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EFFECT OF MOISTURE AND BULK DENSITY SAMPLING ON NEUTRON MOISTURE GAUGE CALIBRATION

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ABSTRACT

Three moisture and bulk density sampling methods were evaluated for use in neutron gauge calibration. Each of the methods was comprised of a single core or portions of a core taken during installation of a neutron access tube. In addition to direct measurement of bulk density, the effect of using "smoothed", "probable" and gamma-probe measured bulk density profiles was evaluated. The use of these three alternative bulk density profiles in the computation of volumetric moisture generally had insignificant effect on the resulting neutron gauge calibration equation. The use of a depth-weighted volumetric moisture profile generally improved calibration statistics, but reduced slopes of neutron calibration equations (% moisture per count ratio). Overall, a total core method which used a tractor-mounted, hydraulically operated coring tool provided the most consistent calibrations with lowest standard errors of estimate, although compression of soil along the perimeter of the cored hole increased subsequent neutron count ratios. A "Madera" down-hole sampler generally provided good calibrations, also. A third, small-volume, down-hole sampler provided valid moisture and bulk density samples; however, the smaller representative volume of the sampler relative to the sampling volume of neutron gauges adversely affected slopes of some calibration equations.

INTRODUCTION

Volumetric moisture and bulk density sampling is an important part of neutron probe calibration. Various mechanical techniques can be used to obtain fixed volume samples of soil (Dickey et al., 1993a). An error analysis of six sampling techniques has been presented by Allen et al. (1993), based on soil sampling conducted during the ASCE Task Committee field study held in Logan, Utah

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during July, 1992. The purpose of the field study was to compare soil sampling and neutron access tube installation procedures and types of neutron gauges. The background of the ASCE study is described by Stone et al. (1993).

Three deep (> 1.5 m), nondestructive, mechanical procedures employed during the ASCE study are evaluated in this paper for their effect on calibration of neutron probes. The three methods are the USU downhole sampler (19 mm dia., 54 mm len., 15 cm^3 vol.), the SCS "Madera" downhole sampler (35 mm dia., 64 mm len., 60 cm^3 vol.), and the ARS Giddings coring sampler (41 mm dia., 150 mm leng., 200 cm^3 vol.). Dickey et al. (1993a) summarized the extraction procedures and resulting bulk density profiles for these samplers. The data utilized in the analysis for this paper were comprised of gravimetric moisture and bulk density samples from one hole per neutron access tube installation. After soil sampling, the hole was used to install the neutron access tube. Additional, adjacent cores obtained with the ARS method were not utilized in this analysis to provide an equal basis between methods.

Bulk density measurements were also made using a gamma nuclear density gauge. Calibration of the gamma gauge and interpretation of the gamma bulk density data are discussed by Wright et al. (1993). The gamma bulk density data have been used in this analysis along with a "mean probable" bulk density profile to evaluate the effect of bulk density sampling procedures and data filtering on neutron calibrations. The mean probable bulk density profile was computed at each site as a weighted composite of six mechanically obtained bulk density profiles (Allen et al., 1993). The mean probable profiles are intended to represent the most probable bulk density profile at a site, based on agreement and trends among the six sampling methods. The mean probable profiles averaged 1 % higher than gamma-measured profiles.

The analyses described in this paper were designed to indicate the sensitivity of neutron gauge calibrations, in terms of calibration slope and standard error of estimate, to the method of soil and bulk density sampling and data reduction and filtering technique. The data reduction and filtering techniques included "smoothing" bulk density profiles prior to computing volumetric moisture contents, using a "probable" bulk density profile, and computing "weighted" average volumetric moisture contents along the depth profiles.

PROCEDURE

The three soils sampled near Logan, Utah during July, 1992 were a Millville silt loam (site 1), a Nibley clay loam (site 2), and a Kidman fine sandy loam (site 3). Descriptions of typical soil profiles are included in Stone et al. (1993). Wet and dry profiles were sampled at each soil site. The USU and SCS down-hole and ARS core methods sampled to 1.5 m when possible in 0.15 m (6 in.) increments. The down-hole and core sampling methods were largely "nondestructive" in that they did not remove soil in excess of that needed for installation of neutron access tubes in the sampled holes. The gamma probe was inserted into the same holes excavated by the samplers after installation of aluminum access tubes (Wright et al., 1993). The USU, SCS, and ARS sampling holes were located within 0.6 m of one another at each site.

Initially, 50.4 mm (2 in.) diameter aluminum access tubes with 1.27 mm wall thickness were inserted into the USU, SCS, and ARS sampling holes. Hole depths and tube lengths were generally greater than 1.6 m unless rocks or other obstructions were encountered. The hole diameters were such that the tubes had snug fits. A series of neutron readings were taken at 0.15 m (6 in.) depth increments beginning at 0.15 m by at least two CPN neutron gauges and two Troxler neutron gauges. After reading all profiles, the aluminum tubes were removed from the USU and SCS holes and 60 mm diameter PVC tubes with 2.15 mm wall thickness were installed. Holes were enlarged to accommodate the PVC tubes by reaming with a 60 mm bucket auger.

"Smoothed" bulk density profiles were obtained by plotting measured bulk density vs. depth and constructing smoothed profiles which followed general trends in the points. This procedure was purely subjective. Only bulk density samples for one method at a time were evaluated, so that the subjective analysis was not biased by results of other sampling methods. Samples from both a wet and dry hole at each site were plotted on one graph so that trends in two bulk density profiles were considered. Separate curves were usually constructed for the wet and for the dry profiles. In some cases, the smoothed profiles omitted sharp increases or decreases in the bulk density profiles which were confirmed as being real points by the gamma gauge measurements. Therefore, the smoothing may have introduced error by omitting real variations in bulk density as well as removed error due to omitting poor measurements.

Allen and Segura (1990) suggested using weighted averages of measured volumetric moisture contents along depth profiles to improve results of calibration regression. The weighting was done so that moisture content attributed to a particular depth better represented the larger volume of soil sampled by a neutron gauge. For 0.15 m sampling increments, Allen and Segura suggested computing weighted volumetric moisture contents as: $\theta_{w\,i} = 0.25\theta_{i-1} + 0.5\theta_i + 0.25\theta_{i+1}$ where θ_{i-1}, θ_i, and θ_{i+1} are volumetric moisture contents at i-1, i and i+1 depths and $\theta_{w\,i}$ is the weighted moisture content for depth i. This same weighting was evaluated in the following analysis.

Neutron calibrations were computed as $\theta = a + b\ (CR)$ using least squares regression where CR is the count ratio (average count at a soil depth divided by a standard shield count). Data from 0.3 m through 1.5 m depths were used for calibration when available. Three counts averaging about 10,000 and 5000 thermalized neutrons for the CPN and Troxler gauges were taken at each depth. θ was used as the dependent variable to accommodate graphical presentation. Samples from a wet and a dry hole at each site were used to compute a single calibration equation. Standard errors of estimate represent the mean absolute deviation between the predicted (calibration estimate) moisture content and original data point which was not exceeded 68 % of the time. Units of SEE are percent moisture, and were computed with n-2 degrees of freedom where n was the number of paired θ - CR observations.

RESULTS

Plots of volumetric soil moisture (θ) vs. count ratio (CR) are included in Figures 1-3 for the three soil types for Troxler meter "6". Each figure represents typical results from the three sampling methods (USU, SCS, and ARS). Plotted points include directly measured θ (Direct), weighted θ, and θ computed using probable, gamma, and smoothed bulk density profiles. In general, strong, linear trends were obtained for all three sampling methods at sites 1 and 3 (silt loam and sandy loam soils). The clay loam soil at site 2 complicated sampling, resulting in increased scatter for all sampling methods. In general, the use of probable, gamma, or smoothed bulk density profiles did not visually alter the variation or scatter in θ with count ratio. The effect of smoothing profiles was more pronounced at site 2. Conversion of θ into a weighted average did not have a large effect for sites 1 and 3, but did smooth plots for site 2. The slope of θ vs. CR was generally reduced by the weighted averaging.

Slopes of θ vs. count ratio and SEE's for calibration regressions are listed in Table 1 for the CPN "#1" and Troxler "#6" neutron gauges for both aluminum and PVC tubes. Resulting calibration slopes for soil 1 were similar for all three sampling methods and for all 5 data filtering techniques, indicating that all methods could produce essentially equivalent calibrations for soil 1. SEE's were lowest for the ARS method, indicating less scatter about a linear relationship and in general more consistent sampling.

Calibration slopes for soil 2 were substantially different among the three sampling methods, reflecting the difficulty in obtaining good samples for the clay loam soil and perhaps variation in background hydrogen or other elements with depth. When probable or gamma measured bulk densities were used, the slopes for the SCS and ARS methods came to within 10% of one another for the CPN #1 gauge and within 2% for the Troxler gauge. The USU slopes were significantly higher in all cases for soil 2, indicating the effect of the small sampling volume on sample representativeness in a heterogeneous profile. SEE's were lowest for the SCS method for the clay loam soil when direct samples were used to calibrate, whereas, SEE's were lowest for the ARS method when the probable and gamma measured bulk density profiles were used.

Calibration slopes with the CPN gauge were similar between the SCS and ARS methods for soil 3 and were similar among all three methods for the Troxler gauge. As with soil 1, calibration slopes for soil 3 were generally stable, irrespective of the type of bulk density data filtering applied. SEE's for the CPN gauge were lowest at soil 3 for the ARS method using probable and gamma measured bulk density data and were lowest for the Troxler gauge for directly obtained ARS core measurements. Similar results occurred for both gauges and for all soils when PVC tubes were inserted into the USU and SCS holes.

SEE's generally decreased when θ was converted into a weighted average (Table 1 (Wtd.)), especially for the smaller USU sampler. Calibration slopes were generally not affected by weighted averaging at soils 1 and 3 for the CPN and Troxler gauges, but were significantly reduced for soil 2, due to smoothing of abrupt changes in the moisture profiles at this location. Based on comparisons of slopes derived for USU samples and the larger, more complete ARS samples, the reductions in calibration slopes resulted in an improvement in prediction accuracy only for the USU sampler, even though the scatter of points about calibration equations was reduced for all samplers. The weighted averaging brought calibration slopes for the USU sampler closer to those for the larger ARS and SCS samplers at soils 2 and 3 for both neutron gauges.

An interesting observation made from Figures 1-3 is that count ratios for the ARS sampling-tube installation method were consistently higher than for the USU and SCS methods. This can be seen by comparing the lowest and highest count ratios among the three methods in the figures (note: the lowest CR shown for USU in Figure 2 was not plotted for the other two methods). The higher count ratios for the ARS hole are indicative of soil compression around the hole which occurred during insertion of the coring tool. This compression is discussed by Wright et al. (1993). The Giddings coring tool was shaped to force soil away from the inner core to eliminate compression of the sample. The external soil compression and corresponding increase in moisture density around the ARS tubes did not appear to alter the slopes of calibration curves listed in Table 1 but did decrease intercepts of calibration equations by about 0.5 % moisture (data not shown). The USU and SCS samplers were similarly shaped, but had smaller diameters. Reaming of the USU and SCS holes to accommodate access tubes may have removed most of the compressed soil.

CONCLUSIONS

Smoothing bulk density data prior to computing volumetric moisture and the use of mean probable or gamma-measured profiles generally had an insignificant effect on the slopes of neutron calibration equations at the silt loam and sandy loam sites for all three sampling methods and for both CPN and Troxler gauges. Using a mean probable bulk density profile based on weighting of six sampling methods and using a gamma measured profile improved the estimate of calibration slopes for the more difficult clay loam soil. Overall, the ARS method of obtaining samples comprising the total extracted core using a tractor-mounted, hydraulically operated coring tool provided the most consistent calibrations with lowest standard errors of estimate (SEE), although compression of soil around the hole perimeter increased count ratios. Calibrations with the "Madera" down-hole sampler were generally also quite good. The small volume of the USU down-hole sampler relative to the sampling volume of neutron gauges adversely affected the slopes of some calibration equations. These results are similar to those reported by Dickey et al. (1993b).

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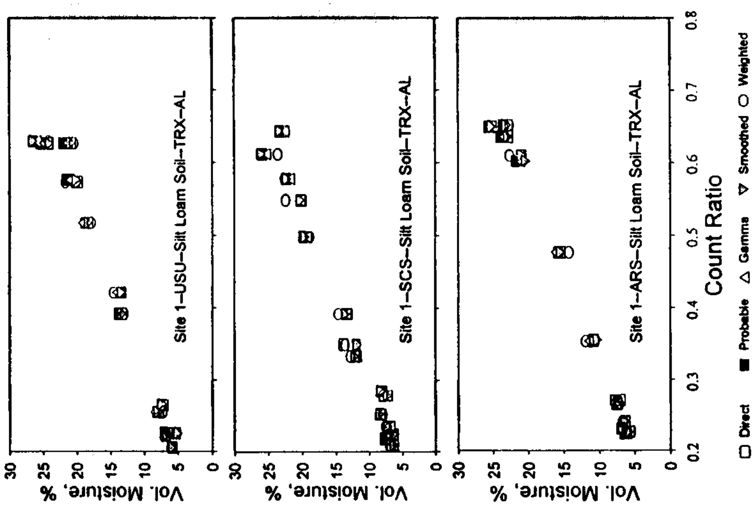

Figure 1. Volumetric moisture vs. Troxler neutron count ratios for a silt loam soil for three sampling methods showing effects of direct, probable, gamma, and smoothed bulk density profiles and weighted average moisture.

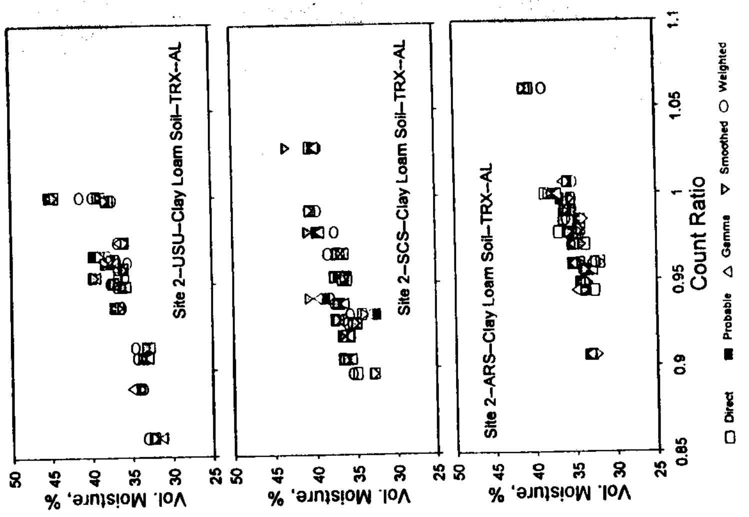

Figure 2. Volumetric moisture vs. Troxler neutron count ratios for a clay loam soil for three sampling methods showing effects of direct, probable, gamma, and smoothed bulk density profiles and weighted average moisture.

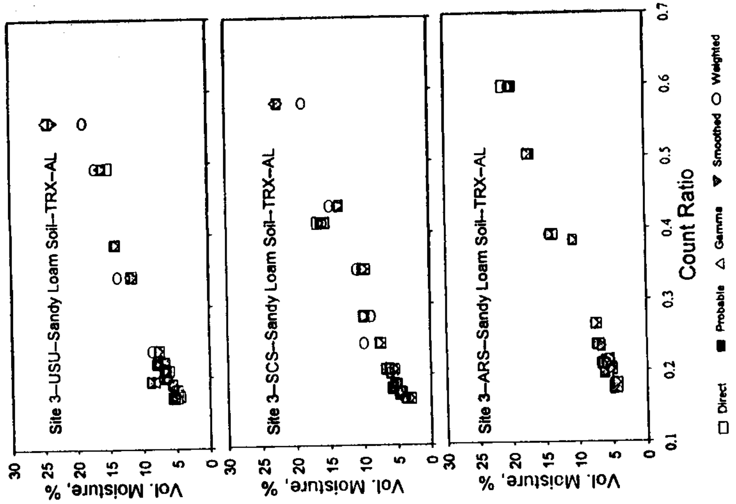

Figure 3. Volumetric moisture vs. Troxler neutron count ratios for a sandy loam soil for three sampling methods showing effects of direct, probable, gamma, and smoothed bulk density profiles and weighted average moisture.

Table 1. Slopes and standard errors of estimate for regressions of volumetric moisture vs. count ratio for various methods of determining volumetric moisture content.

	Slope of %Moisture vs. CR					SEE of Regression (%Moist.)				
Soil-Meth	Direct	Prob.	Gam.	Smth.	Wtd.	Direct	Prob.	Gam.	Smth.	Wtd.
			CPN #1 Aluminum Access Tubes							
1-USU	20.6	21.5	20.9	20.4	20.1	1.47	1.36	1.31	1.53	1.07
1-SCS	21.7	22.2	21.1	22.0	20.9	1.18	1.34	1.17	1.32	1.04
1-ARS	20.3	21.0	20.1	20.1	19.9	0.89	0.86	0.68	0.84	0.85
2-USU	42.6	46.5	46.8	43.7	30.6	1.38	1.43	1.30	1.34	0.99
2-SCS	29.9	38.3	37.4	50.4	21.8	1.17	1.60	1.42	1.47	0.78
2-ARS	39.3	35.3	33.3	38.7	26.6	1.33	1.19	1.16	1.42	1.07
3-USU	30.2	28.8	30.4	27.3	22.4	0.74	1.23	1.22	1.25	1.18
3-SCS	18.9	18.5	19.3	18.5	16.9	1.37	1.21	1.23	1.31	1.10
3-ARS	18.8	16.8	17.7	17.4	18.2	0.68	0.54	0.45	0.60	0.53
			Troxler #6 Aluminum Access Tubes							
1-USU	42.3	44.4	43.0	42.2	41.3	1.35	1.21	1.20	1.35	0.99
1-SCS	43.3	44.5	42.4	44.1	41.8	1.15	1.17	1.15	1.14	1.12
1-ARS	41.6	42.7	41.1	40.7	40.8	0.75	0.73	0.66	0.77	0.79
2-USU	61.4	63.6	64.8	62.3	46.8	1.75	2.05	1.92	1.78	1.08
2-SCS	42.2	53.8	50.6	66.2	31.0	1.13	1.57	1.46	1.65	0.73
2-ARS	55.8	52.8	50.2	60.0	41.0	1.28	1.00	0.96	1.11	0.89
3-USU	41.8	42.2	44.5	40.5	37.0	1.34	1.23	1.22	1.19	0.76
3-SCS	42.1	41.0	42.8	41.2	37.3	1.07	0.96	0.94	1.04	0.97
3-ARS	40.3	36.3	38.2	37.5	38.9	0.56	0.65	0.61	0.75	0.76
			CPN #1 PVC Access Tubes							
1-USU	31.3	33.2	32.1	31.5	30.6	1.93	1.90	1.63	1.98	1.55
1-SCS	31.9	32.2	31.5	31.7	30.9	1.40	1.96	1.17	2.11	1.28
2-USU	49.4	55.6	56.0	51.6	36.5	1.87	1.87	1.77	1.79	1.27
2-SCS	16.6	20.1	20.1	29.6	7.6	1.67	2.23	2.07	2.49	1.22
3-USU	27.6	27.6	29.2	26.5	24.6	1.44	1.38	1.35	1.35	0.75
3-SCS	28.3	27.7	29.2	27.7	25.2	1.54	1.34	1.40	1.47	1.30
			Troxler #6 PVC Access Tubes							
1-USU	69.0	73.0	70.3	69.2	67.7	1.97	1.90	1.75	2.00	1.47
1-SCS	72.3	74.0	70.3	73.2	69.4	1.11	1.24	1.11	1.25	1.24
2-USU	85.0	94.0	95.3	87.4	65.1	1.83	1.89	1.77	1.81	1.13
2-SCS	33.4	37.8	42.9	60.5	17.6	1.73	2.33	2.13	2.58	1.26
3-USU	60.3	60.4	63.9	57.9	52.7	1.17	1.17	1.14	1.17	0.88
3-SCS	64.5	63.0	65.9	63.1	57.1	1.50	1.30	1.31	1.44	1.39