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Soil Moisture Measurement Techniques

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ABSTRACT

With the increasing interest in soil water, demand of its information for planning of the watershed, forecasting of yield in an improved way, irrigation scheduling, partitioning of rainfall into its runoff and infiltration components and also net radiation into latent and sensible components along with desertification etc., is becoming increasingly important in the areas of agriculture, hydrology and meteorology. The thickness of the soil layer enabling measurement of soil moisture, however, depends on the type and stage of the soil-plant cover; is only around 2m depth from the ground surface. The soil moisture retention in this depth is about 0.005% of the total water on the earth's surface. But, this amount is very important for the survival, sustenance and growth of the plants.

The paper discusses various techniques for measuring soil moisture. In fact, an effort has been made to compile the information available on the techniques to make them more viable for their efficient use in a number of applications and thrust areas.

Introduction

In a number of known processes affecting the rainfall-stream flow relationship within agricultural watershed, the most significant amongst them is the storage of water in the soil mantle, called soil moisture. The term applied to the quantity of water held in the soil by means of molecular attraction. It forms a film around the soil particles, fills the small wedgelike spaces between soil particles and may completely fill the smaller interstitial spaces.

In terms of total volume, soil moisture accretion is the largest abstraction from the rainfall and thus it becomes an important factor in deciding the overall performance of a watershed. It also governs the air content and gas exchange of the soil, thus, affecting the respiration of roots, the activity of microorganisms and chemical state of the soil. Idso et al. [1975(a)] has described the need of soil moisture information for many diverse applications. Hydrological applications have been dealt by Charney, et al. (1977), Idso (1977), Walker and Rowntree (1977) and Gannon (1979) and seasonal variations by Mether (1974). The information on global moisture content has been given by Nace (1964).

Measurement Techniques

There are various techniques for the determination of soil moisture. Some of the important techniques are described below.

1. Gravimetric technique
2. Tensiometric/Psychrometric technique
3. Hygrometric technique
   (Porous Sorption Blocks)

4. Thermal conductivity technique
5. Electrical Resistivity technique
6. Nuclear techniques.
   - i) Neutron scattering technique.
   - ii) Gamma ray attenuation technique.
7. Electromagnetic technique
8. Remote sensing technique
   - i) Thermal technique
   - ii) Microwave technique

In all above measurement techniques, soil moisture measurements are made at selected depths below the ground surface. Site and depth are selected on the basis of soil survey and morphology of the soil profile. Measurements are taken on regular basis and on as many sites as feasible and can be maintained adequately. Some of the supplementary observations are required to be maintained to the extent possible before and after the storm events and consecutively on days during the periods of drainage and evapotranspiration also. With this, it will be possible to estimate soil moisture recharge due to infiltration of rainfall and losses due to drainage and evaporation. Records taken before and after rain storms are useful in explaining the performance of watershed under different conditions of soil moisture.

The selection of a particular technique is based on the requirement of precession and accuracy and some other features of the techniques (performance, size, computability) and instrumentation involved and also their operation and maintenance etc.

Selection of site is another important feature as it is affected by profile characteristics-slope, landuse, treatment and exposure etc. It is necessary to perform preliminary statistical survey to know about coefficient of variability w.r.t. soil moisture properties and areas of different sizes consistent with homogeneity considerations are selected. Limited information on proper techniques for the selection of sites for moisture-station is known. Therefore, analysis of data should be kept current so that adequacy of the sampling procedure can be determined.

1. Gravimetric Technique

The technique has been discussed in details by Black (1965), Brakensiek et al. (1979), and Reynold [1970 (a), (b)]. It is the most common, direct and standard technique applied for the measurement & calibration of all other soil moisture measurement techniques. It is given the name even drying technique also. In this technique, weighed soil samples are placed (for 10 to 24 hrs) in an oven maintained at 221° F (105° C) until a constant weight is obtained. The time required for drying up is a function of sample size, no. of samples in the oven, moisture content of the sample and type of the oven used. The ratio of difference in weight before and after drying to that of weight of dry soil, multiplied by 100 is the measure of % moisture content by weight. Multiplication of dry density of soil system with moisture content by weight provides information of moisture content by volume.

There are two techniques :

- i) Standard technique
- ii) Non standard technique

i) Standard Technique

In this technique, conventional type shorels, spiral hand augers, bucket augers, power driven or hand driven soil sampling tools e.g. veihmeyer tube are used for collection of soil samples from the field. Soil samples of field are placed immediately in leak proof polythene bags and transported to the lab for oven drying. Generally, 100 gram to 200 gram sample is collected in each bag. A 100 gram sample may contain about 20 gram of water and on error of 0 1 g in measurement will represent error of 0.5% in percentage moisture content by weight.

(ii) Non Standard Techniques :

Non standard technique is employed only for some special purposes or in emergencey of needs where prompt and quick results are desirable. Drying the samples at 105°C is preferable in case of sandy textured soil only. It can not be generalized for all type af soils as some of the volatile compounds of soils may be evaporated and would cause considerable error in measurement. There are some other non standard techniques for measuring soil moisture. They are given below in brief.

(a) Soil sample is taken in a bottom of tarred perforated container and methanol is pored on to the soil until an appreciable amount drips down in another container (metal saucer) placed below. The methanol being miscible with water, removes some water from the soil by mass flow and provides heat for evaporation of water. The amount of alcohol required will depend on soil sample, texture and moisture content. The dripped content is subjected to ignition where alcohol is burnt and water is left below. Here also, there may be an error due to losses of a good amount of volatile components from the soil on heating or actual combustion.

(b) In some situations, carbine bombs are used for the measurement of soil mojsture, In this technique, moist soil sample is mixed with calcium carbide in a closed chamber where acetylene is produced as a result of reaction between the available water of soil and calcium carbide. The pressure of the gas inside the chamber is measured. This pressure is proportional to the soil moisture content in the soil. The technique has an advantage for providing quick results in the field.

(c) Measured amount of polar and non-polar liquids are added to the soil sample in the pycnometer and measurement of soil moisture is done. This method is not in practice because it is not convenient and limits its use for large number of samples.

(d) Commercially available semi-moisture balances or moisture meters are also used for soil moisture measurement. A small amount of soil (6-10 gm) sample is placed in a permatnent or disposable aluminium dish and dried up by the heat received from infrared heating temperature. The time of heating is determined dby trial and error method but in most of the cases, 10-15 minutes are requested to dry up the soil samples. The equipment needs electricity and cumbersome to be used for processing of a large number of samples at a time. This technique is almost similar to the normal gravimetric technique. The difference is only that, it requires less amount of sample, less time to dry up and reduces the error of absorbing hygroscopic moisture during the weighing of heated soil samples. Its use is limited for a regular soil moisture sampling in situ. The gravimetric method of soil moisture determination needs excavation and back filling of holes and for a long term study of a small area, a considerable portion of the area is disturbed. This affects the hydrology of the area.

Percentage volumetric content of soil moisture is the ratio of volume of water sample to that of bulk volume of the sample multiplied by 100. Here we assume that sp. gravity of water in the soil remains constant. In case the sp. gravity is consiaered to be a variable, then

$$M_v = (M_w \, . \, \rho_d / W_d \, . \, \rho_w) \times 100$$

where

W_w — weight of water in g.
W_d — weight of dry soil in g,
ρ_d — dry density of soil in g/cm^3
ρ_w — density of water in g/cm^3

$$M_v = (W_w / W_d) \, \rho_d \times 100$$

where ρ_w is constant. But $(W_w/W_d \times 100)$ is the M_w (i.e. % of soil moisture by weight). Therefore, the relation between % soil moisture by volume and % soil moisture by weight is given by

$$M_v = M_w \times \rho_d$$

Percentage volumetric moisture content is useful in the sense that it may be converted into surface units of water. Therefore, it becomes compatible with the quantities like rainfall or irrigation water applied. Depths of water applied in the soil is given by

$$d = [D\ (\Delta \rho_w)\ \rho]/10.0$$

where D — depth of sampling layer (cm.)

ρ — average bulk density of soil (mm)

d — depth of water applied (mm)

$\Delta \rho_w$ — soil moisture content on volume basis corresponding to D.

2. Tensiometric / Psychrometic Technique

Tensiometer is an instrument used for the measurement of capillary potential, soil moisture potential, stress, suction or matric suction of soil moisture. The name was given by Richards and Gardner (1936) and by Richards (1949). Baver et al. (1972) have described capillary potential as total potential. Measurement of this potential in terms of suction force of soil for water was described by Baver et al. (1972) & Richards (1965). Various designs are available for the measurement of pressure by making use of Bourden tube or transducer for electrical output. One design of the tensiometer is shown in Fig. 1. Ethylene glycol water is used for cold regions (Mckim et. al. (1976)]. Communication of tensiometric data has been described by [McKim et al. (1975), Elzeftawy and Mansell (1975) & Gilham et al. (1976)]. Abele et al. (1979) described the range of tension changes from 200 to 800 cm of H_2O with 1% change of soil moisture by volume. In all such cases, users require a relation between moisture content and soil moisture potential. But, no such unique relationship for most soils exists. It is becuse of the property of hysteresis observed as a result of watering and dewatering that may be by irrigation & evaporation respectively. Thus, the soil moisture content at a given capillary potential is a function not only of the capillary potential, but, also of the history of soil volume characteristics [Brakensiek et. al. (1979)]. In certain cases contribution of osmotic potential is high. Then, the measurement of capillary potential is taken with care.

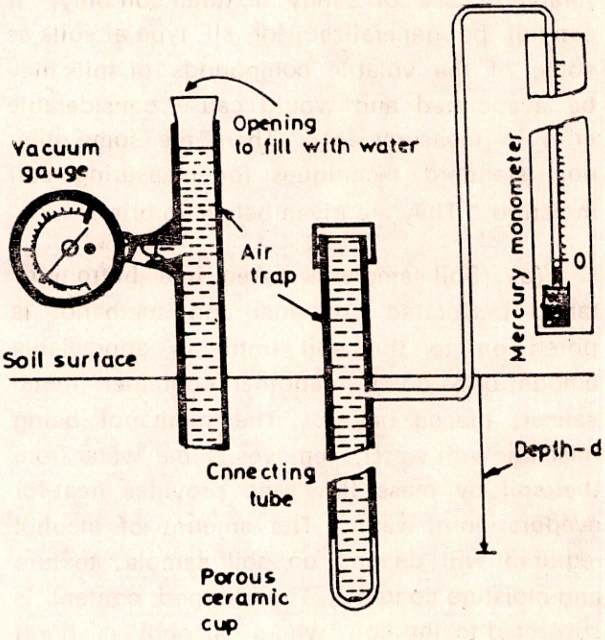

Fig. 1 Tensiometer

Bianchi (1962), Klute and Peters (1962), Watson (1967), Rice (1969), Anderson and Burt (1977) have stated the advantages of using pressure transducer type of tensiometers for monitoring changes (gradient) in case of infiltration, irrigation, ground water recharge and evapotranspiration.

The essential part of the soil moisture tensiometer is a porous membrane. It is made of ceramic with uniform pore size and capable of withstanding maximum capillary suction. The porous membrane of the tensiometer is saturated with water before it is subjected to field for installation. Bubble creates negative pressure inside the tensiometer and this situation must be avoided. Boiled water or degassed water is usad in vacuum for charging. After charging the ceramic cup, it is wrapped with wet rag or inserted in a container of water. For good contact between the ceramic cup and and ground, a slurry of mud with water is prepared and the porous cup of tensiometer is set in it. A casing or impermeable barrier around the tube is provided. The barrier may be a layer washer cut from a sheet of rubber, asphalt of bitumen, a layer of clay, caulking compound or various chemical grouts. Sufficient time is needed for the tensiometer to reach to the equilibrium condition with the surrounding soil moisture. In case the tensiometer is installed below the plant root zone, the installatian may take several weeks. Some tensiometers have the provision for the measurement of electrical conductivity of the solution also. Tensiometer readings undergo diurnal changes even when there are no apparent changes in the soil moisture content. Therefore, the readings should be taken at the same time each day, preferably early in the morning.

Dalton and Rawlins (1968), Brown (1970) have discussed development of highly precise miniatured thermocouple psychrometers for in situ measurement of soil moisture potential. Cross section of a thermocouple Psychrometer, contained in air filled ceramic cup has been shown in Fig. 2. One junction of the thermocouple is placed inside a hollow porous cup embedded in the soil and the other in an insulated medium to provide a temperature lag. As a consequence of Peltier effect [Yavorsky and Detall (1972) an e.m.f. is generated between the junctions. This e.m.f. is indicative of the soil moisture potential. The soil water potential is related to the vapour pressure by

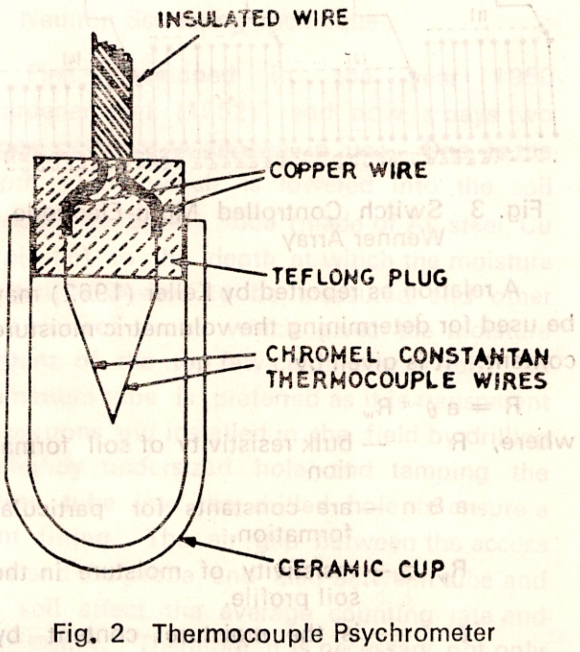

Fig. 2 Thermocouple Psychrometer

$$\phi = RT \ln (p/p_0)$$

Where, ϕ is soil water potential, R is Specific gas constant for water vapour, p is vapour pressure of the soil water, p_0 is vapour pressure of pure, free water at same temperature and air pressure, and T is the temperature of the soil.

3. Hygrometric Technique

The technique is based on the monitoring of relative humidity of the atmosphere inside the porous material of which moisture content changes with the change of moisture content of the soil. Different type of sensors can be employed for the above purpose. They are Electrical Resistance, Capacitance, Piezoelectric sorption, Infrared absorption and Transmission of dimensionally varying element, Dew point and Psychrometric. Chemical salts and acids, aluminium oxide, electrolytes, thermal & white hydrocol are used to measure relative humidity in electrical resistance hygrometers. Bouyoucos and Cook (1965) considered this as best. Phene et al. (1971, 1973) developed a heel discipitation sensor that could be used to measure matric potential.

4. Thermal Conductivity Technique

The heat capacity and thermal conductivity are related with $n = (KC)^{1/2}$; where n—thermal intertia, K — thermal conductivity & C — heat capacity.

The thermal inertia increases as a result of increase in the thermal conductivity and it depends on the external factors of meteorology e.g. solar radiation, air temperature, relative humidity, cloudiness and wind. All these affect diurnal variation of surface temperature of the earth. Since heat capacity and thermal conductivity of the soil increases with the incrnumber of counts per second gives the value of the soil moisture content.

Calibration of the neutron probe is essential. For this, neutron counts are taken at various depths and correspondingly soil samples are also collected from nearbyarea by the help of hand auger. Gravimetric technique is employed on the collected soil samples to determine soil moisture of different depths of soil profile. Several readings are taken for finding out a reliable relation between the counting rate and soil moisture. By the help of least square fitting technique a best fit curve is obtained. This curve serves the purpose of calibration curve. Kiran shankar et al. (1979), in one of their experiments for the University of Roorkee area, have stated calibration equation obtained from best fit as

$$M = 0.212\ Mc - 16.758$$

The relation holds good for the particular site only. Different relationship for different soil and location is required ; because, counting rate is a function of bulk density and composition or the constituents like Bi, Cd and Cl etc. present in the soil. In certain cases the equipment has more than one range of counting. In such cases, calibration curves for both the range are required. Efforts have been made by Kiran Shankat et al. (1979) to establish a relationship in the above sets of data. They have reported 76% correlation.

The accuracy of the probes can be determined from the deviation calculated by regression analysis where neutron counts are converted in terms of moisture content on volume basis. The calibration in the field is difficult as it depends on the strength and geometry of source, nature of detector, the material used in the probe, the size and composition of the access tube and physical and chemical properties of the soil.

The moisture content values are the averages of the representative soil column of the soil. The equipment needs frequent calibration and thus being an electrical equipment normally suffers from potential drifts, temperature effects and aging of the batteries.

In isotopic technique, the precision of measurement is a function of the total no. of counts. The statistical analysis of the counts will be necessary. A large count be taken for each measurement depth. As count rate is interpreted as volumetric moisture content, knowledge of soil bulk density is required for calibration. This probably is the largest source of error in the calibration procedure. The neutron moisture depth gauge is not reliable for the measurement of soil moisture upto a depth of (15 to 31 cm) because of the escape of neutrons from the top soil. For this, surface probe equipment are advisable. It is good practice to check the standard count readings three times a day; in beginning, in the middle and at the end of the work. The precision is high and the results are excellent. The errors in measurement can usually be detected and corrected at the time of measurement.

(ii) Gamma Ray Attenuation Technique

This method assumes that scattering or absorption of gamma rays are the function of the density of the medium through which they pass. In case of soil, its sp. gravity remains almost constant and its wet density commonly changes with the increase or decrease in the moisture content. The changes in wet density is measured by the above technique. Mass absorption coefficient of hydrogen for gamma rays (600 Kev) is greater than rest of the constituents of the soil. Therefore, the change in counting rate is largely due to change in the moisture content of the soil. Kumar and Singh (1981) have reported the procedure for the standardization of gamma ray spectrometer with which measurements for the changes in counting rate can be taken accurately to account for the moisture content. Gurr (1962), Ferguson and Gardner (1962) and Davidson et. al. (1963) were instrumented in developing the theoretical basis and procedure for the use of this technique. Kumar and Singh (1979, 1988) introduced a new approach for calibration of gamma ray transmission method and developed automatic count rate stabilization technique in gamma ray spectrometer, Singh and Chandra (1977) modified the equation of gamma ray transmission technique by employing a factor responsible for scattering effects. Theoretical aspects of the techniques have been given in detail by Saxena et. al, (1974) and Singh and Kumar (1988). Mansell et. al. (1973) stated Collimated radiations (γ-rays) from 300 mCi from 241 A_m or 137 C_s of energy peaks 60 & 62 KeV are highly intense and found appropriate for γ-ray transmission technique. These rays are allowed to pass through a column of soil water system of thickness (say x) and resulting transmitted intensity is detected in terms of count rate. As these rays are attenuated while passing through the medium (soil-water system) because they are absorbed by the medium; the counting rate is reduced. The natural logrithm of their difference is found to be directly proportional to the change in the soil moisture. The following relation is used to evaluate the soil moisture content at different depth of the soil profile.

$$\mathrm{In}\ N_{sw} - \mathrm{In}\ N'_{sw} = (\mu_w/\rho_w) * C \quad (\vartheta'_v - \vartheta_v)$$

where

N_{rw} — Initial count rate of the system at any instant

N'_{sw} — Final count rate at any other instant after moisture is changed in the system

μ_w — Absorption Coefficient of water.

ρ_w — Density of water at constant temperature.

C — Calibration constant

θ_v — Initial moisture content

θ'_v — Final moisture content

In this technique absorption coefficient, density of water calibration constant and also the thickness of soil water column are assumed to be constant at a particular temperature. The experimental setup in of the technique-laboratory and field are given in figures 5 & 6 respectively.

The techniques have superiority on gravimetric, conductometric and thermal techniques in general use. In such techniques, it is assumed that changes in the density are due to the changes in the water content. The bulk (dry) density of the soil is assumed to be constant. When the soil is recently filled or swells or shrinks, then, the measurements are not so reliable.

Normally the chances of health hazard is involved but may be minimised provided adequate safety measures are taken.

7. Electromagnetic Technique

Bottcher (1952) observed that the soil moisture depends on the frequency of the electromagnetic radiation which in turn depends on dielectric response function

$$\psi\omega = \psi_r(\omega) + j\,\psi_i(\omega)$$

where

$\psi_r(\omega)$ — real part of ψ

$\psi_i(\omega)$ — imaginary part of ψ

j — square root of (—1)

ω — angular frequency of the radiation.

The real part is the measure of the energy stored by the dipoles under the influence of external electromagnetic field, whereas the imaginary part is a measure of the energy dissipation rate in the medium. The imaginary part first rises to a peak (ωR), resonant angular frequency and thereafter decreases due to the presence of permanent dipoles in the medium or consumption of energy needed for direct molecular excitation in the sub millimeter or

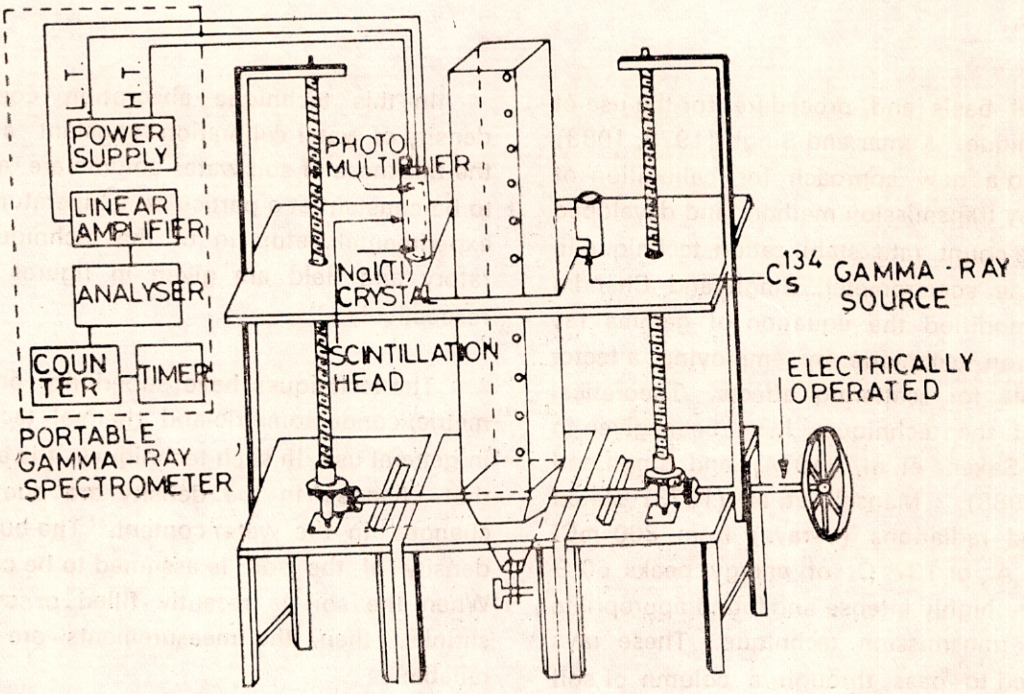

Fig. 5 Laboratory set-up Gamma Ray Transmission Technique

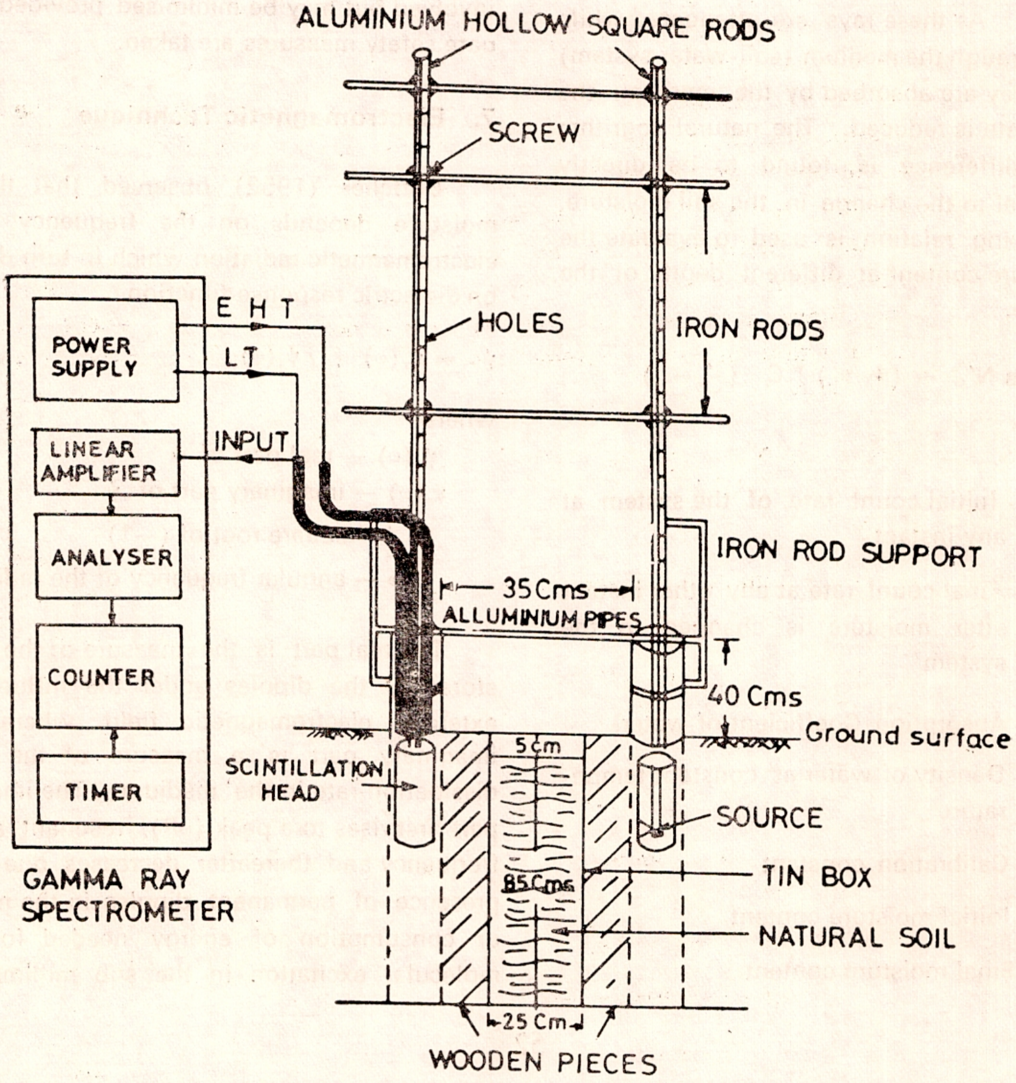

Fig. 6 Field set-up of Gamma Ray Transmission Technique

infrared region. Hoekstra and Delaney (1974) obseved that in soils, it is around 1 GHz. The dielectric constant of soil ranges between 3 to 5 whereas for water its value is 80; for ice it is 3.5 only. Further, it is observed that the soil moisture content depends on the soil texture-particle size distribution also. For large size particles, it is less; whereas, for fine sized particles it is higher, but, near wilting point it is at least linear (Lundien, 1971; Newton, 1977). A variety of sensors depending on the measurement of resistivity or polarisation at different electromagnetic frequency of radiation have been constructed and tried by a number of researchers [Wexler, 1965; Roth, 1966; Thomas, 1963; Gagne and Outwater, 1961; De Plater, 1955; Silva et al., 1974; Selig et al., 1975; Walsh et al , 1979; Layman, 1979; Wobschall, 1978]. The capacitance is measured to measure sensitivity of polarization. (Walsh et al., 1979 and Layman, 1979) have described to use EM waves ranging from 10 to 100 MHz by employing bridge technique to measure changes in moisture content by measuring the changes in capacitance values. The measurement technique of soil moisture by EM technique has advantages over the conventional techniques as this can give absolute value of soil moisture and the sensors can be implanted to any depth, thus, provides profile data of the required soil profile. The disadvantages are associated with the improper installation which increases disturbance and also long term reliability can not be assured. Cost of the sensors interface and devices also is another factor which restricts its use in remote locations.

8. Remote Sensing Technique

In this technique, measurement of intensity of reflected or emitted electromagnetic radiation from the soil is considered as basis for the measurement of changes in soil moisture. However, this depends on the dielectric properties and temperature of soil and wavelength of radiation being used. Solar spectral reflectance from moist soil depends on several factors like spectral reflectance of the dry soil, roughness of soil surface, geometry of illumination, constituents and texture of soil. [Jackson et al, (1978); Idso, et al., (1975b)] pointed out that this energy responds to thin layer of soil only. Schmugg, (1978) described the use of thermal infrared (10 m) i.e. thermal technique and microwave (1-50 cm) wavelengths i.e. Microwave technique.

1) Thermal technique

In this technique, surface temperature of the soil forms basis for the measurement of soil moisture. Reginato et al. (1976); Schmugge et al. (1978) have described techniques for the measurement of thermal infrared using aircraft. The technique is not so reliable in case of fields with vegetative coverage. Wiegand and Namken (1966), Ehrler and Van Bavel (1967), Hiler and Clark (1971), Ehrler (1973), Hiler et al. (1974) have reported techniques for the measurement of crop stress by measuring vegetation and air temperatures.

2) Microwave technique

Dielectric properties of the soil are strong functions of their moisture contents. Radiometric (passive) and radar (active) techniques are used to measure emmisive and reflective microwave intensities. The change in their intensity is mainly due to changes in the moisture contents of the soil. High penetration of their low order wavelength make the techniques very attractive for use as soil moisture sensors. Vegetation and surface roughness parameters are taken into account for introducing correction in the measurement. In radiometry, thermal emission from the surface is measured. This is directly proportional to the product of temperature and emissivity of the surface i.e. brightness temperature (by Rayleigh & Jeans approximation). It is given by

$$T_B = t\,[\gamma\, T_{sky} + (1-\gamma)\, T_{Soil}] + T_{Atm.}$$

where

T_B — brightness temperature
γ — surface reflectivity
t — atmospheric transmission

The first term is the reflected sky brightness temperature. The second is the emission from the soil ($1-\gamma = e$ emissivity) and the third term is the contribution from the atmosphere between the surface and the receiver. In active microwave sensing technique, we make use of the property of back scatter coefficient / dielectric properties whereas in passive technique, microwave emission, dielectric properties as well as temperature measurements are made to find out the changes in soil moisture contents. Now a days, these techniques have gained tremendous importance for continuous monitoring of soil moisture status of whole of the soil surface of the earth by making use of satellites with active and passive sensors.

Remote sensing approaches have been compared and summarized hy Schmugge et. al. (1980) and they are pressnted below :

Approach	Advantage	Limitation	Noise Source
Thermal Infrared (10-12m)	High resolution (400 m) Large Swath, Basic Physics well understood	Cloud cover limits frequency of coverage	Local meteorological condition, Partial vegetative cover, surface topography
Passive Microwave	Independence of atmosphere, moderate Vegetation penetration	Poor spatial resolution (5-10 km at best), interference from man made radiation sources, sources, limits operating wave-lengths	Surface roughness, vegetative cover, soil temperature
Active Microwave	Independence of atmosphere, high resolution possible	Limited swath width Calibration of SAR	Surface roughness, Surface slope, Vegetative cover

Remarks

From the above known techniques, it is clear that none of the individual techniques completely satisfies the requirements of the applications - precession, accuracy and methodology in a cost effective manner.

The sample size in most of the sampling in field measurement was discussed by Snedecor and Cochran (1967); Schmngge et. al. (1980) as

$$S = 4 (\sigma/L)^2$$

where σ is the standard deviation of soil moisture, S is the sample size and L is the desired level of accuracy. Topography is the most important factor to be considered during investigating soil moisture for a large field, because, it controls the distribution of soil moisture. The presence of vegetation tends to diminish the soil moisture variations caused by topography, while the effect of minor variations in soil type are usually found insignificant. The measurement techniques should be such as to provide repetitively information on soil moisture both with respect to space and time so that proper managcment for the growth of crops and plants could be done.

In all such integrated systems of techniques, advantages are more than the disadvantages. A wide variety of techniques have been discussed in this paper but for large scale soil moisture monitoring, each of the above techniques has advantages and disadvantages and limitations of their use and limits applicability in field conditions. However, these techniques are of importance not only in scheduling irrigation and providing approximate estimates of amount of water to be applied in each irrigation with respect to a fixed soil depth; but, can provide information of soil moisture which may be utilised for water budgeting, water balance studies and for other hydrological interest.

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