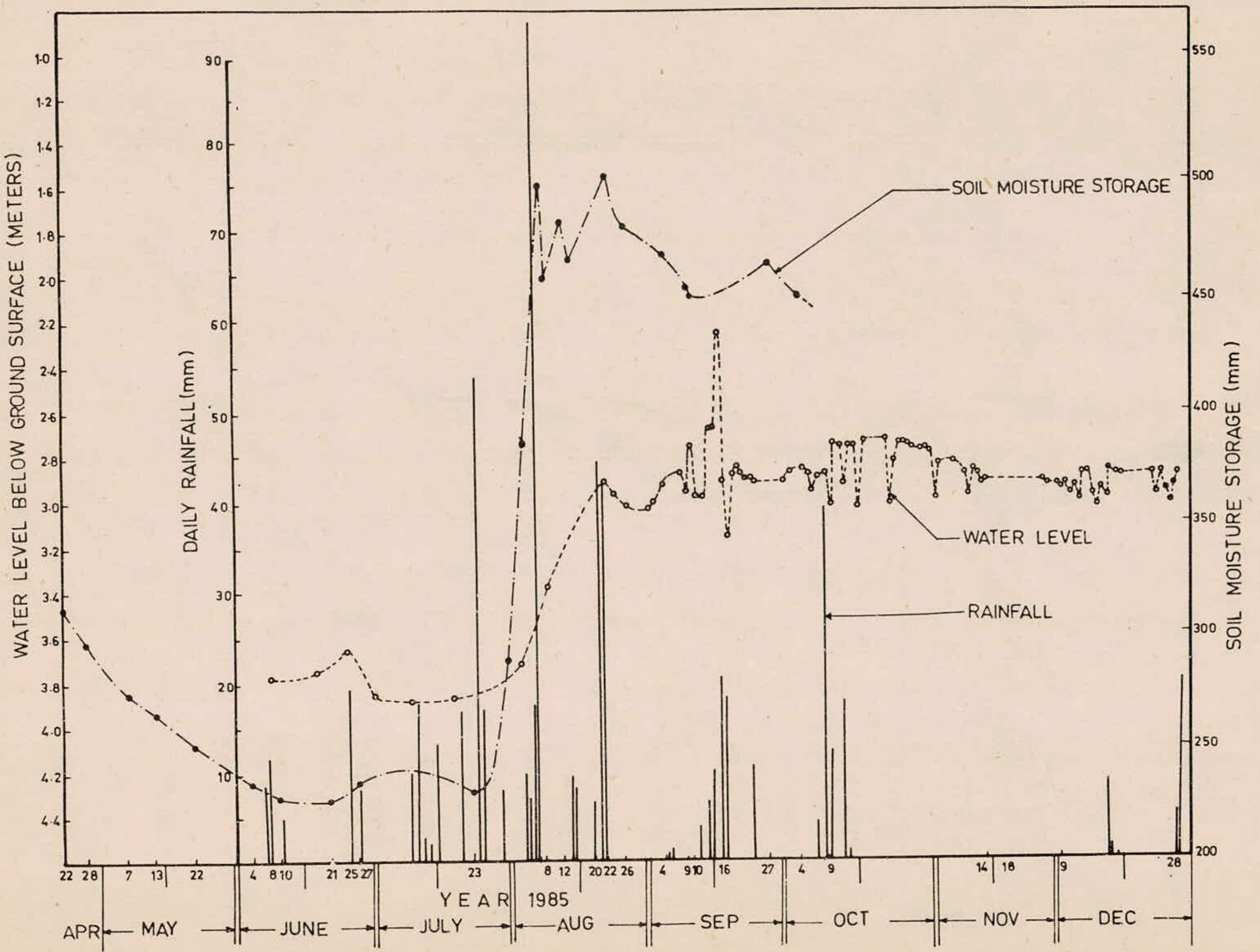

FIG. 6-WATER LEVEL FLUCTUATIONS, RAINFALL & VARIATION OF SOIL MOISTURE STORAGE (UPTO 1·2 M. DEPTH) APRIL-DEC. 1985.

7.0 CONCLUSION

The investigations carried out in the campus of National Institute of Hydrology clearly bring out the potential of neutron depth moisture gauge for studying movement of soil moisture in the unsaturated zone. The probe allows measurements at different times and at different depths at number of locations, and thus provides a varsatile method for study of soil moisture distribution in space and time. The instrument though somewhat expensive, is very suitable for studying variations of moisture in the root zone.

During the dry periods the neutron probe provided data to compute actual evaporation and the studies also show that drainage losses for the soil structure in NIH Campus are relatively small in the zones below 60 cm depth. Depletion in moisture content and water gained by the soil during a rainstorm is clearly indicated by the soil moisture profiles, and it is seen that these is not much variation in the moisture content below 120 cm depth.

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