Measuring Moisture Near Soil Surface . . .

minor differences due to neutron source type

ROBERT R. ZIEMER IRVING GOLDBERG

NORMAN A. MACGILLIVRAY

ABSTRACT: Moisture measurements were made in three media--paraffin, water, saturated sand--with four neutron moisture meters, each containing 226-radium-beryllium, 227-actinium-beryllium, 239-plutonium-beryllium, or 241-americium-beryllium neutron sources. Variability in surface detection by the different sources may be due to differences in neutron sources, in length of source, or both.

RETRIEVAL TERMS: soil moisture measurement; neutron moisture meter soil moisture meter; soil surface moisture; vertical resolution; americium-beryllium; hydrometeorology.

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Since 1956, the U.S. Forest Service and the California Department of Water Resources jointly have been studying the problem of soil moisture depletion The aim of these studies is to measure water use by wildland vegetation. In addition, the Department has been making studies of water use by various agricultural crops.

The development of the neutron soil moisture meter in the 1950's did much to advance the technology of soil moisture measurement.[1] Such measurements made by the neutron method are affected by abrupt changes in soil moisture content. This effect is particularly evident near the soil surface where neutrons are lost into the air.

The usefulness of the neutron meter is limited if it is necessary to measure moisture near the soil surface. Most researchers need to know the shallowest depth at which moisture observations are unaffected by the surface. When such measurements are needed, a neutron instrument of different design must be used or alternative methods of soil moisture determination must be considered.

Until recently radium-beryllium was the only fast-neutron source feasible for use in soil moisture meters because of its low cost, small size, and long half-life. Radium, however, has the disadvantage of emitting gamma radiation at an undesirably high intensity. And the heavy lead shielding required for safe use of the radium meter limits its portability in the field. Consequently, isotopes with lower gamma/neutron ratios are coming into wider use. Some studies of surface effects have been made using 226-radium-beryllium--the ‘standard’ neutron source--in the soil moisture meters. To date, little has been published on the effect of alternative isotopes on soil moisture measurement near the surface.

Equipment

At the time we made this study, four Nuclear-Chicago Model 2800-A scalers[2] and four P-19 depth moisture probes each containing different neutron source types (table 1) were available to the Experiment Station and the California Department of Water Resources.

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[1] Lawless. et al. 1963: McGuinness. et al. 1961; Nixon and Lawless 1960; Stolzy and Cahoon 1957; Stone, et al. 1955; Van Bavel, et al. 1954, 1963.

[2] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture or by the State of California is implied.

Examination of the decay schemes of these isotopes indicated that differences in neutron energies would be expected. We hypothesized that the influence of the neutron meter would vary in volume with the effective neutron energy. Therefore, data from meters containing sources having higher neutron energies might be affected by the soil-air interface at deeper depths than from those with lower neutron energies,

We wanted to determine the effect of different neutron source types upon the depth at which the air-soil interface was detected. We measured count rates with four neutron moisture meters of similar geometry (side-mounted source) using either 226-radium, 227-actinium, 239-plutonium, or 241-americium as the primary alpha emitter (table 2). The neutron source in the meters tested is located 4 inches above the bottom of the probe housing and at the side of and midway along the 6-inch long slow-neutron detector. The count rates from three media--paraffin, water, and saturated sand--were compared (table 3). We concluded that the differences in detection of the soil surface between the sources studied are so small as to be of minor significance for most field applications.

Experimental Procedures

We melted commercial paraffin in a barrel 16.9 inches tall and 16 inches in diameter. A 1.6-inch diameter aluminum access tube was installed in the center along the vertical axis of the barrel. The paraffin was allowed to solidify very slowly to avoid air pockets developing in the medium,

The water medium was prepared by filling with tap water a 55-gallon barrel with a 22-inch diameter and a 33-inch height. This medium was previously demonstrated to be effectively infinite in volume. An aluminum access tube was installed in the center along the vertical axis of the barrel.

To prepare the sand medium, we placed an access tube in the center of a 55-gallon barrel. After filling the barrel with sand, we added water slowly through a fitting in the bottom of the barrel until the liquid began to appear on the surface,

In both the water and sand media, a one-minute count was taken at l-inch increments from 4 inches above the bottom until the source was positioned above the medium-air interface and the count rate was about zero. In the paraffin medium, we made counts at l/2-inch increments.

To normalize the data for differences in source strength and detector tube volume, count ratios for each medium and source were computed by dividing the count rate at each depth increment by the mean of the count rates which were unaffected by the surface. These count ratios were then plotted against distance from the surface for each source in each medium (fig. 1).

Results and Discussion

We found that the ratio profiles with each source in each of the three media could be described by a vertical straight line at the 1.00 count ratio, another straight line at about 0.00 count ratio, and a sloping straight line connecting the vertical lines. These three lines could be connected by two arcs tangent to those straight lines. In the figure we have indicated the depth at which the surface was first detected. Surface detection was assumed to be the point where the data began to depart from the 1.00 count ratio.

The surface was detected at a fairly consistent depth with each source in a particular medium. The interpretation of the radius of curvature and the precise point of departure from the 1.00

Table 1. --*Characteristics of four soil moisture meters evaluated*

Meter	Source strength	Neutron flux	Source dimensions (diam. X length)	Detector diameter
	Mc.	*10^5 n/cm^2/sec*	*Inches*	
Radium (Ra)	4.84	0.79	0.28 x 0.30	1.00
Actinium (Ac)	12.2	2.20	.49 x .54	.87
Plutonium (Pu)	125.	2.09	.44 x 1.00	.87
Americium (Am)	100.	2.33	.37 x 1.00	1.00

Table 2. -- *Characteristics of neutron sources used in measuring soil moisture*

Neutron source	Half-life	Specific activity	Neutron yield	Gamma ose rate per 10 n/sec	Principal alpha energies
	Years	***Curies/gram***	***10^6 n/sec. C***	***Mrhm***	***Mev***
^{226}Ra-Be	***1,620***	***0.98***	***13***	***60***	***4.78 -- 7.68***
^{227}Ac -Be	***22***	***71.89***	***18***	***8***	***5.71 -- 7.44***
^{239}Pu -Be	***24,360***	***.06***	***1.4***	***1.7***	***5.15***
^{241}Am-Be	***458***	***3.24***	***2.7***	***.1***	***5.48***

Table 3. --*Characteristics of three media used to test neutron source types*

Medium	'Moisture' content	Container dimensions (diameter x height)
	Percent volume	***Inches***
Paraffin	[1]113	***16.0 x 16.9***
Water	***100***	***22.3 x 33.5***
Saturated sand	***39***	***22.3 x 30.0***

[1] Neutron capture cross section for H in paraffin ($C_{22}H_{46}$) is less than for H in water (H_2O).

Table 4.--*Vertical distance between the intersection of the 1.00 and 0.00 count ratio lines, with a straight line passing between the intermediate data points for each source in each medium*

Source	Medium		
	Sand	Water	Paraffin
		Inches	
Pu-Be	5.9	4.2	3.9
Am-Be	5.6	4.4	4.0
Ac-Be	5.3	4.1	3.9
Ra -Be	5.4	4.0	3.7

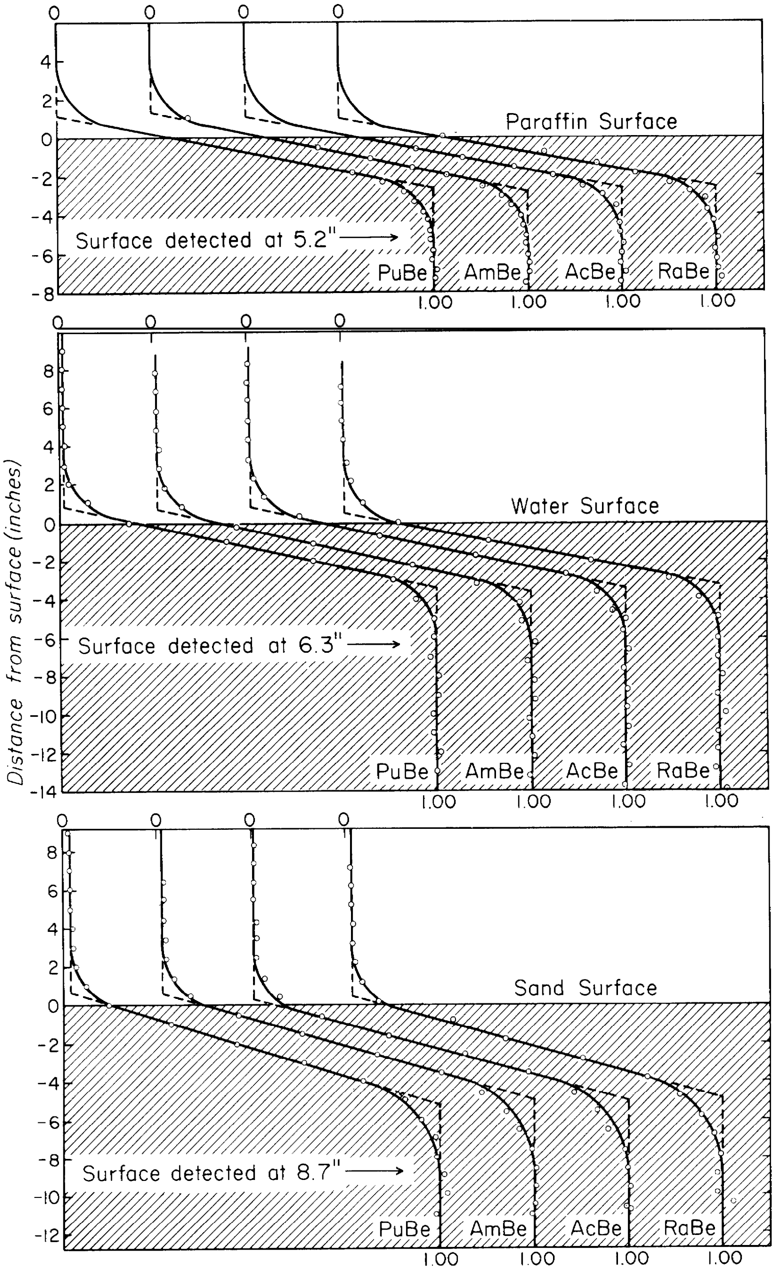

Figure 1. --*Comparison of the count ratios from neutron meters containing four different source types positioned at various distances from the surface of three study media.*

count ratio line is quite subjective and should not be considered a precise measure of differences due to the source type. The straight line passing through the data between the areas of curvature when extrapolated intersects the vertical lines passing through the 1.00 count ratio and 0.00 count ratio. The vertical distance between these points of intersection is less subjective and therefore provides a better measure of differences in the surface effect due to source type. These vertical distances vary slightly between sources in the same medium (table 4).

The vertical resolution--the ability to detect abrupt changes in moisture content-- of neutron meters with side-mounted sources is not strictly independent of the source. The variability in surface detection may be the result of a combination of two main factors: (a) differences in neutron energy, and (b) differences in the length of the source.

Goldberg, MacGillivray, and Ziemer (1967) found that meters with radium sources gave corrected counts which were about 3 percent lower than the corrected counts from americium and plutonium sources in finite-sized containers of soil. Their results confirmed the hypothesis that a larger volume of soil is sampled with radium sources, which emit higher energy neutrons, than with americium and plutonium sources, which have lower energy. Differences in count rate between sources due to differences in neutron energy would be minimized in the vertical direction because of the geometry of the detection system.

The length of the radium source capsule used in the study was 0.30 inch (table 1). The actinium capsule was 0.54 inch long. The plutonium and americium capsules were 1 inch long. It is reasonable to expect that the length of the radioactive alloy contained in the inner capsule of each source is proportional to the length of its outer source capsule. Given two sources containing identical isotopes, we might expect the meter with the longer source capsule to detect the soil surface at a slightly greater distance than that with the shorter capsule. Therefore, we might expect the meters with Am-Be and Pu-Be sources to detect the surface first, then the Ac-Be source, and finally the Ra-Be source. But from the previous experiment we confirmed the hypothesis that the higher energy Ra-Be sources sampled a greater volume of soil than the lower energy Pu-Be and Am-Be sources, Therefore, the Ra-Be source should beexpected to detect the surface first. Consequently, the surface detection by these meters (fig. 1) probably represents the result of these offsetting effects.

Literature Cited

Goldberg, I., MacGillivray, N. A., and Ziemer, R. R.
1967. *Effects of neutron source type on soil moisture measurement* Trans. Amer. Nuclear Soc. 10(1): 20-21.

Lawless, G. P., MacGillivray, N. A., and Nixon, P. R.
1963. *Soil moisture interface effects upon readings of neutron moisture probes.* Soil Sci. Soc. Amer. Proc. 27(5):502-507.

McGuinness, J. L., Dreibelbis, F. R., and Harrold, L. L.
1961. *Soil moisture measurements with the neutron method supplement weighing lysimeters.* Soil Sci. Soc. Amer. Proc. 25:339-342.

Nixon, P. R., and Lawless, G. P.
1960. *Detection of deeply penetrating rain water with neutron-scattering moisture meter.* Trans. Amer. Soc. Agr. Eng. 3:5-6,

Stolzy, L. H., and Cahoon, G. A.
1957. *A field-calibrated portable neutron rate meter for measuring soil moisture in citrus orchards.* Soil Sci. Soc. Amer. Proc. 21: 571-575.

Stone, J. F., Kirkham, D., and Read, A. A.
1955. *Soil moisture determination by a portable neutron seattering moisture meter.* Soil Sci. Soc. Amer. Proc. 19:419-423.

Van Bavel, C. H. M., Hood, E. E., and Underwood, N.
1954. *Vertical resolution in the neutron method for measuring soil moisture.* Trans. Amer. Geophys. Union 35:595-600.

Van Bavel, C. H. M., Nixon, P. R., and Hauser, V. L.
1963. *Soil moisture measurement with the neutron method.* U.S. Department of Agriculture, Agricultural Research Service, ARS-41-70. 39 pp.

The Authors

ROBERT R. ZIEMER heads the Station's research on flood and sediment reduction in the conifer forest zone, with headquarters in Berkeley, Calif. He received his forestry education at the University of California.. Berkeley (B.S. 1959; M.S. 1964), and joined the Station staff in 1966.

IRVING GOLDBERG received B.S. (in chemistry, 1949) and M.S. in soil chemistry, 1950) degrees at the University of California, Berkeley. Since 1958, he has been with the California Department of Water Resources, Sacramento, where he is an associate soils specialist (radiologic).

NORMAN A, MacGILLIVRAY is an associate land and water use analyst in the California Department of Water Resources' San Joaquin District, Bakersfield. Before joining the Department he worked for the US Agricultural Research Service He holds a B.S. degree in irrigation science (1951) from the University of California, Davis.