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"Neutron Water and Gamma Density Gauges in Soil Water Studies"

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NEUTRON WATER AND GAMMA DENSITY GAUGES IN SOIL WATER STUDIES

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In many parts of the world, inadequate water is the most important constraint in agricultural production. In general practice farmers have the tendency of applying more irrigation water than it is actually needed because they think "if little is good, more must be better". However excess irrigation eventually causes soil salinity if appropriate precautions are not taken to prevent rising of ground water table in farm lands. The measurement and manegement of soil water is therefore of great importance in meeting the demands of food for ever increasing human population. Methods used to measure soil water content are discussed in the following sections.

METHODS TO MEASURE SOIL WATER CONTENT

Direct Measuring Methods

This is simply based on gravimetric sampling. It requires sample containers, a weighing device, balance, oven or some other means of drying equipment. It is very simple and meassurements are precise; however, it is quite laborious and results can only be available in the next day. Additionally, number of samples and their associated locations influence on accuracy of field mean values.

Indirect Measuring Methods

1. Tensiometers

They can measure directly soil water capillary head. One can also measure soil water content indirectly if soil water charecteric curves are available (Fig.1).

2. Resistance and Capacitance Blocks

They are simply based on resistance or capacitance measurements made between two metal conductors imbeded into a porous material either made of nylon or gypsum. The blocks are placed at different soil depths and measuring sites of interest. An equiblirium exists between water present within the porous blocks and water in soil.If soil in the vicinity of the blocks is dry, water within the blocks tends to go out of blocks and a new equilibrium is established. One can indirectly measure soil water content with these porous blocks using calibration curves relating water content to either resistance or capacitance measured in the blocks (Fig.2).

3. Time-domain Reflectometry

The method is essentially based on measurement of propagation velocity of an electrical volatage step imposed between two transmission lines inserted into the soil where measurement is needed.The method directly gives dielectric constant of soil. It has been shown that a unique relation exists between volumetric soil water content and dielectric constant of soil and it is not influenced by different types of soils (12).

4. Nuclear Methods

There are essentially two nuclear methods used in soil water studies: (1) Neutron scattering (or thermalization), (2) gamma ray attenuation and back scattering. Following sections separately are devoted to the nuclear methods.

NEUTRON SCATTERING METHOD

Neutrons are uncharged particles of mass 1.008982, slightly higher than that of protons. They decay into proton and electron with a half life of 12.8 minutes. They are classied based on their kinetic energy levels (Table 1)

Table 1. Energy levels of neutrons

Description	Kinetic energy
Fast neutrons of high energy	> 10 MeV
Fast neutrons	10 MeV - 10 KeV
Intermediate	10 KeV - 100 eV
Slow neutrons	100 eV - 0.03 eV
Epithermal neutrons	1 eV
Thermal neutrons	0.025 eV

Neutron interactions with matter are rather complex. Calculation of neutron fluxes involves probability and diffusion theories. For simple practical engineering applications, however,one can simplify these interactions as following:

i. inelastic scattering
ii. elastic scattering
iii. absorption

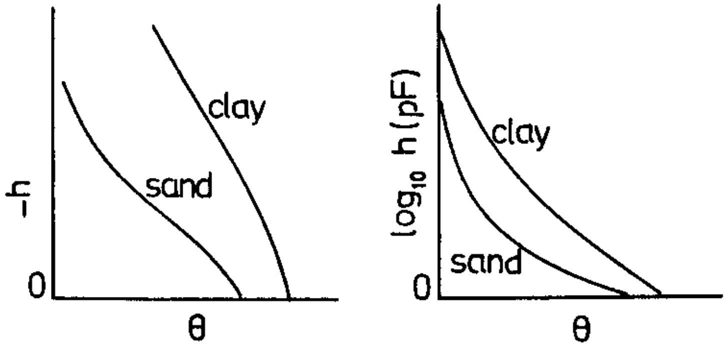


Figure 1. Soil water charecteristic curve.

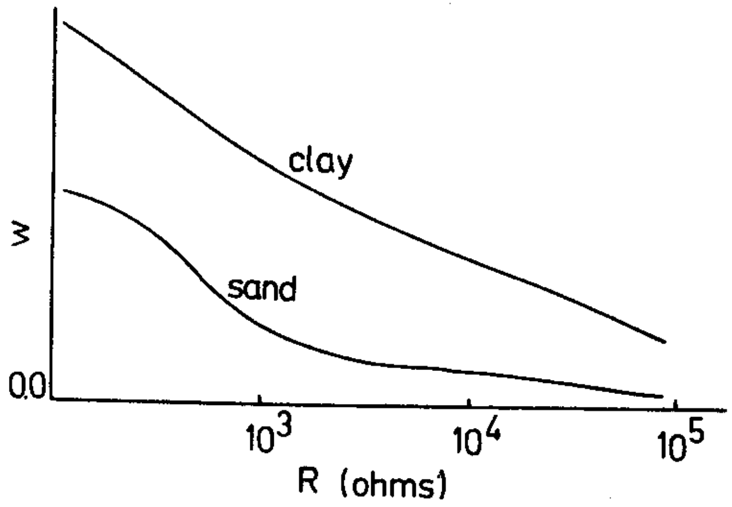


Figure 2. Example of resistance block calibration curve.

Inelastic scattering involves transformation of kinetic energy to some other form of energy and it is important for fast neutrons. Interactions interest us are elastic scattering and absorption (capture). In the absoroption, neutrons end their existance as a result of a nuclear reaction which is often used as a basis for detection of neutrons. Scattering occurs as a result of principle interactions of fast neutrons, whereas, absorption occurs as a result of interactions of slow neutrons. The scattering of fast neutrons results slow neutrons The slow neutrons are simply the end result of elastic scattering of fast neutrons through interactions with nuclei of surrounding atoms present in the media. Probability of various means of interactions of neutrons with other elements is measured with what is called "cross sections". Table 2 gives neutron cross section of various soil elements. As it can be seen from the table, probability of interactions of fast neutrons with common soil elements is approximately same. However, when low kinetic energies are reached through succesive elastic scatterings, scattering cross section of hydrogen increases about 40 fold. And similarly cross sections for oxygen, clorine and iron increase significantly. Gardner and Kirkham (1) pointed out that weight of atomic nucleus also influence on scattering process as much as cross sectional areas. The energy loss through elastic scattering is greeter the lighter is the nucleus of interacting element. It can be concluded therefore that hydrogen is the primary element causing scattering and slowing down of fast neutrons in moist soils. Multible scatterings owing to elastic collisions of neutrons with nucleus of elements result reduction of neutron energies to the point where they are in thermal equilibrium with a gas at 20 degrees C. Neutrons reached to this level of energy may gain as much energy as they lose through farther collisions. They are considered slow neutrons of thermal energy state. The element H requires the least number of collisions to slow down neutrons to thermal energy state (Table 2). It is this condition which is used as a base to measure soil water content with neutron scattering technique with the assumption that all the H atoms stem from water molecules. However one should not ignore secondary effects of chlorine and iron on the slowing down of neutrons if they are in high quantities.

Neutron Water Gauges

In neutron water gauges, neutrons are usually produced through (α,n), (β,n) or (γ,n) reactions. As an example, neutrons are produced based on following nuclear reaction in some neutron gauges:

$9Be(\alpha,n)12C$

Neutrons produced by this reaction have a spectrum of energives from 0 to 10 MeV with an average value of 4.5 meV. The 12C is left in excited state which in turn produces a photon of energy 1 - 10 meV and goes down to ground sate.

What neutron moisture gauges measure is simply number of slow neutrons (n). Because of the following relations

$cpm = f(n)$
$n = g(H)$
$H = s(\theta)$,

one can demonstrate that generally a linear relation exists between neutron count rate (cpm) and volumetric soil water content. If one has such a calibration relation constracted previously and valid for his own conditions, soil water status of plant root zone can be continously, nondestructively and easily monitored.

Table 2. Neutron cross sections of important soil elements in barns per atom (10E-24 cm2per atom)*

Element	Scattering fast neut. 2.5 MeV	Scattering slow neut. 0.025 eV	Absorption slow neut. 0.025 eV	Collisions
H	2.5	81.5	0.33	19.0
B	-	7.5	755	109.2
C	1.6	5.5	3.2	120.6
N	1.0	11.4	1.9	139.5
O	1.5	4.2	0.00	158.5
Na	2.6	3.4	0.5	224.9
Mg	2.0	3.7	63.0	237.4
Al	2.5	1.5	0.23	262.8
Si	3.2	2.4	0.13	273.3
Cl	2.7	16.0	31.6	343.3
K	3.8	2.2	1.97	378.0
Ca	4.9	3.2	0.43	387.3
Fe	3.0	11.8	2.53	537.2

* Adapted from van Bavel(2)

Calibration

Neutron gauges give only measurement of slow neutrons. One needs a calibration curve to convert slow neutron counts to water content. Because it is not easy to calculate the relation between slow neutron counting rates and soil water content, an empirical approach is usually used. However emprical relations are only valid for a given soil type that they are derived for. Soil chemical compositon and soil density have significant influence on calibration curves of neutron gauges. Therefore users of these type of gauges must be aware of various sources of errors involved in their calibration.

1. Field Calibration

Usually a simple linear relation is fitted to the calibration data of the neutron gauges (Fig.4). Field calibration is carried out by installing access tubes in natural field soils. First neutron count rates are measured at different soil depths known to vary in chemical composition and bulk density, covering complete plant rooting depth. Then, volumetric soil samples are taken from the same soil depths where neutron count rates are measured. Volumeric soil samples taken should be as close as possible to the neutron gauge access tube so that the sample represents a volume of soil which in fact comes from sphere of influence of slow neutrons (Fig. 3). It is recommended that one should take a couple samples circling the access tube from the same soil depth. Mean volumetric

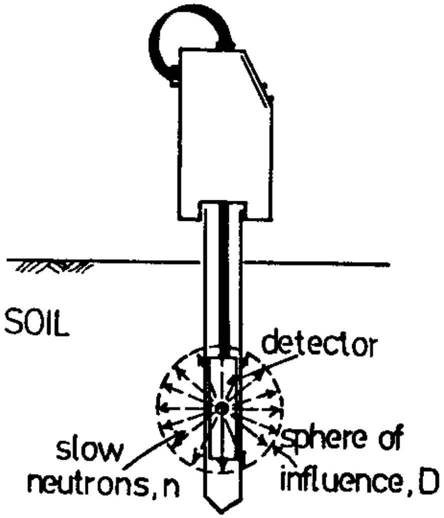


Figure 3. Basis of soil water content measurement with sub-surface neutron gauge.

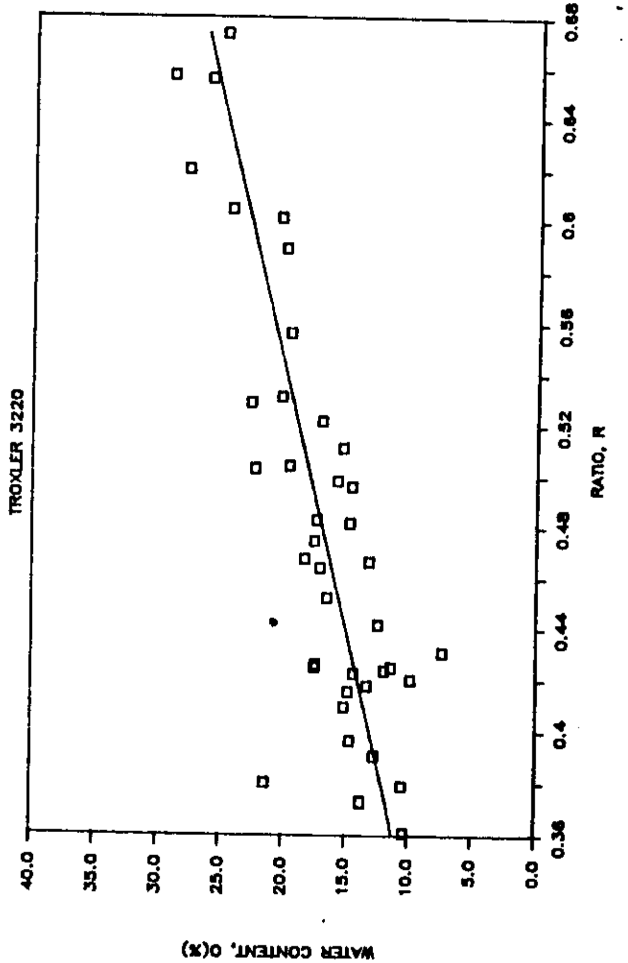


Figure 4. Neutron gauge calibration curve.

soil water content of the samples, measured gravimetrically is later related to neutron count rate at that specific soil depth. In actual practice however, neutron count rate ratios, not the count rates, are used. For this propose, neutron count rate is first measured in a standard medium which is usually water before one starts field measurements.Neutron count rate ratios (R) are calculated by simply dividing neutron count rates obtained in the field with the neutron count rate of the standard medium.

Measurement made in one site during the field calibration provides only a single point (i.e. one volumetric water content corresponding to one neutron count rate ratio. More points can be obtained at other randomly scattered measuring sites of the field. Optimum number of points in the calibration procedure varies depending on field variability.The calibration relation should cover complete range of change in soil water content. For this purpose, either the field is partially irrigated or measurements are made in both when the soil is dry and wet. The calibration relation produced in this way covers rather wide range of variation of field soil water content, which is desirable in calibration curves.

In some cases, users prefer to calibrate their equipment as a supplementary work to their field experiments. In other words, they immediately start up field research work before they calibrate their equipment. In this case, they install the access tubes right in the experimental plots where, most likely, they have crops growing. Because they do not want to spoil the experimental plots, they can not take soil core samples very close to the access tubes. In this case, neutron count rates taken right in the experimental plots are regressed to water content measurements made with soil core samples taken outside of the plots. In some cases, soil water content is measured using disturbed soil samples where one can measure soil water content on weight basis which is later corrected to volume fraction by simply multiplying with soil bulk density, measured in the experimental plots at the end of the experiment. This method of calibration provides more data than when soil samples are taken directly next to the access tubes. However here, soil density and chemical composition of the sites where gravimetric soil samples are taken may be significanly different than the sites where the access tubes stand, in the center of the experimental plots. Future research work should evaluate if calibration of the gauges using soil samples taken at larger distances away from the access tubes gives significantly different results. Many previously published works used this later method of calibration; however, to our knowledge, no one has yet compared the two different approaches, taking soil samples very close to the access tubes or at some distance away from the tubes.

Correlation coefficients of the calibration curves made using field data may sometime be very low because of field heterogeneity. Users should not be discouraged with low correlation coefficients as long as error of estimate is within the range of acceptable limits which should also change depending upon specific objectives of the user.

Field calibration relations carries combined errors arised from field soil heterogeneity and compaction of volumetric soil samples. Followings are various sources of errors in field calibration procedure:

(1) Soil water content measured by direct soil sampling does not necessarily represent soil water content within the sphere of influence of neutron gauge,

(2) Volumetric soil samples needed in calibration may be compacted at some level but the user has no means of measuring or estimating resulting error,

(3) It is known that the field calibration relation is influenced by soil horizones of different chemical composition and soil bulk density (3).

2. Laboratory Calibration

Van Bavel (2) suggests using homogeneous volumes of soil in laboratory conditions to calibrate neutron gauges. However it has been shown that soil containers have to be sufficiently large size so that neutron count rates are independent of the soil volume (4).It has been indicated that 1 m3 of soil sample was about minumum volume (2,4) for low soil water content. Size constraint may not be very critical for water contents over 20 % volume fraction (2). The following steps should be taken in the laboratory calibration procedure:

(1) The sample should be prepared as homogenous as possible with regard to both soil water content and bulk density,

(2) Soil water content measurement should be based on whole volume of the soil sample, or large sub samples must be used,

(3) Separate samples should be prepared for each point of measurement for the calibration relation.

3. Calibration by Simulation

In laboratory calibrations, large soil samples are required and the work involved is too laborous. As a result relatively more permanent and easily constructed standards made either from neutron moderators or combination of moderators and absorbers are suggested. The followings are some example mixtures used for this propose:

(1) Mixture of alum and sand in large barrels to correspond to certain known soil water content (5).

(2) Paraffin and sand mixtures (6).

(3) Liquid standards containing either boric acid or cadmium chloride (4).

However one has to note that calibration with simulation standards can only be used as a supplement to known calibration relation in soils. Thus they can not substitute the actual calibration relation and only help to evaluate the behavior of the equipment in long run. Calibration with simulation standards also provides valuable data for interchange of calibration curves developed for a given type of probe. This is very useful when a user buys a new gauge and he wants to adapt the calibration curve of his old gauge for the new one. This is only possible if the user had calibrated his old equipment both in the field and using simulation standards. One can estimate coefficients of the calibration curve for the new probe with measurements made only in the simulation standards. Nakayama and Reginato (16) used plastic blocks to estimate field water equivalence of neutron counts of a given gauge with two calibration curves of an other gauge, one for the field and the other supplementary calibration made in the plastic blocks.

4. Theoretical Calibration

This is essentially based on a numerical model calculating neutron diffusion in the soil of interest from laboratory measurements of neutron diffusion cross section areas of the soil sample. So it simply involves measurement of neutron diffusion and absorption cross sections of the field soil.However neutron diffusion and absorption cross section of field soils can only be measured in specific laboratories. At the final stage of calibration calculation, one again has to rely on a reference calibration curve prepared for a sipecific probe. The method seems to be promising; however,further effort should be continued to improve and simplify measurement of field soil neutronic diffusion and absorption cross section areas.

Issues Dealing with the Use of Nuclear Gauges

1. Calibration in Gravelly Soils

Soil water content measured with neutron gauges is an average value integrated over a spherical volume of the soil which is called "zone of influence" of the gauge. The measurement gives volume fraction of water existing in the soil. If soils dealt with contain high amount of gravel, water content measurements are not necessarily what plant roots are exposed to. Plant roots would normally sense available water in soil fraction, excluding gravel. Therefore one has to correct calibration curves if he is to measure water only as fraction of fine soil particles. Figure 5 shows calibration curves for 3 level of gravel content. The calibration data was for the experimental field of the IAEA Seibersdorf Laboratory, where soil is classified as Typic Eutrocrepts with coarse clay loam texture This soil contains rather high portion of gravels of size 5 to 10 cm. The figure shows that calibration curves for 15 to 30 % gravel are not significantly different. However, the intercept of the calibration decreases if the gravel contnent is higher than 40 %. It appears that slope of the calibration remains to be the same. This implies that if one is merely interested in relative chages of water content, not the absolute quantity, then there is no need to concern with soil gravel content. Figure 6 compares calibration curves with or without correction for soil gravel content.

In field calibration of the neutron gauges, soil cores are used. If the soil contains gravels of size 5 to 10 cm, then core size of 100 cu. cm will not suffice for the work. In this case, one should either use larger size of core sampler, or find other means of measuring soil bulk density. One can use paraffin method to measure bulk density of undisturbed soil olods (14) as an alternative technique to the soil core sampling. In the paraffin method, volume of irregularly shaped soil clods can be estimated very simply. First, the soil clod specimen is coated with paraffin, then volume of water displaced by paraffin coated sample is measured. Sample volume is simply equal to the volume of the displaced water with appropriate correction for the paraffin coat. Thus one can measaure soil bulk density with parrafin method which is used to convert water content measurements of weight basis (i.e., w) to volume fraction (i.e.,0). One can find other alternative approaches to measure soil bulk density in gravely soils. For example, one can can simply take disturbed soil samples for the calibration of the gauges, and volume of the samples can be estimated by filling the void, left after the sample, with well granulated sand. The later method is known as "sand cone method" and extensively used to control the compaction of earth filled embankments in civil engineering works. The volume of the sample can also be estimated by simply filling the sample void with water, with necessary precautions taken to prevent percolation, a thin plastic film can be used for this purpose. Table 3 compares calibration data obtained with the later three methods, paraffin, sand-cone and water methods, with standard core sampling technique where a core size of 600 cu. cm was used. Both intercepts and slopes of the calibration curves found with the later three methods were not statistically

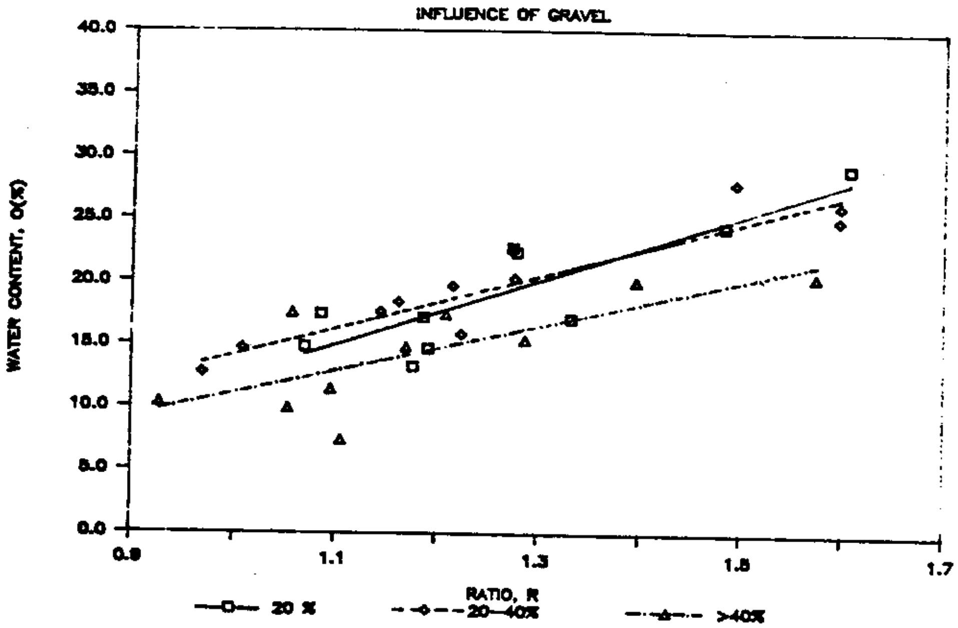


Figure 5. Influence of soil gravel content on neutron gauge calibration curve.

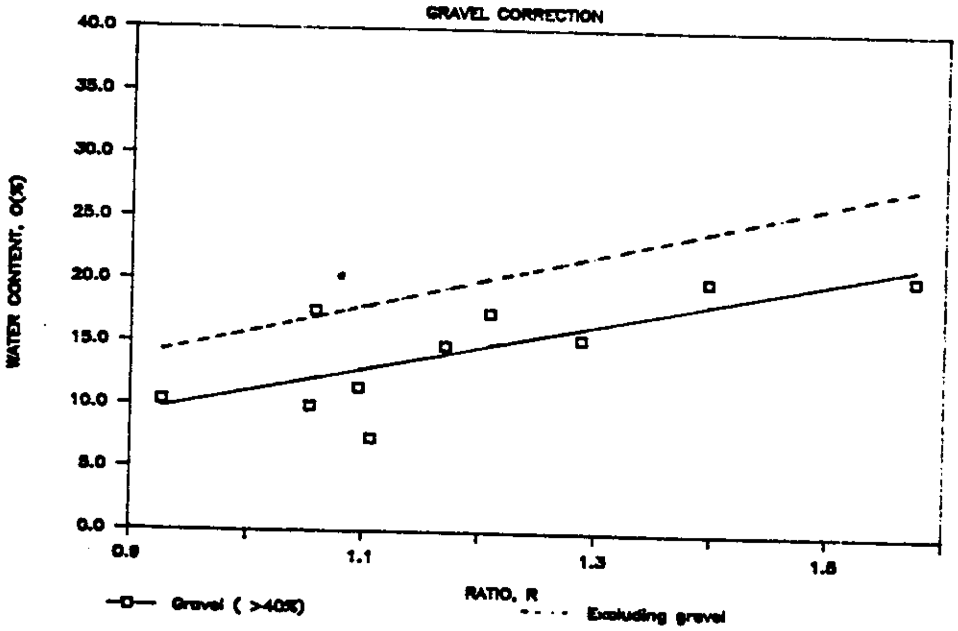


Figure 6. Neutron gauge calibration curve with or without correction for soil gravel content.

different than those for the core sampling technique. Therefore, paraffin, sand-cone and water methods can be alternatively used in field calibration of the neutron gauges, particularly in gravely soils where soil core sampling may be difficult.

Table 3. Comparison of different methods in calibration of neutron gauges. The data is for CPN 503DR gauge.

Method	A	B	r	Err. est	N
Core	-9.70	22.3	0.842	2.759	40
Paraffin	-3.65	19.6	0.763	3.302	36
Water	-3.06	18.5	0.667	3:873	38
Sand	-1.75	16.7	0.741	3.162	33

2. Influence of soil cracking on neutron gauge measurements

Some soils crack due to shrinkage upon drying. In such instances, the neutron access tubes are exposed to air in the measuring sites. Therefore, the users of the gauges are concern if the measurements would be eroneous under such conditions. During the calibration work, if the range of field soil water content covers extreme dry conditions, when the soil contains cracks, the user should not worry for error of measurements.

3. Number of Measuring Sites for Neutron Gauges

If one has prior knowledge of site variability as standard deviation of estimated water storage with the nuclear gauges, it is very simple to calculate number measuring sites needed to attain a given level of accuracy in the measurements using the procedure described by Johns et al.(1). If the measurements are assumed to follow a normal probability distribution, then one can write

$$N = t_p^2 S^2 / D^2$$

where N is the number of the measuring sites, t_p the tabulated value of t for the probability level p, S^2 the variance of the measurements and D is the specified deviation from the true mean which is to be estimated. As an example, for 95 % probability, using an approximate t value of 2.0, for S = 10 mm and D = ± 5 mm

$$N = 4 \times 100/25 = 16 \text{ sites.}$$

In general practice, the aim of soil water studies is to compare different treatments. Therefore, user wants to estimate how many measuring sites he needs, in each treatment, to achieve a specified least significance difference (L.S.D.) between the treatments. Again following the procedure described by Johns et al. (14) one can write

$$N = 2 t_p^2 S^2 / (L.S.D.)^2$$

where (L.S.D.) is the 5 % least significant difference. As an example, for S = 10 mm, to achive a 5 % L.S.D of 10 mm, one would need

$$N = 2 \times 2 \times 100/100 = 4 \text{ measuring sites.}$$

Acccess Tube Installation

Aluminum, aluminum alloy, brass and stainless steel tubes are among the most commonly used material for neutron access tubes. Eales (7) gives a complete discussion in all aspects of access tubes and their installation. This section is prepared based on his work.

The following factors affects on the choice of the tubing material:

(1) Soil chemistry,
(2) Durability of tubing material,
(3) Depth of access tube installation.

Aluminum is the most transparent material to thermal neutrons; brass may reduce the count rate slightly, however it is less corrodible in sodium affected soils. Stainless steel tubes are the most durable material; however, neutron count rates are reduced significantly owing to their large absorption cross-sections.

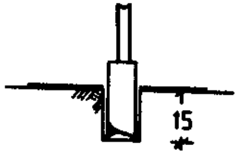
Bottom end of the access tubes should ideally be closed by a tapered plug of the same material when they are installed.Top of the tube must be also closed by either using a rubber bang or some other appropriate cap.

For installation of access tubes, hand operated soil augers should be used. Motor powered mechanical augers may cause drastic disturbance of the soil structure owing to churning with caught-up stones, compression, over sizing etc. The following equipments are needed for an ideal installation of access tubes:

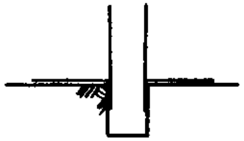
(1) Aluminum plate,
(2) Guiding tube made of steel with cutting edge,
(3) Hand auger,
(4) Tube extractor,
(5) Access tubes.

The following steps are taken for the access tube installation:

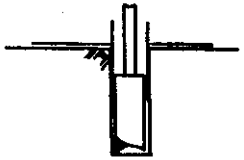
(1) Place the aluminum plate on the site selected for installation of the access tube,



(2) Working through the hole at the center of the aluminum plate, go 12 to 15 cm with hand auger,



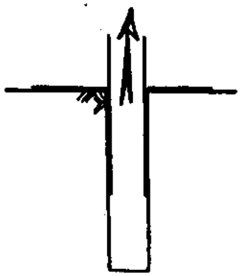
(3) After the auger is withdrawn, insert the steel guiding tube to a depth same as the auger has just reached. Make sure that the tube is placed vertically,



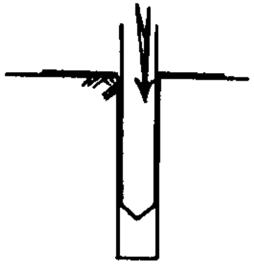
(4) With hand auger, once again go for an other 12 to 15 cm deep, withdraw the auger and hammer down the guiding tube to the bottom of the augered section,

(5) The loose soil can be taken out with auger through the guide tube,

(6) Continue this procedure until the required depth is reached,



(7) After insertion of the guiding tube to the required depth, it is withdrawn back with care to prevent widening of the auger hole,



(8) Insert the permanent access tube by ramming gently to get it down.

(9) The top of the access tube is cut off at the desired height.

The guide tube can be sometimes easily removed by twisting and pulling with a tommy bar.But in some cases it must be hauled out with block and tackle. It is essential to rotate the tube particularly to withdraw from wet and heavy clay soils.The whole objective behind all these procedures is to avoid enlargement of the access tube hole.

Prebble et al.(16) summarized different procedures used in access tube installation, which would normally vary depending on nature of the work and soil types.

GAMMA RADIATION

Gamma radiation is electromagnatic radiation and as a result, it has more penetrating effect than other type of radiation of same energy. Absorption of gamma rays in matter depends mainly on (1) photon energy, (2) proton number and (3) density of absorbing material. Various types of absorption are described below:

i. Photoelectric absorbtion

This is mainly for relatively low energy gamma radiation and absorbing materials of high Z. Gamma rays (photons) interact with K or L electron of absorbing atom.While gamma ray is completely absorbed, an electron is ejected with energy slightly less than that of the absorbed gamma ray (Fig. 7a). The energy difference is equal to binding energy of the electron.

ii. Compton effect

It is interaction of gamma photon with an outer electron of the absorber atom.Part of the energy is absorbed (transferred to the electron) and the photon is scattered off in a new direction.After multible scatterings, the photon goes through photo electric absorption (Fig.7b).

iii. Pair-production

This can only occurs when gamma photons have at least initial energies of 1.02 MeV. Here gamma photons interact with positive field of nucleus of absorbing atom. Its energy is completely used up in producing a positron and electron pair. The energy 1.02 MeV is the treshold energy for pair production. Both positron and electron cause ionization along their respective paths (Fig. 7c).

Gamma Radiation Probe

Based on known interaction of gamma rays with orbital electrons of soil constituents, one can measure wet soil density.Gamma photons with energy less than 1 meV interact with surrounding electrons with so called "compton effect" and/or photo electric absorbtion.As number of electrons increases per unit volume of soil, that is to say with increase of soil density, the compton scattering power of the medium increases proportionally.Thus as the electron density increses in the medium,probability of multiple scattering will increase.This condition implies that probability of photoelectric absorption will also increase and thus causing reduction of gamma photons reaching to detector. Gamma probes comercially available work on mainly two princibles which are discussed below:

i. Gamma-ray Atenuation Technique

When monoenergetic and collimated gamma rays pass through a given material, intensity of incident beam I is attenuated owing to interaction of gamma photons with the material. The attenuated fraction of gamma rays (dI/I) is directly proportional to tickness of the material X, as described below:

$$dI/I = -\ kX$$

In this relation, k is refered as linear attenuation coefficient which is sum of several attenuation coefficients representing individually occurring attenuation processes (11):

$$k = k_c + k_e + k_p + \ldots.$$

where subscripts c, e and p represent compton, photoelectric and pair prodution effects.The sum of these coefficients indicates the total probability of attenuation of gamma rays of specific energy during trasmission through a given material of some specific chemical composition.

Gamma ray attenuation coefficients can also be expressed as mass attenuation coefficient, μ which is simply the linear coefficient (k) devided by density of

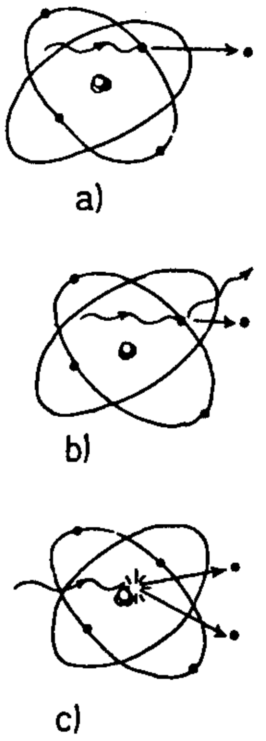


Figure 7. Different mode of interactions of gamma rays. a) Photoelectric absorption, b)Compton effect, c)Pair produktion.

material (ρ).

Attenuation of gamma rays is described with following relations:

$$dI/I = -\mu\rho x$$

$$\ln(I/I_0) = -\mu\rho x \quad \text{or}$$

$$I/I_0 = \exp(-\mu\rho x)$$

Field soils are composed of solid particles, liquid water and air space. If one ignores attenuation by soil air, then we can write

$$I/I_0 = \exp[-(\mu_w\theta + \rho_s\mu_s)x]$$

In practice americium-241, cesium-137 or cobalt-60 is used as a gamma source in laboratory gamma attenuation set-ups. Approximate gamma attenuation coefficients of water and soil for monoenergetic radiation from these mentioned sources are given in Table.4.

Table 4. Approximate gamma attenution coefficients of water and soil.

Source	Energy	w	s
Am-241	60 keV	0.200	0.25 - 0.42
Cs-137	662 keV	0.085	0.077
Co-60	1173		
	1332 keV	-	-

Followings can be measured with laboratory gamma attenuation set-ups:

(1) Water content if one knows soil bulk density and μ_s.

(2) Soil bulk density if one knows water content and μ_w.

(3) Change of soil water content under non-swelling conditions using the relation

$$\Delta\theta = (1/\mu_w x).\ln[(I/I_0)_1/(I/I_0)_2]$$

where subscripts 1 and 2 are for initial and later stage of gamma attenuation measurements.

(4) One can measure soil water content and the density simulteneously if he uses dual gamma source (10).

ii. Gamma Back Scattering

Gamma rays from monoenergetic gamma sources go through successive scatterings before they reach a detector (Fig. 6). Primary interactions of gamma rays in this type of probes are compton scattering and photo electric absorption. One can obtain directly wet soil density with this type of equipment using simple empirical calibration relation of the type shown in Figure 8.

Gamma probes which are presently in use are coupled with neutron probes to measure soil dry density and volumetric water content simultaneously.

USE OF NUCLEAR METHODS IN SOIL WATER STUDIES

The nuclear methods namely neutron moisture and gamma density probes have rather wide area of applications in agricultural research. They are nondestructive methods. Once they are calibrated, they are very easy to use. For certain type of work, they can be used directly, without any need for calibration relations. They are fast responding equipment. Following section deals with their various uses in agricultural research.

Plant Root Zone Water Storage

Information on plant root zone water storage can be used in many areas. Decision on different type of cropping systems which can be used in a given region should be based on seasonal change of plant root zone water storage. Effective rainfall at the end of a rainy season can be easily assessed with again change of water storage before and after the rains. Water retention capacity of soils influencing on water availability to plants can be calculated if one knows change of water storage in plant root zone before and after irrigation.

One needs soil water content distribution profiles within the plant root zone to calculate the soil water storage. This can be easily assessed with neutron moisture probes using the relations.

$$S(t) = \int_0^L \theta dz$$

$$S(t) \cong \sum \theta\Delta z$$

where right side of the relation is simply area under soil water profile curve (Fig.9).

Plant Rooting Habits

Plant rooting habits can be used in plant breeding studies. It is generally accepted that plant cultivars

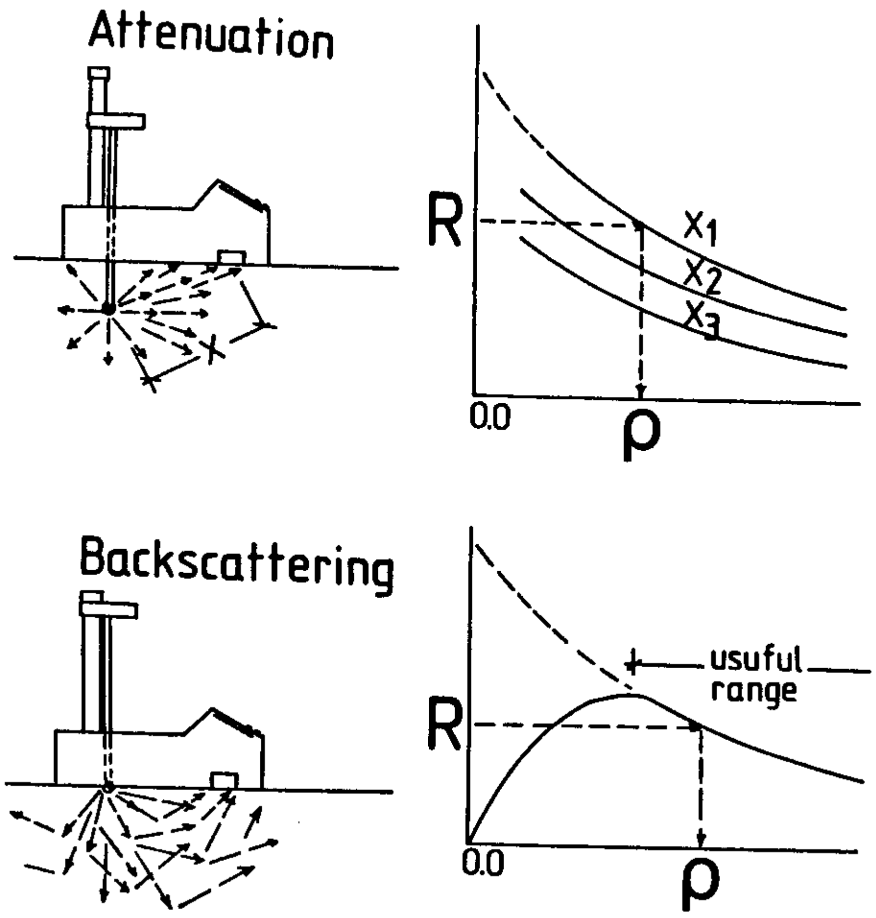


Figure 8. Princible of commercial gamma probes working either based on backscattering or attenuation.

having deep roots are known to be drought resistant. Thus plant rooting habit can be used as criteria in selection of drought resistant cultivars.

Information on plant rooting habits is a good asset for irrigation management practices and fertilizer application.For instance, irrigation engineers use a concept called "effective rooting depth" in irrigation system designs, which is the maximum soil depth providing 80 % of water used by plants. The effective rooting depth is needed to calculate irrigation water requirement. Adequacy of irrigation water application can be best evaluated if one knows the effective plant rooting depth.

Rooting habits of field crops can be easily determined with neutron moiture gauges.For this purpose, all one has to do is calculation of water depletion during a prescribed time period (Fig.10).

Measuring Soil Hydraulic Properties

Accurate calculation of solute and water fluxes in field soils is only possible if one has good data on hydraulic conducvity.Many computer simulation models on plant root zone soil water status, leaching of fertilizers and other agrochemicals, waste disposal and pollutant transfer problems in soils need information on unsaturated hydraulic conductivity of soils.Some type of experimental work on plant water consumption also necesitates data on hydraulic conductivity measurements.Hydraulic conductivity of field soils is very important physical property which influences on water infiltration charecteristics of soils.In drainage work of wet lands, one also needs hydraulic charecteristics of soils.

There are number of methods exist for in situ measurement of soil hydraulic conductivity.In general, all the methods require a fairly uniform water content distribution within a given depth of soil profile. This condition can be obtained if one covers field soil surface right after irrigation with basin method. Partial differential equation describing transient water flow can then be solved for the unsaturated hydraulic conductivity. There are two main approaches that one can use to calculate hydraulic conductivity. The first approach is that described by Nielsen et al.(8) and necesitates soil water tension measurements in addition to rate of soil water content decrease within the soil profile (Fig.11). The following relations can then be used to calculate the hydraulic conductivity:

$$K(\theta) = [L(d\theta/dt)]/(dH/dz)$$

where dH/dz is the hydraulic gradient mesured at soil depth L using tensiometers.

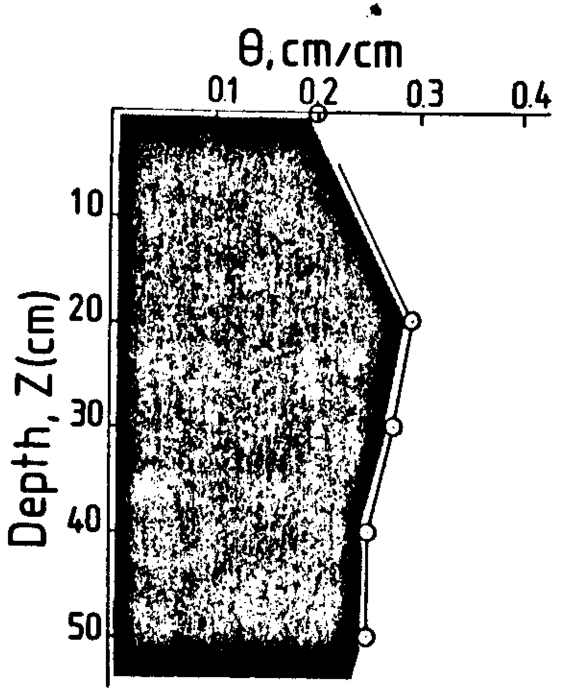
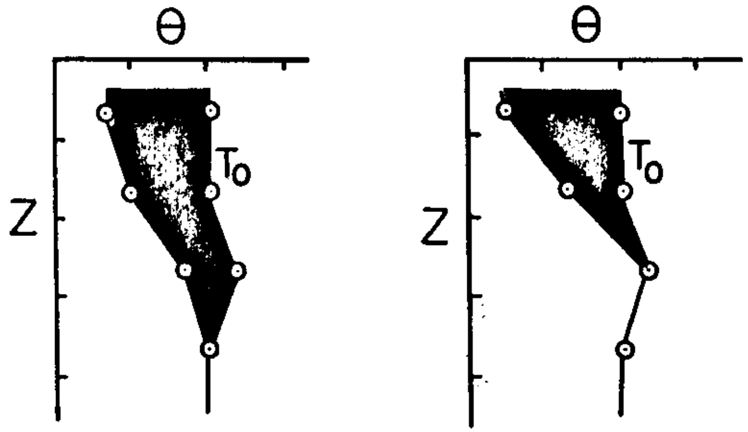


Figure 9 . Soil water storage in plant root zone.



Deep rooting

Shallow rooting

Figure 10. Assessment of plant rooting habits.

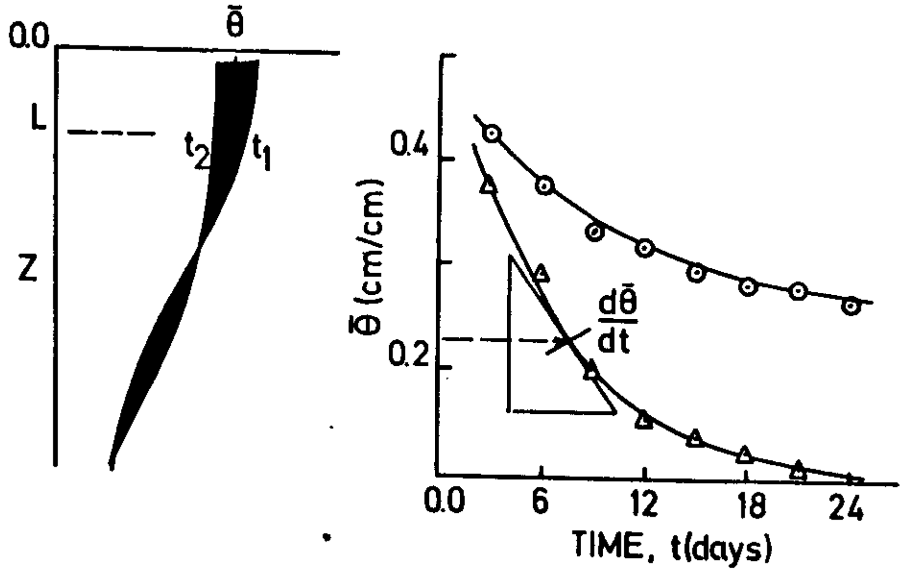


Figure 11. Basic field data needed to estimate unsaturated hydraulic conductivity, $K(\theta)$.

The second approach is more simple and does not require tensiometer measurements. Jones and Wagenet (9) reviewed and compared several simplified methods for measuring soil hydraulic conductivity. One of the methods tested was that described by Libardi et al.(11). In this approach, $K(\theta)$ was of the form

$$K(\theta) = K_o \exp[\beta(\theta_o - \theta)]$$

where β is constant and K_o and θ_o are the values of K and θ at saturation, respectively. The values of β and K are to be calculated using the field data as seen in the Figure (11) and the relation

$$\ln|z(d\theta/dt| = -\beta(\theta_o - \theta) + \ln K_o$$

A semi-log plot of the absulute value of $[z(dO/dt)]$ against $(\theta_o - \theta)$ gives and $\ln K_o$ from the slope and intercept, respectively.

Plant Water Consumption Studies

In plant water consumption studies, water balance approach is the simplest method one can use. Figure (12) describes main components involved in estimation of plant water requirement. Water balance in the plant root zone L can be described by

$$I + R - (D + E) = \mp \Delta S$$

where I and R irrigation and rainfall which can be easily measured, S change of plant root zone soil water content storage which can be measured with neutron moisture gauge; D and E drainage and evapotranspiration, respectively. Drainage water D can be estimated if one has tensiometer data in addition to changes of soil water storage. However one may have

$$I = 0; \; R = 0; \; D = 0$$

during certain periods of plant growing season. In this case, plant water consumption (i.e. evapotranspiration) is simply

$$E = -\Delta S$$

Water Use Efficiency Studies

In arid and semiarid regions, well being of farmers is very much influenced by availability of water resources. Irrigation water is not always available. Thus dry farming practices are commonly used. Crop cultivars with higher water use efficiency (WUE) have prime importance for optimum use of available water resources. Hence research work to select crop varieties with high WUE has immediate practical application. For

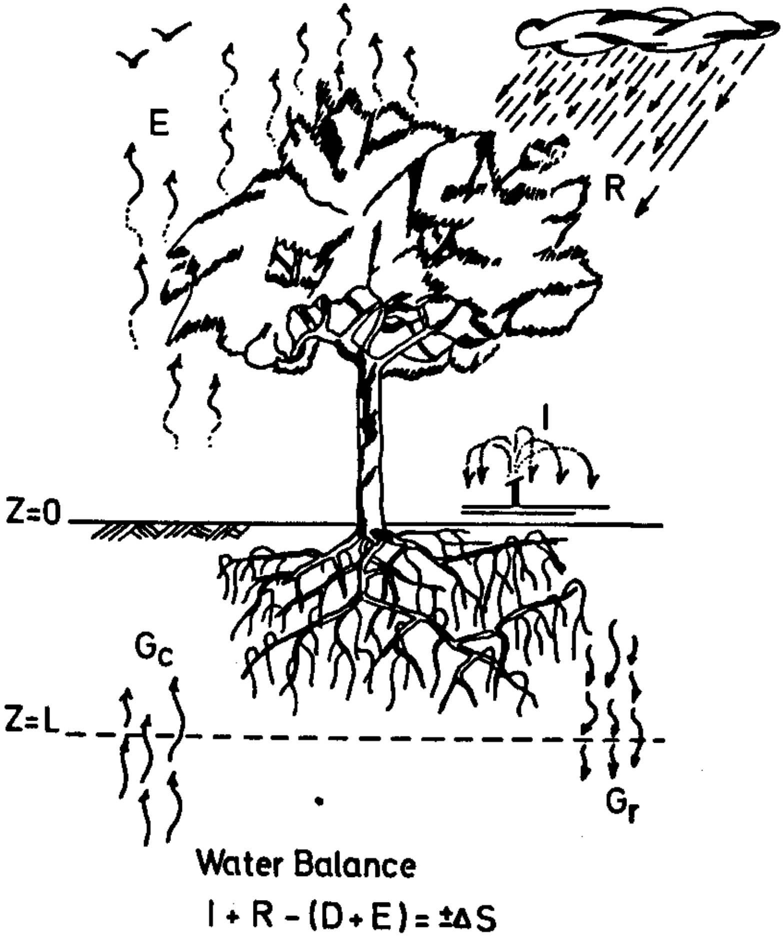


Figure 12. Water balance approach to estimate plant water requirement.

estimation of WUE, all one needs is crop water consumption during the growing season, which can be easily assessed with neutron moisture gauges as described above. The following relation is used to calculate WUE:

WUE : Yield / water consumption

= (Kg/ha)/mm water

= Kg/ha.mm

Irrigation Scheduling

It is usual practice to use available soil water content as a criteria to decide if irrigation is needed. Soil water content profiles based on measurements made with neutron moisture gauges (Fig.15) can describe depletion of available soil water content rather accurately. Although it may vary depending on different type of crops, the usual practice is such that the irrigation is started when available water content is decreased down to 50 %.

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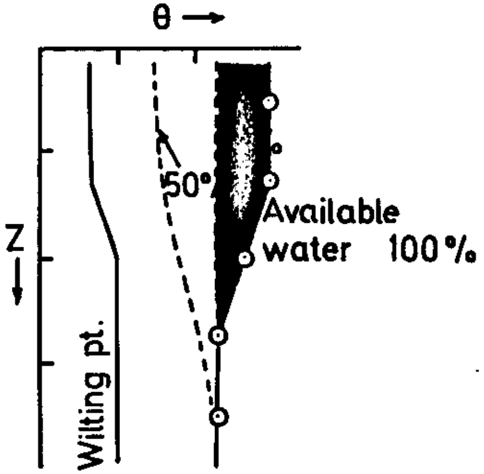

Figure 13. Irrigation scheduling based on available soil water content.

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