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Measuring Soil Bulk Density Profiles with a Single Probe Gamma Density Gauge

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Abstract

Calibrating neutron depth gauges for measuring soil water content profiles requires soil bulk density data. In this study, the feasibility of using a single probe gamma density gauge to measure the soil wet bulk density was investigated for use in neutron gauge calibration. The same sites, access tubes, and conventional gravimetric soil data used for the ASCE Neutron Gauge Calibration Study were used for the Gamma Gauge Study. Iterative procedures were successfully developed to calibrate the gamma density gauge, and then to convert wet bulk density to dry bulk density data for the three soil sites studied.

Introduction

The ASCE task committee on neutron gauge calibration met at Logan, Utah, July 1992, to obtain data for possible standardization of procedures for installing access tubes and for obtaining soil samples for calibrating neutron moisture gauges (see Stone et al., 1993, these proceedings, for an overview of the committee objectives and general procedures used in the study). This paper concerns the use of a single probe gamma density gauge and conventional gravimetric soil sampling procedures to measure the wet bulk density of soil profiles at the selected study sites. Soil sampling procedures have been used for many years to calibrate neutron meters (Greacen, 1981); however, there is still concern about the variety of procedures in use and the potential for errors in volumetric soil sampling (Dickey et al., 1993, these proceedings). Bulk density soil sampling procedures are laborious and time consuming.

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The single probe gamma density gauge provides a means of obtaining indirect measurements of wet soil bulk density in a manner similar to the indirect measurement of water content with the neutron gauge. While single probe gamma density gauges have been available for many years (Lal, 1974), they have not been widely used in calibrating neutron probes. Some studies have indicated the need for gamma gauge calibration curves based on the texture and chemical composition of soil, as well as bulk density (Lal; 1974, 1979). Ward and van Deventer (1993) found no significant difference in results between the factory-supplied calibration equation and equations developed with their field data; nonetheless, they suggested that similar gauges need to be evaluated for a wide range of soils and water contents.

The specific objectives of this study were (1) to evaluate the utility of using the single probe gamma density gauge to measure soil profile bulk density while calibrating neutron depth gauges for measuring soil water content, (2) to determine the relative effects of the several methods of access tube installation on gamma gauge readings, and (3) to determine the bulk density profiles for the soils at the selected sites. The same sites, access tubes, and gravimetric data obtained in the neutron meter calibration study were used for the gamma gauge study.

Methods

Gravimetric data from properly obtained soil samples can be used to calculate parameters pertaining to soil water content and bulk density by

$$\theta M = (MW - MD)/MD = (MW/MD) - 1 \quad [1]$$

$$\theta V = (MW - MD)/(V * DH) \quad [2]$$

$$DD = MD/V \quad [3]$$

$$DW = MW/V \quad [4]$$

$$\theta V = DD * \theta M/DH \quad [5]$$

where MW and MD are the sample mass (g) before and after oven drying, respectively; θM and θV are the gravimetric fractional mass water content (g g^{-1}) and fractional volumetric water content (cm^3 cm^{-3}), respectively; V is the sample volume (cm^3); DD and DW are the dry and wet soil bulk densities (g cm^{-3}), respectively; and DH is the density of water (g cm^{-3}), which, practically, is unity but is necessary for unit consistency. It is more convenient to calculate θV by Eq. [5], if dry bulk density data are known or can be reasonably estimated, than by Eq. [2]. The masses MW and MD can be measured quite accurately so that θM by Eq. [1] is a good estimate of the mass soil water content. However, it is much more difficult to achieve the same precision in the volumetric measurement as needed in Eqs. [2], [3], and [4].

The three soils sampled near Logan, Utah, were a Millville silt loam (SiL) at Site 1, a Nibley clay loam (CℓL) at Site 2, and a Kidman fine sandy loam (fSL) at Site 3 (see Stone et al., 1993, for detailed soil descriptions). Wet (W) and dry (D) profiles were sampled at each soil site. Volumetric soil samples were collected during the removal of soil from the access tube hole (see Dickey, 1993, for details). Aluminum access tubes [OD = 2 inches (51 mm)] were then inserted into the holes. The access tubes installed by teams from Utah State University (USU) and the Soil Conservation Service (SCS) used holes created with hand-sampling tools with diameters less than that of the access tubes. Only portions of the soil removed were used for gravimetric analysis. After sampling, their holes were enlarged to accommodate the diameter of the access tube. The Kimberly, Agricultural Research Service (ARS) team formed the access tube hole with a tractor-mounted, hydraulically operated Giddings[2] soil sampling unit using a soil coring tube fitted with a cutting head having an OD of 2⅛ inches (54 mm) and a soil tube OD of 2 inches (51 mm). So far as possible, the entire core removed from the hole was used for analysis.

A Troxler Electronic Laboratories, Inc.[2], Model 1351 gamma depth density gauge equipped with a Model 504 depth density probe was used to measure wet bulk density profiles at each of the 18 access tubes. The probe was 1.865 inches (47.37 mm) in diameter by 18.125 inches (460.4 mm) long. The gamma radiation source (8 mCi, Cesium - 137) was positioned at the bottom of the probe with the detector above the source. The gauge operates in the back scatter mode. The more dense the material, the fewer the events of scattered radiation back to the detector. The gamma gauge was supplied with calibration information consisting of a table of densities as a function of count ratio (the ratio of counts for a given density divided by the standard count). Standard counts were obtained at each of the three soil sites, before and/or after reading the six aluminum tubes at the site, by placing the gauge atop the gamma gauge case, and taking five consecutive, 60 s readings. For the soil readings, the probe was lowered into the access tube at 6-inch (15.2 cm) intervals beginning at the 6-inch depth, and two, 60 s readings were made at each depth.

Data Analysis

The gravimetric data were firstly screened for volumetric reliability for use in determining the specific relationship of the gamma probe count ratios to the gravimetrically determined wet bulk densities. The factory-supplied gamma probe calibration was initially accepted as applicable for calculating the tentative wet bulk density ($DW\gamma_f$) profiles from gamma gauge readings. A gamma-based "tentative" gravimetric sample volume ($V\gamma_f$) was calculated by

$$V\gamma_f = MW/DW\gamma_f \qquad [6]$$

If sample $V\gamma_f$ was within $\pm$ 2.5% of the profile mean $V\gamma_f$, and samples were reasonably free of sampling problems, the sample was considered acceptable for calibration purposes.

[2]Mention of products or companies is provided for the information of the reader and does not imply endorsement by the authors or their institutions.

The gravimetric DW data, determined by Eq. [4], for selected samples and for fairly uniform portions of the soil profile, were then used to obtain the relationship of gamma count ratio to wet bulk density. The specific calibration relationships were next used to calculate the final gamma probe wet bulk density profiles for all access tubes. The calibrated gamma probe wet bulk density ($DW\gamma_c$) can be used with the mass gravimetric data to calculate a gamma-based dry bulk density ($DD\gamma$) and volumetric water content ($\theta V\gamma$):

$$DD\gamma = (MD/MW) * DW\gamma_c \quad [7]$$

$$\theta V\gamma = DD\gamma * \theta M/DH \quad [8]$$

Results and Discussion

Analysis of variance of the standard counts showed that the average gamma gauge standard counts for the three sites were not significantly different from each other (Mean = 5702 cts/min, CV of Means = 0.6%, $P < 0.01$). The gamma gauge count ratio profiles obtained for the ARS, USU, and SCS access tubes at the wet and dry locations at each of the three soil sites are shown in Fig. 1. The gamma count ratio profiles of the USU and SCS access tubes were similar, while the ARS profiles were consistently less than the other two profiles at each location. These results indicate that the soil surrounding the ARS access tubes, installed with the Giddings soil probe unit, had an artificially higher bulk density than the soil surrounding the USU and SCS hand-augered holes. The cutting heads used with the Giddings coring tools cut cores with a cross sectional area of about 13 cm^2 but created holes with areas of about 23 cm^2. Thus, about 10 cm^3 of soil was displaced laterally for each 1-cm depth of sampling. The side-wall compression effect would be expected to also affect neutron probe readings (see Allen et al., 1993). There was much less, if any, lateral compression in the sidewalls of the USU and SCS access tube holes.

Some results of the gravimetric sampling and the gamma probe measurements are listed in Table 1 for the ARS, USU, and SCS access tubes at Site No. 1-Wet, as an example of the computational scheme and relationship of the gravimetric to the gamma probe data. Data for the 6-inch depth were omitted because the depth was insufficient to give reliable gamma probe readings. Comparison of $DW\gamma_f$ (Table 1, Col. 7) with DW (Col. 6), calculated by gravimetric analysis of the access tube soil core, shows that the two were similar for the ARS tube but were different for the USU and SCS tubes (as was discussed relative to Fig. 1). The variability with depth of the first estimate of $V\gamma_f$ (Col. 8), computed from gravimetric and gamma probe data by Eq. [6], reflects the precision with which gravimetric samples were obtained as well as the representation of the soil volume "seen" by the gamma probe. The absolute difference between V and $V\gamma_f$ for the USU and SCS access tubes resulted partly from the effects of the assumed gamma probe calibration. This assumption did not affect the variability in $V\gamma_f$. The CV's of $V\gamma_f$ (Table 1, Col. 8) for the 12- through 48-inch depths for the ARS, USU, and SCS profiles were 4.5%, 3.4%, and 2.8%, respectively. While the CV of the ARS samples was higher than of the others, the ARS samples

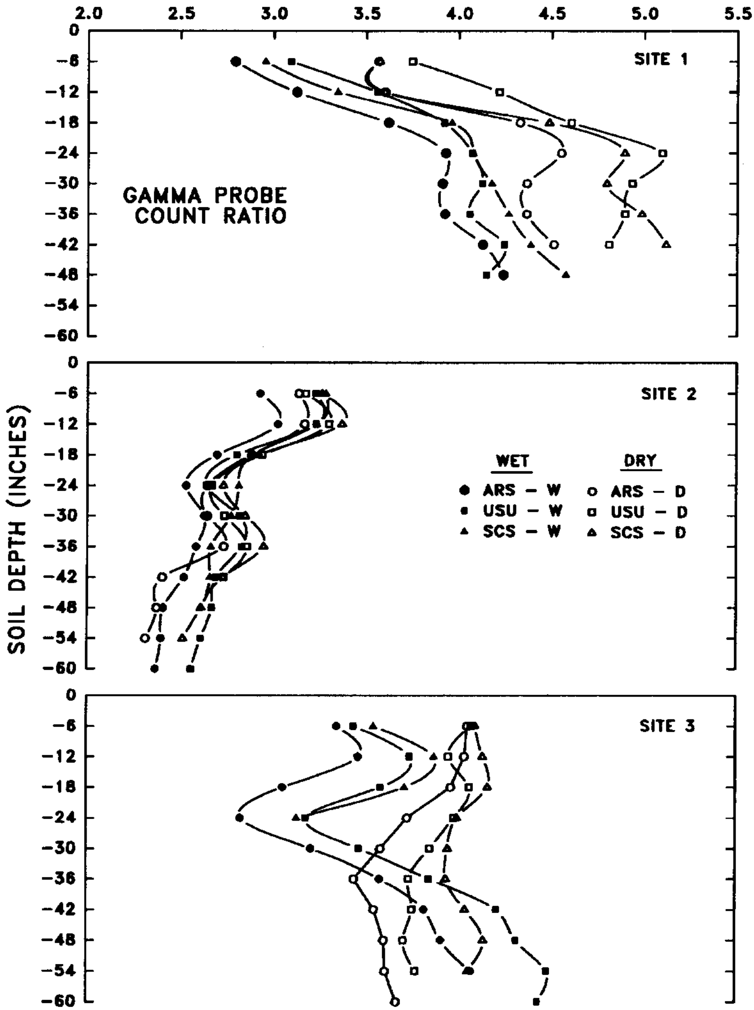

FIG. 1. Gamma gauge count ratio profiles for the ARS, USU and SCS access tubes at three soil sites.

Table 1. Data for Site No. 1, Wet, as an Example of the Computational Scheme and the Relationship Between the Gravimetric and Gamma Probe Data.

Soil	Gravimetric					First estimate		Final estimate	
depth	MW	MD	V	θM	DW	DWγf	Vγf	DWγc	DDγ
in.	g	g	cm^3	$g\ g^{-1}$	gcm^{-3}	gcm^{-3}	cm^3	gcm^{-3}	gcm^{-3}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
					ARS				
12	339.9	293.6	197.1	.158	1.72	1.76	193.1	1.73	1.49
18	306.1	264.9	197.1	.156	1.55	1.60	191.3	1.60	1.38
24	304.9	252.2	197.1	.195	1.55	1.51	201.9	1.52	1.27
30	294.9	249.9	197.1	.180	1.50	1.52	194.0	1.52	1.29
36	327.0	281.9	197.1	.160	1.66	1.51	216.6	1.52	1.31
42	280.5	250.1	197.1	.122	1.42	1.46	192.1	1.47	1.31
48	272.7	251.4	197.1	.085	1.38	1.43	190.7	1.44	1.33
Mean			197.1	.151	1.54	1.54	197.1	1.54	1.34
					USU				
12	24.43	21.29	15.1	.147	1.62	1.62	15.1	1.69	1.47
18	22.90	19.91	15.1	.150	1.52	1.51	15.2	1.59	1.38
24	23.83	19.84	15.1	.201	1.58	1.47	16.2	1.56	1.30
30	22.60	18.97	15.1	.191	1.50	1.46	15.5	1.55	1.30
36	23.55	20.31	15.1	.160	1.56	1.47	15.9	1.56	1.35
42	21.86	19.09	15.1	.145	1.45	1.43	15.3	1.52	1.33
48	21.30	19.29	15.1	.104	1.42	1.45	14.7	1.54	1.39
Mean			15.1	.157	1.52	1.49	15.4	1.57	1.36
					SCS				
12	104.0	90.0	60.0	.156	1.73	1.67	62.3	1.75	1.51
18	93.4	81.4	59.4	.148	1.57	1.50	62.3	1.58	1.38
24	94.6	79.2	60.0	.200	1.58	1.47	64.4	1.56	1.30
30	93.7	80.3	60.0	.168	1.56	1.44	65.1	1.53	1.31
36	93.6	81.6	59.4	.146	1.58	1.42	65.9	1.51	1.32
42	86.1	78.1	60.0	.101	1.44	1.39	61.9	1.49	1.35
48	88.3	81.0	60.0	.090	1.47	1.34	65.9	1.45	1.33
Mean			59.9	.144	1.56	1.46	64.0	1.55	1.36

may have been the most representative of the actual bulk density because of their greater length and volume.

Results of the gamma probe calibration are shown in Fig. 2 where the gamma probe count ratio data are plotted vs. the gravimetric wet bulk density for the selected data pairs for all tubes and sites. The factory-supplied relationship is also shown in Fig. 2. The gamma probe calibration derived for the ARS access tubes (with the compressed side walls) was similar to the original factory-supplied curve, but USU and SCS access tubes warranted a separate calibration curve (the USU and SCS calibration curves were significantly different from the ARS curve, $P < 0.001$). The calibration relationships developed for the ARS tubes and the combined USU and SCS tubes are also shown in Fig. 2, short-dashed and long-dashed lines, respectively. It was not feasible, or necessary, to develop separate calibrations for each of the three soil types because of the high variability between paired samples. The shift from the factory calibration no doubt resulted from soil specific effects and changes with time in the gamma gauge source strength and detector sensitivity.

The final $DW\gamma_C$ values of Table 1, Col. 9, were calculated with the gamma probe calibrations shown in Fig. 2. Final dry bulk density data, $DD\gamma$, as shown in Col. 10, and calculated from the $DW\gamma_C$, MW, and MD data by Eq. [7], for all access tubes, were used for error analysis of bulk density measurements (see Allen, et al., 1993).

The $DD\gamma$ data, calculated by Eq. [7], could be used to compute θV by Eq. [8] for site specific field calibration of neutron gauges. Had the final neutron gauge data been available at the time of this analysis, a set of dry bulk density profiles could also have been determined by combining the gamma probe and neutron probe data:

$$DD_C = DW\gamma_C - \theta V_n * DH \qquad [9]$$

where DD_C is the combined dry bulk density (g cm^{-3}), and θV_n is the fractional volumetric water content derived from neutron gauge measurements. Once the neutron gauge and gamma gauge were site calibrated, the use of Eq. [9] would eliminate the need for gravimetric determination of dry bulk density profiles.

Conclusions

The results of this study indicate that if a single probe gamma density gauge is available, it can be used advantageously to develop soil bulk density profiles for use in neutron gauge calibration. The method of access tube installation did affect the gamma gauge readings so that site specific calibration of the gamma gauge was needed. The use of a gamma gauge reduces the need for extreme accuracy in obtaining volumetric samples for gravimetric analysis of every access tube soil core in order to determine volumetric water content profiles for neutron gauge calibration. The nature of the gamma probe provides smoothing of the profiles and representation of a larger volume of soil than gravimetric analysis.

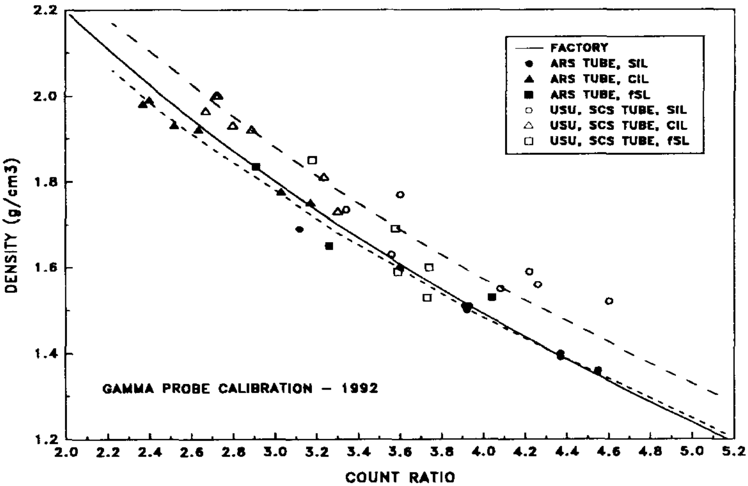

FIG. 2. Gamma gauge count ratios vs. gravimetric wet bulk densities for selected samples at three soil sites.

APPENDIX 1. - REFERENCES

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