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Core Versus Nuclear Gauge Methods of Determining Soil Bulk Density and Moisture Content

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SUMMARY

Soil bulk density and moisture content measurements were obtained using two nuclear gauge systems and compared to those obtained from soil cores. The soils, a Hiwassee sandy loam, a Lakeland loamy sand, and a Lloyd clay, were free of organic matter and uniform in mechanical composition. The regression equations developed for the nuclear gauges in the first phase of the study failed to predict bulk density and moisture content in the validation phase. The test results indicate that if greater confidence is placed on the standard soil core determinations, then regression equations should be developed for the nuclear gauges in each soil condition and for each soil type.

INTRODUCTION

Until recently, soil bulk density was obtained by removing "undisturbed" sample cores for weight, moisture, and volume measurements. The development of nuclear gauges introduced a possible method of determining bulk density and moisture without removal of soil cores. In addition, nuclear gauges have the potential of increasing the speed of measurements, minimizing soil disturbance, and allowing for continual monitoring of the same soil over a period of time.

LITERATURE REVIEW

Early studies using the gamma-ray attentuation technique were conducted by Vomocil (1954), Bernhard and Chasek (1955), and van Bavel et al. (1957). Studies dealing with measurement and calibration techniques have been done by Corey et al. (1971), Mansell et al. (1973), Santo and Tsuji (1977), and Soane and Henshall (1979). Vigier and Campbell (1980) and Smajstrla and Clark (1981) discuss methods to improve the accuracy of nuclear gauges.

Campbell (1973) and Hassan (1977) used nuclear gauges to measure soil compaction and moisture content on forest sites following timber harvesting activities. Their results indicate a high degree of variation in these measurements and a need for correction factors. Soane (1974), in a review paper, summarized the findings of several researchers concerning the types of detectors, probe design and spacing, spatial resolution, as well as gauge accuracy and precision.

The purpose of this study was to compare the accuracy and consistency of values for soil bulk density and soil moisture content obtained with two nuclear gauge systems with those obtained by soil cores (gravimetric).

SOIL TREATMENTS

The soils used in the tests were the lower Ap horizon of a Hiwassee sandy loam (clayey, kaolinitic, thermic, oxide, Typic Rhodudults), a Lakeland loamy sand (thermic, coated, Typic, Quartzisamments), and a Lloyd clay (clayey, kaolinitic, thermic, Typic, Hapludults). These soil materials were collected years ago and are confined in large outdoor bins for testing with full scale farm machinery. The bins are located at the testing facilities of the National Tillage Machinery Laboratory at Auburn, Alabama. Each soil is generally stone free, uniform in mechanical composition throughout its depth, and free of organic material. Its uniformity makes it a good test medium for comparing nuclear gauge determined soil moisture and density to results from standard methods. Selected physical and chemical properties of these soils have been reported by Batchelor (1968).

Each soil bin was prepared with a deep plow pan and rototilled to the plow pan depth just prior to testing to assure a uniform soil mix above the pan. A steel roller (5.5 m wide, 1,950.5 kg) was used to firm the soil (Treatment A) before the test treatments were applied. Treatment A was the control in which no additional forces were applied to the soil. In the four bins receiving additional traffic treatments, three adjoining pathways were made to form a test band 90 cm wide. All measurements were made in the middle of the center pathway to obtain relatively uniform soil conditions. Two treatments (B & C) were obtained using 2 and 4 passes, respectively, with a steel wheel 30 cm wide, 106 cm in diameter, and mass of 581.8 kg. Treatments D & E resulted from 2 and 4 passes of the same wheel, but with a mass of 1,068.2 kg. The different treatment combinations are shown in table 1.

METHODS

Bulk density was determined at two depths, 5 cm and 20 cm, by three techniques in each treatment strip. Ten randomly selected sites in each treatment strip were utilized. At each site bulk density was determined by a Troxler Model 3411[1], a Campbell Pacific Model MC-1, and a Cornelison soil core sampler (fig. 1). At each site measurements were first made using the single probe Troxler unit. Then the Campbell Pacific unit used the existing hole (single probe mode) and a new hole was made for the second probe (dual probe mode). The last measurements were made on the soil cores taken by the Cornelison sampler from the zone between the two existing holes.

[1]The use of trade, firm or corporate names is for the information and convenience of the reader. Such use does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval of any product or service to the exclusion of others which may be suitable.

Table 1.—*Soil compaction treatments*

Treatment code	Number of passes	Steel wheel mass
		Kg
A (control)	1	1950.5
B*	2	581.8
C	4	581.8
D	2	1068.2
E	4	1068.2

*Treatments B, C, D, & E also received treatment A

Soil Cores

The Cornelison sampler removed approximately 150 cm of soil per sample. The soil was weighed, dried at 105 degrees Celsius for 72 hours, and reweighed. The wet and dry bulk densities and the moisture contents of the soil samples were calculated using the following equations.

$$\text{Dry bulk density} = \frac{\text{oven dry weight of soil (g)}}{\text{volume of soil core (cm)}} \quad (1)$$

$$\text{Wet bulk density} = \frac{\text{field weight of soil (g)}}{\text{volume of soil core (cm)}} \quad (2)$$

$$\text{Percent moisture} = \frac{\text{(field soil weight} - \text{dry soil weight)}}{\text{(0.01*dry soil weight)}} \quad (3)$$

Nuclear Gauges

The information supplied by the equipment manufacturers, other sources such as Freitag (1971), and the Soils Manual (1978) explain the theory and use of nuclear gauges.

The gauges in this study used Cesium 137 as a source of gamma radiation and Americum-241 Beryllium for the neutron source. The gauges were used in the direct transmission mode and standard counts were taken at the beginning and end of each day. The general calibration equation (Campbell Pacific Nuclear Corporation 1978) relating the standard count to the actual count is:

$$CR = A\,(e^{**} - BD) - C \quad (4)$$

where: CR = count ratio (actual count/standard count)

A, C = constants dependent on gauge geometry

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B = constant dependent on attenuation coefficient
D = soil wet bulk density
e = natural log, (base e, 2.718282)
** = exponent notation

Each nuclear gauge manufacturer supplied separate equations relating wet bulk density and moisture content to the count ratio as follows:

using: D2 = wet bulk density (lb/ft) at a depth of 5 cm.
D8 = wet bulk density (lb/ft) at a depth of 20 cm.
R2 = density count with the probe at a depth of 5 cm.
R8 = density count with the probe at a depth of 20 cm.
S = standard soil density count
MC = moisture density (lb/ft)
MCR = moisture count ratio (moisture count/standard count)
Ln = the natural log ((base e, 2.718282)

Troxler Electronic Laboratories, Inc. (1975):

D2 = –Ln((R2/S+0.0486)/7.7988)/0.016 (5)
D8 = –Ln((R8/S–0.0141)/13.5525)/0.02637 (6)
MC = –1.57+(57.08*MCR) (7)

Campbell Pacific Nuclear Corporation (1978):

(These equations were supplied for use in single probe mode only; none were available for the double probe mode)

D2 = 332.44–171.78*(R2/S)**0.348180 (8)
D8 = 444.41–339.18*(R8/S)**0.134620 (9)
MC = –1.42+(37.09*MCR) (10)

ANALYSIS

The mean (n=10) of the wet soil bulk density and moisture density meansurements as determined by the Cornelison soil sampler, Troxler, and Campbell Pacific (single probe) is shown in table 2. There were significant differences (t test, Ostle and Mensing 1975) in about 90 percent of the test combinations in the wet soil bulk density and percent moisture means obtained by the soil core and the

Figure 1.—*Nuclear gauges and soil core sampler used in the study (left to right: Campbell Pacific, Cornelison sampler & Troxler).*

nuclear gauges. Therefore, regression equations (table 3) were developed by soil type and depth to relate the nuclear gauge values to those obtained by the soil cores.

VALIDATION

Using the same soils, soil bins, and similar pretest preparation techniques, a second series of compaction tests was conducted. Different levels of soil compaction were obtained by using three skidder tires under different conditions of dynamic load, inflation pressure, and travel reduction. Bulk density and moisture measurements were made in the center of the tire footprints at 1.5 m intervals along the test strips at depths of 5 cm. The means (n=83) obtained by the different methods are shown in table 4. The bulk density and moisture values shown for the nuclear gauges are based on the regression equations for the 5 cm depth by gauge and soil type. The Campbell Pacific (single probe) and Troxler were not used in the Lloyd clay.

There were significant statistical differences in wet bulk density means between the soil core method and the two nuclear gauges, except with the Campbell Pacific (single probe) in the sandy loam. The regression equations developed for the nuclear gauges gave lower wet bulk density values than obtained by the soil core method. With percent soil moisture there were statistical diffferences in the means between the soil core method and the gauges, except with the Troxler in the sandy loam. In all but one case, the regression equations developed for the two nuclear gauges overestimated percent soil moisture as compared to the soil core method.

DISCUSSION

In the first phase of this study, regression equations were developed to improve the correlation between values obtained with nuclear gauges to those obtained by the standard soil core method. The soils involved in the tests were from the Lloyd series, the Hiwassee series, and the Lakeland series. Bulk density measurements were made at 5 cm and 20 cm depths.

The wet bulk density means ranged from 1.19 g/cm to 2.00 g/cm for the soil core method and from 1.48 g/cm to 2.09 g/cm with the nuclear gauges. The nuclear gauges (using the factory equations; equations 5,6,8 and 9) tended to overestimate the wet bulk density.

The moisture content ranged from 5.4 to 21.4 percent using the soil core method and from 3.8 to 23.2 percent with the nuclear gauges. Based on

Table 2.—*Soil wet bulk density and percent moisture means for the three methods of measurement*

Test code	Soil core			Troxler			Campbell Pacific		
	5 cm	20 cm	M*	5 cm	20 cm	M*	5 cm	20 cm	M*
	----g/cm----		%	----g/cm----		%	---g/cm---		%
Clay									
A	1.19	1.38	20.59	1.54	1.53	21.76	1.48	1.50	17.88
B	1.57	1.49	21.39	1.66	1.66	22.91	1.61	1.67	19.27
C	1.63	1.50	20.96	1.75	1.72	23.02	1.72	1.71	19.58
D	1.65	1.58	21.42	1.73	1.75	23.17	1.70	1.75	19.58
E	1.73	1.64	20.89	1.82	1.81	21.61	1.81	1.82	18.35
Sandy Loam									
A	1.57	1.66	8.65	1.49	1.67	7.93	1.45	1.69	6.56
B	1.79	1.82	8.69	1.68	1.88	8.85	1.67	1.92	7.23
C	1.90	1.89	8.16	1.81	1.96	8.52	1.81	2.00	6.88
D	1.89	1.94	8.66	1.77	1.99	8.90	1.76	2.02	7.39
E	1.98	2.00	8.10	1.85	2.05	8.13	1.85	2.09	7.22
Loamy Sand									
A	1.71	1.65	5.40	1.71	1.72	4.68	1.70	1.73	3.81
B	1.77	1.70	5.58	1.78	1.79	4.98	1.79	1.82	4.30
C	1.82	1.71	5.47	1.82	1.82	4.91	1.83	1.85	4.12
D	1.77	1.77	5.42	1.75	1.81	5.03	1.74	1.84	4.13
E	1.81	1.77	5.50	1.80	1.87	5.06	1.80	1.89	4.32

*M=soil moisture in percent

Table 3.—*Regression equations for determining wet bulk density (g/cm) and percent moisture for the nuclear gauges*

Gauge type	Soil type	Regression equation	R-SQ	CV	Equation number
Campbell Pacific (Single)	C	D2= 2.938— 0.706*X+ 0.052*X*X	0.92	1.79	(11)
	C	D8= 2.985— 2.328*X+ 0.839*X*X	0.94	1.51	(12)
	C	M= 7.004+ 48.644*Y— 41.725*Y*Y	0.35	1.51	(13)
	L	D2= 2.590— 0.211*X— 0.061*X*X	0.89	2.74	(14)
	L	D8= 2.955— 2.252*X+ 0.963*X*X	0.97	1.14	(15)
	L	M= 9.142— 0.197*Y— 9.621*Y*Y	0.09	4.83	(16)
	S	D2=—0.713+ 2.825*X— 0.781*X*X	0.80	1.05	(17)
	S	D8= 2.565— 1.419*X+ 0.476*X*X	0.65	1.66	(18)
	S	M= 2.650+ 16.941*Y+ 2.919*Y*Y	0.66	3.57	(19)
Campbell Pacific (Dual)	C	D2= 2.602— 0.989*X+ 0.198*X*X	0.96	1.38	(20)
	C	D8= 2.464— 0.639*X+ 0.091*X*X	0.96	1.19	(21)
	L	D2= 2.530— 0.751*X+ 0.129*X*X	0.90	2.58	(22)
	L	D8= 2.494— 0.532*X+ 0.059*X*X	0.96	1.24	(23)
	S	D2= 1.462+ 0.853*X— 0.465*X*X	0.77	1.13	(24)
	S	D8= 2.761— 0.897*X+ 0.178*X*X	0.87	1.00	(25)
Troxler	C	D2= 2.873— 1.149*X+ 0.166*X*X	0.92	1.82	(26)
	C	D8= 2.873— 2.483*X— 1.027*X*X	0.93	1.59	(27)
	C	M= 12.965— 32.575*Y— 31.632*Y*Y	0.31	1.56	(28)
	L	D2= 3.214— 1.343*X+ 0.234*X*X	0.89	2.67	(29)
	L	D8= 2.824— 2.264*X+ 1.075*X*X	0.96	1.24	(30)
	L	M= 19.489— 114.137*Y+292.295*Y*Y	0.08	4.86	(31)
	S	D2= 0.633+ 2.408*X— 1.181*X*X	0.82	1.01	(32)
	S	D8= 2.130— 0.505*X— 0.097*X*X	0.68	1.59	(33)
	S	M=—5.502+151.099*Y— 500.524*Y*Y	0.56	4.03	(34)

Where:
C=Clay, L=Loam, S=Sand, D2=Wet Bulk Density at 2 inch depth, D8=Wet Bulk Density at 8 inch depth, M=Percent Soil Moisture, X=actual density count/standard density count (by gauge type), Y=actual moisture count/standard moisture count (by gauge type)

the factory supplied equations (equations 7 and 10), the Troxler tended to overestimate moisture content while the Campbell Pacific tended to underestimate.

The regression equations were challenged in a bin prepared with different moisture and density conditions. The validation study consisted of using the same soils with slightly different compaction techniques. The wet bulk density (5 cm depth) and moisture content measurements obtained using regression equations were compared to the values obtained by the soil core method. They did not agree. Based on the results of this study, regression equations for the nuclear gauges would have to be developed for each test condition by soil type and depth. That is, the regression equations developed in the initial tests did not give statistically good results in the validation tests.

When using nuclear gauges to determine soil bulk density and moisture content it is advisable to collect soil core sub-samples in order to test for variations in the two methods. If a greater confidence is placed on the standard soil core determinations, then regression equations should be developed for the nuclear gauges in each soil condition and for each soil depth.