ICW nota 1661-II
november 1985

nota

instituut voor cultuurtechniek en waterhuishouding, wageningen

CALIBRATION AND EVALUATION OF A DIELECTRIC SOIL WATER CONTENT METER

J.M. Halbertsma and C. Przybyla

The contents of this Report earlier have been published as a contribution of the authors in:'International Conference on Hydrological Processes in the Catchment, Krakow, Polen, 8-11 May 1986.

JÔNT HALBERTSMA
CZESŁAW PRZYBYŁA
Institute for Land and Water
Management Research (ICW)
Wageningen
The Netherlands

CALIBRATION AND EVALUATION OF A DIELECTRIC SOIL WATER CONTENT METER

1. Introduction.

Detailed knowledge of the water content in a soil profile is of interest for several disciplines. Dynamic hydrological processes in the soil, such as infiltration and capillary rise, can be studied. The time of irrigation and the quantity of water to be applied can be determined in water use efficiency experiments. The evapotranspiration can be calculated from the change in water content of the soil profile when the percolation and precipitation are known.

Sprinkling experiments on maize were performed at an experimental field station of the Institute for Land and Water Management Research (ICW). Different water regimes were applied to the crop. These experiments allow a verification of coupled crop yield and water balance models [2].

During the last decades several direct and indirect methods have been used to determine the soil water content, such as the neutron-, gamma- and gravimetric methods, gypsum blocks and tensiometers [6]. These methods have different drawbacks. The neutron- and gamma methods are dangerous and need special safety precautions. The gravimetric method disturbs the soil and is also laborious. Gypsum blocks are not accurate, and tensiometers can measure only in a limited range.

Another method that has been used is the capacitive method [1], [5], [7], [8]. It is based on the measurement of capacitance of a capacitor with the soil-water-air mixture as the dielectric medium. A probe with conductive plates or rods surrounded with soil constitutes the capacitor. As compared with water the relative permittivity (dielectric constant) of the soil matrix and air are small (80, <10 and 1 respectively). A change in the water content of the soil will cause a change in the relative permittivity, and thus in the capacitance of the probe surrounded with soil. Usually the capacitor is part of a resonance circuit of an oscillator. Changes in the water content, and thus changes in the capacitor capacitance will change the resonance frequency of the oscillator. In this way the water content is indicated by a frequency shift. The relation between the water content and the frequency shift is non-linear. The relative permittivity of the soil matrix depends on the composition and bulk density. It varies between 2 and 10. Because of these reasons a calibration curve is needed for each separate soil. An important error source with the capacitive technique is the sensitivity for the electrical conductivity of the soil. Changes in the conductivity will also influence the resonance frequency of the oscillator.

Instrumentation used in the capacitive technique consists of a read-out unit, and either a mobile probe to record at different access tube points [4], or fixed probes at selected positions within the soil (fig. 1). A soil water content meter, consisting of probes that have to be placed into the soil and a detachable portable read-out unit, has been developed by the Technical and Physical Engineering Research Service (TFDL) in Wageningen. This instrument compensates for the conductivity of the soil [3].

In this paper we discuss the field and laboratory calibration and the usefulness of the dielectric soil water content meter. It has been used over several growing seasons on the ICW experimental field station the 'Sinderhoeve' in the Netherlands.

2. Calibration of the capacitive probes.

The soil water content meter was calibrated in both the field and in the laboratory.

2.1 Field calibration.

Before the beginning of the growing season the capacitive probes of the water content meter were installed. The probes were positioned horizontally in two columns at depths of 2, 3, 4, 5, 7, 10, 20, 30, 40

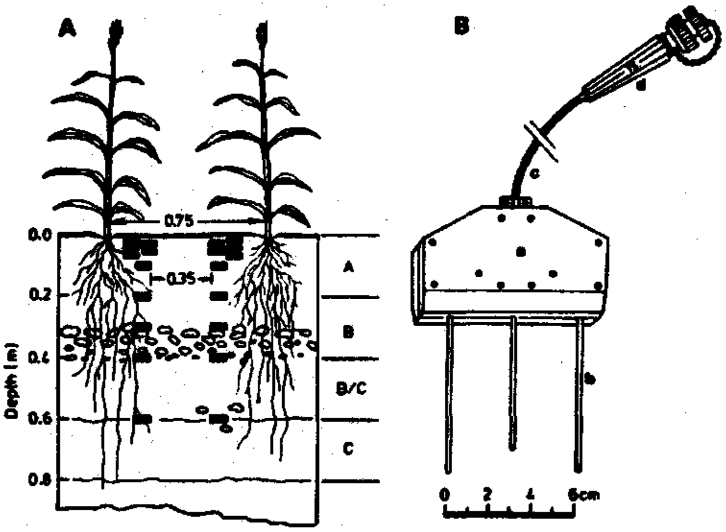

Fig. 1. Soil profile, position and illustration of capacitive probes. A. The soil profile and the position of the probes at the experimental station 'Sinderhoeve'. The soil profile consists of sand, in which a humic topsoil (horizon A) has been developed by addition of farmyard manure. This topsoil consists of gravel and coarse sand of approximately 20 cm thickness. Between 20 and 40 cm there is a podzolic B horizon with less humus and iron bonds. A transition zone between the B and C horizon (B/C) is found from 40 to 60 cm. Below 60 cm the soil consists of coarse sand and gravel. The probes are placed in two columns in between two rows of maize at ten different depths (from 2 to 60 cm). B. The capacitive probe. The probe consists of a plastic holder (a), three electrodes (b), a cable of two meters length (c) and a connector (d).

and 60 cm (fig. 1). During the measuring period soil samples were taken at these ten depths for gravimetric determination of the water content. The sampling was performed within a radius of five meters from the probes. The readings of the instrument were recorded during the sampling. Fig. 2 shows the relationship between the gravimetrically-determined water content and the reading of the instrument. The confidence of the extrapolated part of the calibration curve is substantially lower than the portion within the calibration range. Thus care should be taken to sample the soil water content at different depths for a wide range of water contents. The accuracy of the calibration curve depends on the field variability, and it will increase with the number of calibration points.

2.2 Laboratory calibration.

As the laboratory calibration information of the 1985 season is not yet available, results of 1983 are presented.

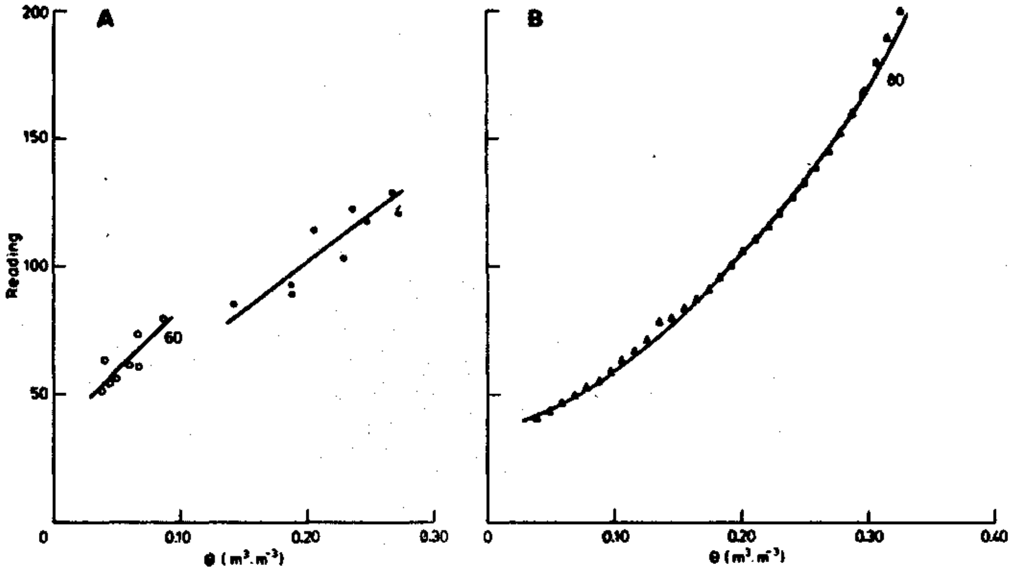

Fig. 2. Calibration of the dielectric soil water content meter for the 'Sinderhoeve' experimental field. The reading of the instrument is plotted against the gravimetrically-determined volumetric soil water content θ. A. Field calibration at a depth of 4 and 60 cm. The relationships are fitted with straight lines by means of linear regression analysis. B. Laboratory calibration at a depth of 80 cm. The relation was fitted with a second order curve by means of polynomial regression analysis.

After the measuring period the probes were removed. Soil cores, with a diameter and a height of 12 and 11 cm respectively, were taken at the corresponding depths and within a 1 m distance from the probes. The soil samples were saturated in the laboratory. The probes were then installed in these cores, and the water content meter reading and weight of the soil sample were recorded at regular intervals during evaporation (until the water content was very low). After oven-drying of the soil samples the water contents were calculated. The apparent non-linear relationship between the reading of the water content meter and the gravimetrically-determined water content was approximated by a second order curve (fig. 2B). The advantage of this calibration over the field calibration is that the whole range from saturation to dry can be calibrated for the same soil sample. The deviations of the calibration points from the curve are small, typically less than 0.02 $m^3.m^{-3}$. A disadvantage is that systematic errors can be introduced when the soil sample is not representative of the soil around the probe.

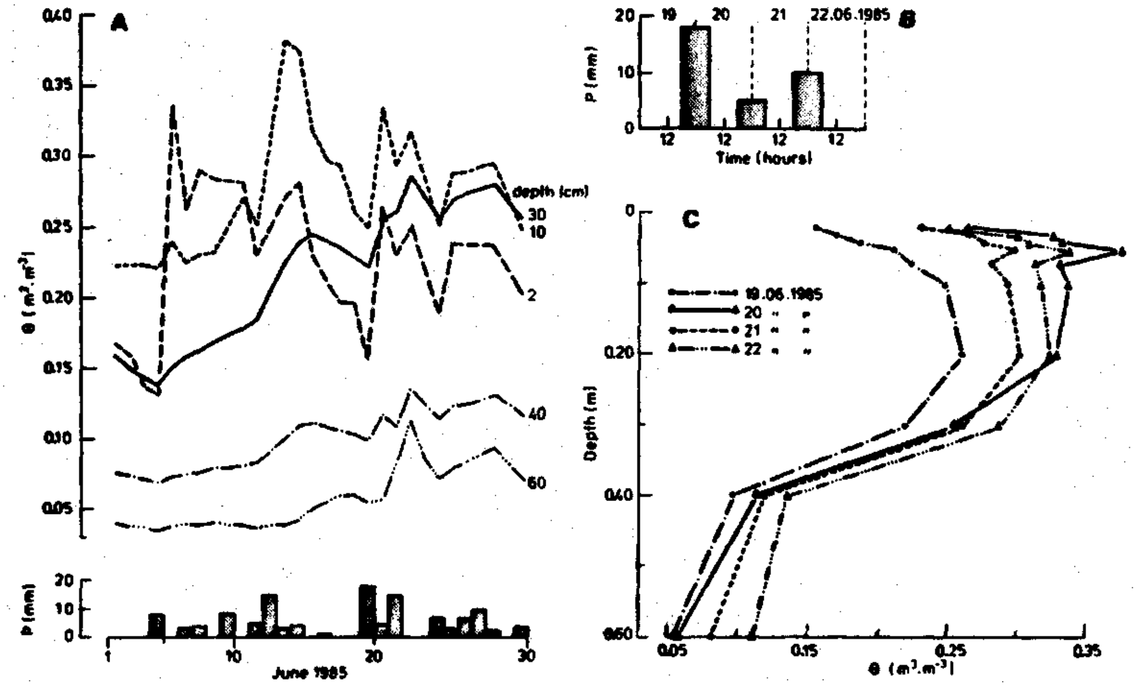

Fig. 3. Volumetric soil water content and precipitation at the 'Sinderhoeve' experimental field. A. Water contents θ at depths of 2, 10, 30, 40 and 60 cm and precipitation P are plotted for June 1985. B. Precipitation P during 19 to 22 June 1985. C. Water contents θ of the profile during 19, 20, 21 and 22 June 1985.

3. Water content measurement.

During the measuring period from May until October 1985, water content measurements were daily made using the dielectric water content meter. On several occasions the measurements were carried out every two hours. Soil water contents at the ten different depths were calculated using the field calibration curves. The water contents were determined by averaging the data from the two probes installed at that depth. Typically the measured water contents from these two probes differed by less than 0.02 $m^3.m^{-3}$. This is an indication of the absolute accuracy of this instrument when a field calibration is used. Larger differences were found when the water content was higher than the calibrated range, e.g. after heavy rainfall. The relative accuracy, i.e. the accuracy of the changes in the water content, can be estimated in the same way as the absolute accuracy. Comparing the changes in water content of two probes installed at the same depth yielded relative errors of approximately ±0.003 $m^3.m^{-3}$. These errors determine the

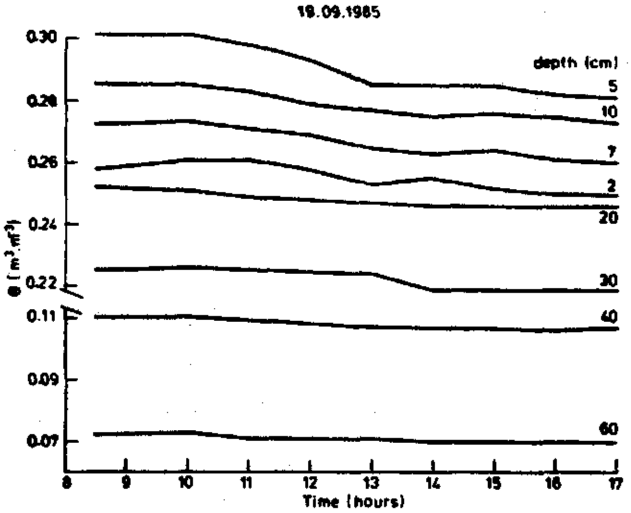

Fig. 4. Changes in the volumetric soil water content θ at different depths during 19 September 1985.

accuracy of the change in the total water content of the profile. This change in water content and the percolation, precipitation and evapotranspiration determine the water balance. The total water content of the profile was calculated from the data obtained with the probes installed in the two columns. Typical differences of 1 mm were found between the daily changes of these total water contents.

Precipitation and water content at several depths are plotted in figure 3A. Rapid changes in the top layers (e.g. at 2 cm), as a combined result of precipitation, evapotranspiration and percolation, and slower changes in the deeper layers (e.g. at 40 and 60 cm) can be clearly followed. The response of the water content in the profile to heavy rain is illustrated in figure 3B and 3C. After a relative dry period (19-6-85) the profile was wetted down to 40 cm (20-6-85). During the next day, the top 30 cm of the profile dried out somewhat as a result of percolation (increase of moisture at 60 cm) and evapotranspiration. The day after (22-6-85), the whole profile was again wetted after a heavy night shower. Water content changes of less than 0.005 $m^3.m^{-3}$ could be followed during the day (fig. 4). The evapotranspiration can be calculated from the water balance during that day. The percolation loss was small, less than 0.03 mm per day. Thus the evapotranspiration approximately equaled the change in the total water content of the profile, which is 4.26 mm. The evapotranspiration of maize was also calculated from meteorological data, using the methods of Feddes et al. [2]. This calculation gives an evapotranspiration of 4.03 mm, which agrees well with the water balance method.

4. Conclusions.

The described dielectric soil water content meter is a safe and useful instrument, that could replace neutron moisture meters as a method of determining soil water content. It is especially suited for studies where a detailed knowledge of the water content throughout the whole soil profile is needed, e.g. in water balance studies. It allows the investigator to measure quickly and accurately the soil water content after a relatively simple calibration procedure. The soil water content can be monitored at many different depths, including the top layer (e.g. at 2 cm). After installing the probes no further disruption of the profile occurs. The response of the instrument is almost instantaneous and water content changes smaller than 0.5% can be measured. The instrument can be applied in automatic measuring and control systems.

5. References.

[1] DE PLATER, C.V. - A portable capacitance-type soil moisture meter, Soil Sci. 80, 391-395, 1955

[2] FEDDES, R.A., KOWALIK, P.J., ZARADNY, H. - Simulation of field water use and crop yield, 188 p., Simulation Monographs, PUDOC, Wageningen, 1978

[3] HILHORST, M.A. - A sensor for the determination of the complex permittivity of materials as a measure for the moisture content. In: Sensors & actuators (ed. P. Bergveld) pp 79-84, Kluwer Technical Books, Deventer, 1984

[4] KURAZ, V. - Testing of a field dielectric soil moisture meter, Geotechnical Testing J. 4, 111-116, 1981

[5] KURAZ, V., KUTILEK, M. & KASPAR, I. - Resonance-capacitance soil moisture meter, Soil Sci. 110, 278-279, 1970

[6] SCHMUGGE, T.J., JACKSON, T.J., McKIM, H.L. - Survey of methods for soil moisture determination, Water Resources Res. 16, 961-971, 1980

[7] SMITH-ROSE, R.L. - Electrical measurements on soil with alternating currents, J. Inst. Elect. Engin. 75, 221-237, 1934

[8] TURSKI, R. & MALICKI, M. - A precise laboratory meter of a dielectric constant of soil of a different moisture, Polish J. Soil Sci. 7, 71-79, 1974

CALIBRATION AND EVALUATION OF A DIELECTRIC SOIL WATER CONTENT METER

Summary

A dielectric soil water content meter and its field and laboratory calibration are described. The water content meter is able to measure quickly and accurately the volumetric soil water content at many depths, including the top layer, without disturbing the profile. The instrument is especially useful in water balance studies, where a detailed knowledge of the soil water content is needed. Field measurements are presented.

KALIBRACJA I ZASTOSOWANIE DIELEKTRYCZNEGO MIERNIKA WILGOTNOŚCI GLEBY

Streszczenie

Przedstawiono wyniki polowej i laboratoryjnej kalibracji dielektrycznego miernika wilgotnosci gleby. Miernik ten pozwala na szybki i dokładny pomiar dynamiki zmian zapasów wody w profilu glebowym, również jego górnych warstw.

Przyrząd może być szczególnie stosowany w badaniach nad bilansem wodnym, którego skladową stanowią zapasy wody w glebie.