Nordic Hydrology 4, 1973, 77–85
Published by Munksgaard, Copenhagen, Denmark

DEPTH INTERVALS AND TOPSOIL MOISTURE MEASUREMENT WITH THE NEUTRON DEPTH PROBE

K. J. KRISTENSEN

Royal Veterinary and Agricultural University, Copenhagen

From measurements and calculations using a depth probe, the relative response is estimated for soil layers of different thicknesses. For a 10 cm thick layer of soil with the instrument centre in the middle, about 40 to 70 per cent of the response is caused by this particular layer at a water content of 8 to 40 per cent by volume. For a 20 cm layer the response for similar conditions is about 65 to 85 per cent.
A special calibration function for the upper (0–20 cm) soil layer is demonstrated for the neutron depth probe. It is found that the water content in this soil layer can be estimated in this way with about the same degree of accuracy as can be expected by conventional methods.

The neutron scattering method for determination of soil water content has been used increasingly in recent years. The method and the working performance of different instruments have been described by several authors (e.g. Gardner & Kirkham 1952, Holmes 1956, van Bavel et al. 1956, Haahr 1963, McHenry 1963, Ølgaard 1965, Long & French 1967, Luebs et al. 1968, I.A.E.A. 1970, Danfors & Skoglund 1971).

The neutron scattering method has advantages compared to other methods, as the soil water content is measured in a relatively large volume of soil which excludes or diminishes the influence of soil variation. Further, the very same soil profile can be measured repeatedly without any disturbance of soil or vegetation. The main disadvantages are that the instrument is expensive and involves some health-hazard if not used properly and that the response volume, i.e. the volume of soil that influences the instrument, is not constant, but depends on the water (actually hydrogen) content of the soil.

The response volume is a spheroid. Therefore, the resolution is rather weak, and thus influences the reliability of the method in soils with abrupt changes in the hydrogen content. As a consequence, the upper soil layers cannot readily be measured with an ordinary neutron depth probe.

This paper is concerned with problems regarding depth intervals and the determination of the water content of the upper soil layers. The instrument used is a BASC depth moisture probe from NEA, Copenhagen. The access tubes used were Al-tubes with a 41 mm inner diameter and a 1.5 mm wall thickness. The tubes extended to a depth of 150 cm.

DEPTH INTERVALS

Due to the spheric form of the response, volume measurement at a given depth, defined by the depth of the active centre of the probe, will be influenced by the hydrogen content of adjacent soil layers. The thickness of the soil layer from which the response originates depends on the vertical diameter of the spheric volume and thereby on the hydrogen content (i.e. mainly the water content) of the soil. The volume of this spheroid, which in the following will be considered a true sphere, is described in the literature as the sphere of influence (van Bavel et al. 1956) or the sphere of importance (Ølgaard 1965). Roughly the sphere of importance (or influence) is defined as the spheric volume from which 95 per cent of the total response originates. Using the definition given by Ølgaard, the radius of the sphere of importance (R_i) can be estimated by:

$$R_i = \frac{100}{1.4 + 0.1\,W_v}\text{, cm}$$

where W_v is the soil water content in per cent by volume. The length of R_i thus varies considerably. In very wet soil R_i may be less than 20 cm, and it may increase to about 50 cm in dry sandy soil.

In practical use treatment of the measurements is generally confined to a soil layer of thickness equal to the depth intervals chosen. The question then is how much of the response obtained in a given position is caused by the soil layer considered and how much originates from soil layers on either side of this layer. In order to answer this question information is needed about the response that is caused by different volumes of concentric shells of thickness ΔR, as R is increased up to R_i.

Kristensen (1971) made calculations based on measurements in an artificial soil profile consisting of two soil layers with different water contents and with a distinct boundary. From these calculations were derived the results illustrated in Fig. 1, The relative amount of response is shown as a function of the ratio R/R_i in order to bring the results for the two water contents on the same scale. As seen, there are differences depending on the water content of the soil. For an average soil the fully drawn curve is assumed to be representative.

The relationship shown in Fig. 1 was used by Kristensen (1971) to calculate the relative response originating from soil layers of different thickness (Δ) as a function of R_i and the soil water content (W_v) calculated according to Ølgaard (1965). The results are shown in Fig. 2 for different values of Δ given in the Figure. The depth interval to be chosen for a given soil depends on the water content and the purpose of investigation. If the purpose is to examine root development, a smaller value of Δ may be justified than if a determination of water balance is the goal. As can be read from Fig. 2, the response from a 10 cm layer is less than 50 per cent of the total response in a rather dry ($W_v = 8$) soil, and even in wet soils ($W_v = 25$–35) only 60–70 per cent of the response originates from the 10 cm soil layer.

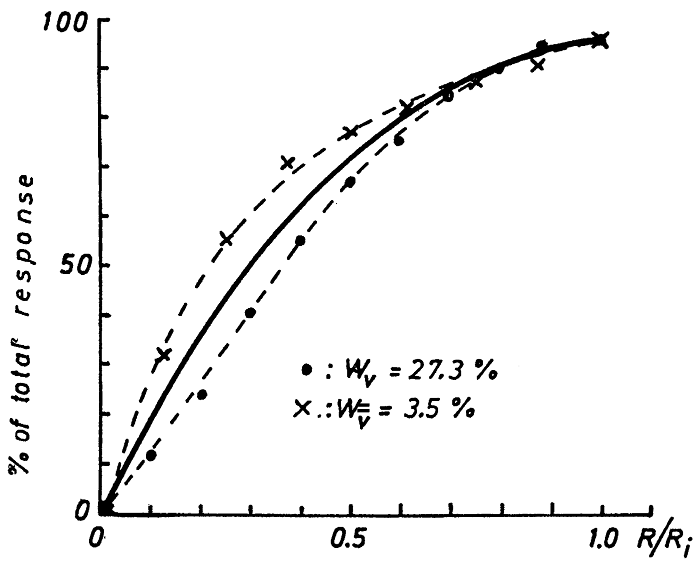

Fig. 1.
Relative response as a function of the relative distance (R/R_i) from the effective centre of measurement at two volumetric water contents (W_v).

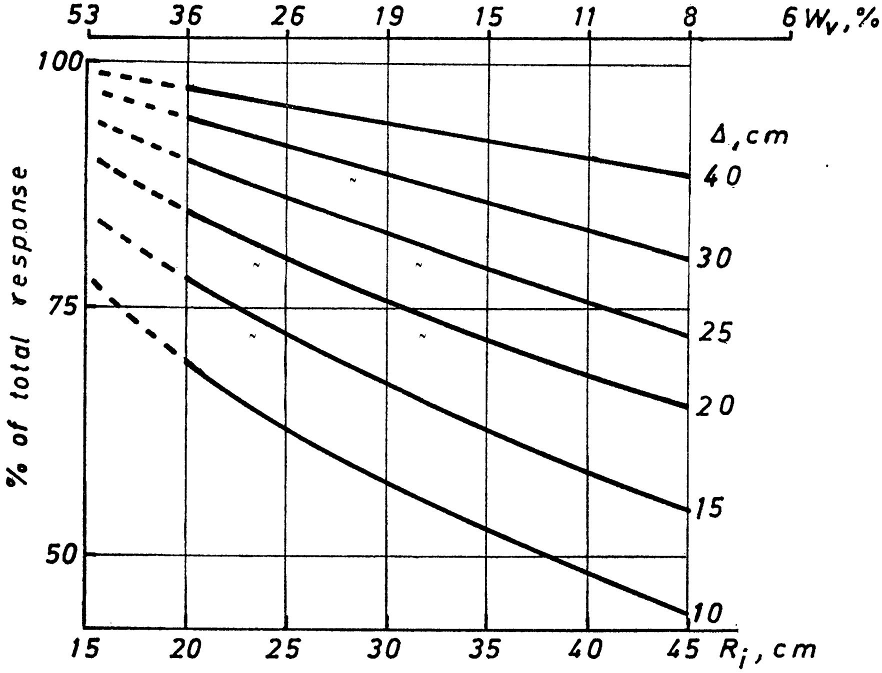

Fig. 2.
Relative response from a soil layer of thickness Δ as a function of the radius of importance (R_i) and volumetric water content (W_v).

The influence of the depth interval can be illustrated by the measurements given in Table 1. The results are from a soil carrying barley. Measurements were taken at the depths indicated.

The integrated water content (mm in the 0–100 cm soil layer) can be found in three different ways when 10 and 20 cm intervals are used.

I (10 cm layers): mm $\equiv 1.5\ W_{v(10)} + W_{v20,30,\ldots 90} + 0.5\ W_{v(100)}$.

II (20 cm layers): mm $= 2\ (W_{v(10,30,50,70,90)})$.

III (20 cm layers): mm $\equiv W_{v(10)} + 2\ (W_{v(20,40,60,80)}) + W_{v(100)}$.

The numbers in brackets indicate the depth of measurements.

The integrated amount of water is only slightly influenced by the method of calculation. The change in water content from one measuring time to another is almost the same for I, II and III, i.e. 66, 54–56 and – 21 mm for the three periods given in Table 1.

From these measurements it is concluded that, for a non-layered soil, not

Table 1.
Soil water content in per cent at different times (1969) under a barley crop, and mm for 0–100 cm depth calculated for 10 and 20 cm soil layers.

	Per cent by volume			
Depth cm	April 18	June 23	Aug. 11	Aug. 18
10	20.6	16.9	9.1	16.7
20	26.7	17.5	13.4	20.0
30	27.6	14.9	11.7	15.4
40	25.9	12.3	10.0	11.3
50	25.0	13.1	9.5	9.9
60	24.7	17.0	11.9	11.9
70	24.8	20.6	14.7	14.8
80	26.9	25.8	18.7	18.1
90	27.6	27.5	20.0	18.9
100	28.0	28.7	20.3	19.6
		mm (0–100 cm)		
I	254	188	134	155
II	252	186	130	151
III	257	191	137	159

much surplus information is gained by decreasing the depth interval from 20 to 10 cm. In most cases, and especially for soils with low water-holding capacities, 20 cm depth intervals may be sufficient for all kinds of investigations. For soils with higher water-holding capacities, some additional information may be gained by using 15 (or 10) cm depth intervals. For the mathematical treatment of the results the uppermost measuring depth should be 0.5 times the selected depth interval.

MOISTURE DETERMINATION IN THE TOPSOIL

Due to the spheric response volume of soil, the neutron depth probe cannot readily be used close to the surface. In fact, due to escape of fast neutrons, the standard calibration function fails to apply if the active centre of the probe is less than R_i below the soil surface. As the water content in the upper soil layer generally varies considerably, an estimation is often of primary interest. Use of conventional methods or of special surface neutron probes has been proposed, and can certainly be used, as a supplement to the depth probe. It is clear, however, that if, by some precautions, the neutron depth probe can be used for the upper soil layers also, this should be of great advantage to the user both practically and economically.

Pierpoint (1966) proposed to cover the soil surface around the access tube with a material high in hydrogen content in order to reduce the escape of fast neutrons from the soil. This method as well as the special surface instruments cannot be used in dense vegetation without damaging or destroying the crop. Luebs et al. (1968) suggested making a special calibration for the upper soil layer, and they report results for five different soils. They found a linear relationship between the soil water content and the count rate and claimed that 97–99 per cent of the change in count rate could be attributed to change in soil water content.

The BASC instrument was calibrated similarly in a clay loam soil. The effective centre of the neutron depth probe was placed exactly 10 cm below

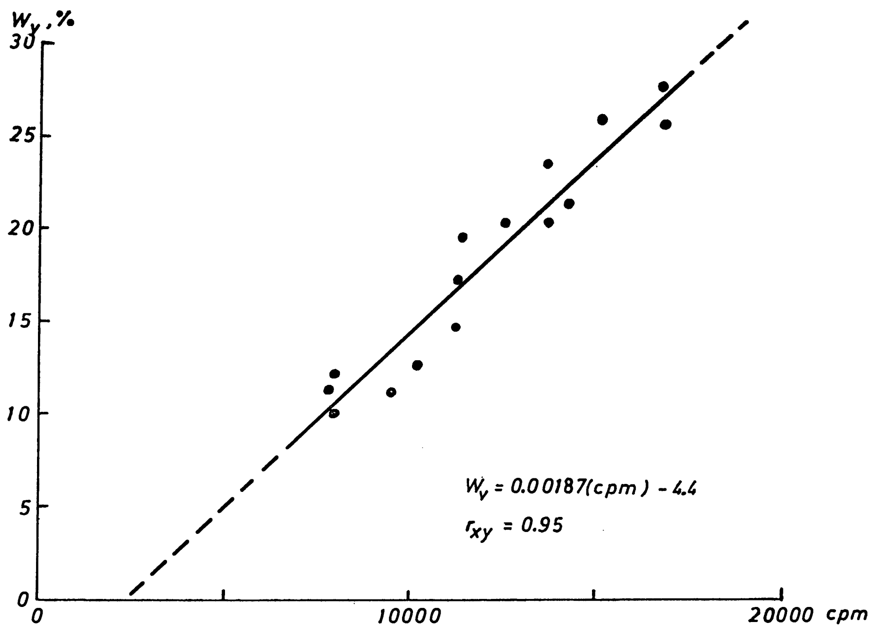

Fig. 3.

Volumetric water content (W_v) as a function of counts per minute (cpm) for the upper 0–20 cm soil layer of a clay loam soil. The equation is calculated by a regression analysis. r_{xy} = correlation coefficient.

the soil surface. The actual soil water content was estimated from gravimetric determination of the water content in six evenly distributed soil samples taken through the 0–20 cm soil layer at a distance of about 50 cm from the access tube in which the count rate was taken.

The results are shown in Fig. 3. In calculating the volumetric water content of the soil samples an average dry soil bulk density of 1.4 g cm^{-3} was assumed. Apparently a straight line function yields the best description in the interval in which the actual water content occurs (10 to 25 per cent). For the soil in question the water content will rarely be outside this interval.

Although the points scatter somewhat, it is concluded that a better estimation of the water ccontent in the upper soil layer cannot be achieved by any other means, not even by sampling and gravimetric measurements, for which the variance for this particular soil is found to be of the order of ± 2 volume per cent (Kristensen 1971).

The accuracy of the relation given in Fig. 3 was verified in a few instances. After a scheduled measurement on May 16, 1972, 27.6 mm rain was received

Table 2.
Recovery of rainfall as soil water measured by neutron scattering (average of 6 measuring positions).

Soil layer cm	Increase in soil water, mm		
	May 16–18	Nov. 7–8	Nov. 8–14
0– 20	22.9	12.7	2.6
20– 40	3.3	2.4	17.9
40– 60	–0.7	–0.3	10.0
60– 80	0.7	0.1	1.1
80–100	0.6	–0.2	0.1
100–120	–0.1	–0.1	1.4
120–140	–0.2	–0.3	1.4
140–160	–0.9	–0.2	–0.2
Recovered mm	26.2 ± 2.7	15.1 ± 1.8	34.3 ± 1.8
Rainfall, mm	27.6	13.3	37.8
Potential evap., mm	1.8	0	1.5
Expected mm	25.8	13.3	36.3
Recovered/expected	1.02	1.14	0.94
Instrument variance, mm	± 1.4	± 1.4	± 2.0

on May 17. Some of the positions were measured again on May 18 in order to recover the rain as soil water. A similar study was carried on again in November. The results appear in Table 2. The rain falling on May 17 and November 7 was fully retained in the upper 0–40 cm soil layer and most of it in the 0–20 cm layer. The rain received in the last period reported in Table 2 penetrated deeper into the soil. For this last period all the depths are considered in calculating recovery, while for the two first periods only the upper 40 cm soil layer is considered.

As seen, rainfall less the potential evapotranspiration in each period is fully recovered or slightly overestimated in the two first periods, and 94 per cent recovered in the last period. The results strongly support the opinion that the water content of the topsoil can be satisfactorily measured with the neutron depth probe, if proper calibration is carried out.

CONCLUSIONS

The depth intervals of measurements to be chosen in measuring soil water content with the neutron depth probe depend on the water content of the soil and the purpose of the investigation. For most soils, depth intervals of less than 15 cm may not be justified and for soils with low water-holding capacities, 20 cm depth intervals may be sufficient. If the aim of the investigation is a water balance, 20 cm depth intervals seem to be satisfactory for all normal soils.

The water content of the upper soil layer can be measured satisfactorly by the neutron depth probe if a proper calibration is made. It is advisable to construct a calibration function for each soil type under investigation. The probe must always be placed exactly at the depth to which the calibration function is referred.

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Received 20 January 1973.

Address:

Lektor K. J. Kristensen
Hydroteknisk Laboratorium og Klimastation
Højbakkegård, DK-2630, Tåstrup
Danmark