SOIL BULK DENSITY SAMPLING FOR NEUTRON GAUGE CALIBRATION

G. L. Dickey (M.ASCE), R.G. Allen (M. ASCE), J.L. Wright, N.R. Murray, J.F. Stone (Aff. ASCE) and D. J. Hunsaker[1]

Abstract
The ASCE Task Committee on Neutron Gauge Calibration met in Logan, Utah in July 1992 to investigate the various methods of soil sampling, installation of access tubes, effect of various parameters on gauge readings, methods of developing field calibration curves and comparison of neutron gauge characteristics. Details of the overall objectives of the study are covered by Stone (1993, this volume). This paper discusses the soil sampling methods and presents a comparative result based on bulk density, time required for sampling and cost of sampling equipment Other papers developed from this study describe the soils, the three sites investigated and the problems related to the tube installation process.

Bulk Density Sampling:
The purpose of soil sampling during neutron gauge calibration is to determine the volumetric soil water content corresponding to the depth where neutron gauge readings are taken. The plot of volumetric soil water content vs. count ratio (the ratio of the reading in the soil at a point to the standard count) provides the calibration curve that relates the gauge reading to soil water content for future readings (Dickey, 1990a). The procedures for calculating volumetric wail water content and the factors affecting calibration are described by Wright (1993, these proceedings) and others (Stone, 1990, Dickey 1990b).

Soil samples are usually taken during the installation of the access tube in the field being monitored. The number of soil samples and range in water content must be sufficient to develop an acceptable calibration curve for the site, otherwise, additional samples must be taken when the soil water content has changed. Bulk density adjustments can be used as a method of calculating the volumetric soil water content if the extent of compaction is known (Allen et. al., 1993a, this volume).

---

[1]G.L. Dickey, Agricultural Engineer, USDA-Soil Conservation Service, Technology Information Systems Division, 2625 Redwing Rd, Rm 110, Fort Collins, Colorado 80526; R.G. Allen, Associate Professor, Department of Biological and Irrigation Engineering, Utah State University, Logan, Utah; J.L. Wright, Soil Scientist, USDA-Agricultural Research Service, Soil and Water Management Research, Kimberly, Idaho; N.R. Murray, Civil Engineer, USDA-Soil Conservation Service, Provo, Utah; J.F. Stone, Professor, Department of Agronomy, Oklahoma State University, Stillwater, Oklahoma; and D.J. Hunsaker, Agricultural Engineer, USDA-ARS, U.S. Water Conservation Laboratory, Phoenix, Arizona.

Types of Sampling Equipment:

Sampling equipment is usually of two types:

1. Equipment that disturbs the soil such as flight and bucket augers.
2. Equipment that attempts to take an undisturbed soil core such as an Oakfield type probe or a Giddings soil tube.

Undisturbed samplers may be of fixed or variable volume. Variable volumes include the Oakfield probe and the Giddings tube where the length or volume of the sample is determined by the operator. Fixed volume samplers include the Soil Conservation Service (SCS) Madera and drive cylinder soil samplers. Fixed volume samplers may be closed or open ended. Closed end samplers tend to compress the sample when over-sampling occurs. Open ended samplers allow the sample to be taken without compression of the sample from over sampling.

Samplers may be variable or fixed depth. Variable depth samplers depend on the operator to determine and describe the depth of each sample. The Oakfield and Giddings are examples of variable depth and variable volume samplers. Fixed depth samplers usually employ a stop mechanism that automatically stops the sampler at the predetermined depth. The stop has to be reset for each sample depth. The SCS Madera sampler is a fixed volume and fixed depth sampler. The Utah State University (USU) sampler (Willardson and Taylor, 1962) is considered a fixed volume, fixed depth sampler because of the depth markings on the shaft even though no mechanical stop is provided. Samples are taken from predetermined depths. Drive cylinders are fixed volume samplers. The volume is fixed by shearing the soil with a straight edge to comply with the top and bottom edge of the cylinder.

Sampling Methods Tested:

Sampling methods tested at a workshop by the ASCE Task Committee on Neutron Gauges held in Logan, Utah in July 1992 included:

1. Giddings tube samplers, tractor mounted, Agricultural Research Service (ARS), 50.8 mm diameter (2 inch) and trailer mounted, Oklahoma State University (OSU), 38.1 mm diameter (1.5 inches),variable volume, variable depth, open ended sampler.
2. Small volume (small diameter) manufactured by Utah State University (USU) 18.75 mm diameter (0.75 inch), fixed volume (15 cm^3), fixed depth, open end sampler.
3. SCS Madera (SCS), 35 mm diameter (1.4 in), fixed volume (60 cm^3), fixed depth, open end sampler.
4. SCS drive ring cylinder (SCS-DRV), 76 mm diameter (3 in), fixed volume (348 cm^3), variable depth, closed end sampler.
5. ARS drive cylinder (ARS-DRV), 68 mm diameter (2.7 in), fixed volume (365 cm^3), variable depth, closed end sampler.
6. Gamma radiation density meter (Troxler Corp, Model 1351, 8 mCi cesium-137 source).

Advantages and Disadvantages:

Giddings Sampler (undisturbed, variable volume, variable depth, open end sampler)- The Giddings samplers were tractor and trailer mounted and were hydraulically driven which facilitates sampling in hard or dense soils. Samples were obtained rather quickly at a site. Sample tubes were about 122 cm (4 feet) in length and open ended to reduce sample compaction from over-sampling. At least two sample cores were taken to obtain a sample depth of 152 cm (5.0 feet). Sample depths were measured and marked on the tube to determine depth and whether compaction occurred during the insertion of the tube. Sample volumes were determined by the operator based on the cross-sectional area of bit multiplied by the length of each sample. The soil samples were rather large which increased the representation of the profile but required large sample cans for processing. Compaction of the soil sample was minimized by designing the inner diameter of the cutting bit smaller than the inside diameter of the collection tube. When compaction occurred, it was difficult to determine what part of the sample was compacted. Two persons were required to operate the equipment in an efficient and safe manner. The trailer rig was lifted from the ground at site 2 due to dense soil. This could create a safety hazard to the operator. Anchors were inserted into the soil to prevent this occurance. Obviously compacted samples were discarded or used only for moisture samples (disturbed sampling). Depths of samples within the profile could only be determined to within about plus or minus 2.5 cm (1.0 inch). Some evaporation from the soil sample occurred while the core tube was laid out and the sample core cut and samples collected into metal sample cans. Processing a 90 cm core may require 3 minutes. The tractor mounted Giddings can work in an established row crop with minimal damage to the crop and sampling site. The sampling equipment cost without the vehicle is about $2,000. Each additional sample bit costs about $100.00.

Small Volume Sampler (undisturbed, fixed volume, fixed depth, open ended sampler)- The USU small volume sampler consisted of a tube sampler 18.5 mm (0.75 in) in diameter with a "T" handle at the top (Willardson et. al., 1962). The overall length of the sampler was about 120 cm (4.0 feet). Extensions could be added to increase the handle length. The sampler was easy to use. Samples were obtained rather quickly. Only one person was required to operate the equipment The operation was faster and more efficient with two persons. Depth marks on the tube allowed the operator to determine the depth of the sample by reading the depth at the soil surface when insertion stopped. The tube was rotated a half turn and extracted. The soil sample portion was detachable from the tube. A slit in the sample portion of the tube allowed the soil sample to be separated from the rest of the core. The bottom of the sample was formed by the shearing of the soil at the bottom of the bit. An extraction tool allowed the sample to be extracted into the soil sample can for processing. The volume was fixed at 15 cm^3. Compaction of the soil sample was minimized by designing the inner diameter of the cutting bit smaller than the inside diameter of the collection tube. This eliminated wall friction on the sample. In dry soils the sampler was forced into the soil profile using a mallet. A bucket auger was used to excavate the surplus soil and to enlarge and deepen the hole to the next desired sample depth. The auger diameter was equal to the outside diameter of the access tube to be installed. Access tubes were inserted into the hole upon completion of sampling. The equipment cost about $300 including the extension for sampling to 152 cm. Each additional bit costs about $90.

SCS Madera Sampler (undisturbed, fixed volume, fixed depth, open end sampler)- the Madera Sampler consists of a detachable sampling bit, a tubular handle with holes drilled at 15.2 cm (6.0 inches) intervals and an adjustable cross-bar (Dickey, 1982). The bit is open ended to reduce sample compaction from over-sampling. Slits are cut in the detachable bit for inserting two spatulas to separate the 60 cm^3 sample from the material not desired for sampling.. Detaching the bit makes sample extraction easy. The cross-bar is inserted in the holes in the handle to automatically stop the sampler a multiple of 15.2 cm (6 inches) from the soil surface. The cross-bar also acts as a foot support for inserting the sampler. Fixed volume and fixed depth sampling requires very little training of the operator. The 60 cubic centimeter sample is large enough to minimize most of the normal sampling and processing errors to an acceptable level (Gardner, 1986,Hawley et.al., 1982). Medium soil sample cans are adequate for containing the sample for processing. The sampler can be operated by one person. Two persons makes the process much faster and more efficient Access tubing is installed in the hole where samples are taken. This allows soil samples to be taken at the exact same depth that neutron gauge readings are taken. Tubing can be installed at any time without interfering with the crop. Additional samples can be taken adjacent to the installed access tube at times when the soil water content has changed to obtain additional calibration points. The cost of a Madera sampler, including the handle, cross-bar and two bits, is $180.

SCS and ARS Drive Cylinder Samplers (undisturbed, fixed volume, closed end, variable depth, surface layer sampler) - The drive cylinder samplers consists of a cylinder with a cutting edge, a top cover with a rod and sliding weight or other means for driving. The SCS sampler used a cylindrical sleeve inserted inside the drive cylinder to contain the soil sample. The soil surface is excavated to the desired depth to begin the sample. The cylinder is driven into the soil until the sampler is completely filled. The cylinder is then carefully excavated and removed with the sample in the cylinder. The sleeve is extracted and trimmed on the top and bottom with a sharp straight edge to conform to the exact length of the sleeve. The diameter of the cutting bit and the length of the sleeve determine the volume of the sample. Cylinders are available in various diameters. Cylinders with a diameter of 7.62 cm (3.0 inches) were used by SCS while ARS used a driver with a 6.76 cm (2.66 in) diameter and 30.5 cm (12 in) in length. Excavation to the depth that the desired sample was to be taken limited the sampling depth to about 90 cm. Sampling destroyed the site. The site could not be used for access tube installation after sampling. Sampling by this method is limited to adjacent areas or to the access tube site after the tube is removed. Care had to be taken not to over drive the sampler and compact the sample against the top drive cover. Stiff clays were difficult to smooth to the end of the sleeve without creating some surface voids. Soil cores were extracted from the ARS cylinder in either 5.08 cm (2-in) or 10.16 cm (4-in) lengths with an extraction apparatus built by the ARS, U.S. Water Conservation Laboratory, Phoenix, Arizona. The equipment requires only one person to operate but sampling advanced much faster and more efficiently with three persons because of the trimming and excavation requirements. Sampling can be done at any time but destroys the crop for several feet in each direction from the sample site. Samples are rather large and require a large sample container or samples must be split into several smaller sample containers. ARS placed the soil samples in plastic bags, sealed them and stored the samples inside an ice chest for protection and transport. Sampling to a depth of 61.0 cm (24 in) was accomplished efficiently with three persons. Drive sampler is used primarily in surface sampling for earth compaction tests for dam and roadway construction. Equipment cost is in the $300 to $400 range with additional cost for excavation tools.

Single Probe Gamma Density Gauge (non destructive, in-place, density gauge) - The gamma density gauge consists of a gamma radiation source, detector tube, cable and scalar unit with radiation shield. The unit is placed over the access tube and the source and detector are lowered down the tube to the desired depth of reading. The displayed count represents total density, including the soil and water. Calibration curves or correction factors are required for each soil type because of variations in soil minerology if precise density measurement is desired. Wright (1993, this volume) describes the calibration procedure. Training and a radiation operator's license is required to operate the equipment. The equipment can be operated by one person. The equipment costs about $5,000 and requires a secure storage area.

Study Results:

Five, and sometimes, six different methods were used to collect soil samples at each site. Samples could not be obtained from the same specific location, so the next best choice was to locate them as close together as possible. Samples were taken within 45 cm (18 inches) of each other. Soil bulk densities vary considerably due to wheel traffic, tillage operations and soil structural variations (Wilding et al, 1983). Therefore, all the differences in bulk densities may not be directly related to the sampling method used. The results of the bulk density by depth for each site, for each sampling method are shown in figure 1. The "mean-probable" bulk density was based on an average of several methods. See Allen et al (1993b, this volume) for a discussion of the method and an error analysis of the various sampling methods. The gamma probe density was based on an average of three holes at each site after calibration corrections were made for each soil. Note that some compaction may have occurred in all methods of tube installation. Compaction occurred when the Gidding probe was inserted into the soil and when the access tube was driven into a slightly smaller hole in the soil to avoid air gaps on the exterior of the tube. Compaction adjacent to the tube has a greater effect on gamma probe readings than compaction at a greater distance. For uniform weighting, only one sample was compared from the Giddings samplers even though the average of three holes around the access tube was used in developing the actual calibration curves for a neutron gauge.

Time required to develop and process samples at a site was determined by the total time required to collect, describe and process the total number of samples taken divided by the number of samples processed. Table 1 shows the average time in person-hours required per sample for the various methods which does not include the time for oven drying which varies with the soil type and water content and not by sampling method. Actual time required for each method reflects the relative averages for the entire workshop since several scheduling difficulties and delays were experienced.

TABLE 1 COMPARISON OF TIME REQUIREMENTS FOR VARIOUS SOIL SAMPLING METHODS

Sampling Method	Total Sampling Time Per Site (hours)	Number of Samples Taken Per Site	Minutes per Sample
OSU-GID	1	12	5
USU-SML	1	10	6
ARS-GID	2	24	5
SCS-MAD	1.5	10	9
SCS-DRV	4	5	48
ARS-DRV	2	8	15

OSU-GID = Oklahoma State University Giddings; USU-SML = Utah State University small diameter sampler; ARS-GID = Agricultural Research Service Giddings: SCS-MAD = Soil Conservation Service Madera Sampler; SCS-DRV = Soil Conservation Service drive sampler; ARS-DRV = Agricultural Research Service drive sampler.

Some sampling methods require much more equipment than others and initial costs vary from about $180 to more than $2,000. Equipment purchased must be amortized over its expected life in order to arrive at an average annual cost. Some equipment, such as the Giddings, may also be used for other purposes. Rather than perform this economic analysis, the total estimated initial cost of the equipment is listed in the discussion of advantages and disadvantages and the calculations are left up to the reader if he or she is interested.

Conclusions:

Field calibration procedures for the neutron gauge have been established that provide a method of developing a site specific calibration curve. The procedure requires some specialized equipment which ranges in cost from $300 to more than $2,000. The time required to develop a field calibration curve varies from one to four hours per site.

All methods used to obtain undisturbed soil samples were acceptable but may have caused some compaction. Compaction may occur to the soil sample or to the soil area adjacent to the outside tube surface. Open end samplers reduce the probability of compaction from over sampling. Samplers with enlarged inside barrel diameters past the cutting tip reduce the probability of compaction from wall friction. Sharp cutting tips reduce the probability of compaction during the cutting or insertion process but are more prone to damage by gravel. Sample size should be 50 cubic centimeters or greater in order to reduce the processing errors. All methods tested were acceptable when used by a trained operator.

Fixed volume samplers allow the calculation of volumetric soil water content without the use of bulk density. Plotting the count ratio vs soil water content allows compacted samples and processing errors to be identified and eliminated before the calibration curve is developed. Bulk density adjustments can be used as a method of calculating the volumetric soil water content if the extent of compaction is known. A sampling method should be selected that is consistent with the volume of sampling to be done, the budget available and the crops to be monitored. A well defined procedure and a fully trained staff is the best investment for consistent, high quality results.

References:

Allen, R.G., G.L. Dickey and J.L. Wright, 1993a, Using Bulk Density for Corrections in Volumetric Soil Water Contents, Proc of the ASCE National Conference on Irrigation and Drainage Engineering, Park City, UT, July 21-23, 1993. (This volume).

Allen, R.G., G.L. Dickey, J.L. Wright, J.F. Stone and D.J. Hunsaker, 1993b, Error Analysis of Bulk Density Measurements for Neutron Moisture Gauge Calibration, Proc of the ASCE National Conference on Irrigation and Drainage Engineering, Park City, UT, July 21-23. (This volume).

Dickey, Gylan L., 1982, Radiation Safety, Calibration and Use of the Neutron Soil Moisture Gauge, USDA-Soil Conservation Service, Second Draft, April.

Dickey, Gylan L., 1990a, Field Calibration of Neutron Gauges: SCS Method, Proceedings of the ASCE 1990 National Conference, Irrigation and Drainage Division, Durango, Colorado, July 11-19, 1990, pages 192-201.

Dickey, G.L., 1990b, Factors Affecting Neutron Gauge Calibration, Proceedings of the ASCE 1990 National Conference, Irrigation and Drainage Division, Durango, Colorado, July 11-19, 1990, pages 9-20.

Gardner, Walter H., 1986, Water Content, Chapter 21, Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, American Society, Soil Science Society of America, Madison, Wisconsin, Agronomy Monograph No. 9, Arnold Klute, Editor, Second Edition, pages 495-507.

Hawley, McCuen and Jackson, 1982, Volume Accuracy Relationship in Soil Moisture Sampling, ASCE Irrigation and Drainage Division Proceedings, 108 (IR1):1-11.

Stone, J.F., 1990, Relationship of Soil Type and Chemicals to the Calibration of Neutron Meters, Proceedings of the ASCE 1990 National Conference, Irrigation and Drainage Division, Durango, Colorado, July 11-19, 1990, pages 32-38.

Stone, J.F., R.G. Allen, G.L. Dickey, J.L. Wright, F.S. Nakayama, and R.W. Phillips, 1993. The ASCE Neutron Probe Calibration Study: Overview. (This volume.)

Wilding, L.P., N.E. Smeck and G.F. Hall, 1983, Pedogenesis and soil Taxonomy, I. Concepts and Interactions, Elsevier Science Publishers B.V., Amsterdam, pp99-116.

Willardson, L.S. and S.A. Taylor, 1962, Soil Sampler for Direct Moisture Determination, Agricultural Engineering, 43(1):33-44.

Wright, J.L., R.G. Allen and G.L. Dickey, 1993, ASCE Neutron Probe Study: Gamma Density Gauge, Proc of the ASCE National Conference on Irrigation and Drainage Engineering, Park City, UT, July 21-23. (This volume)

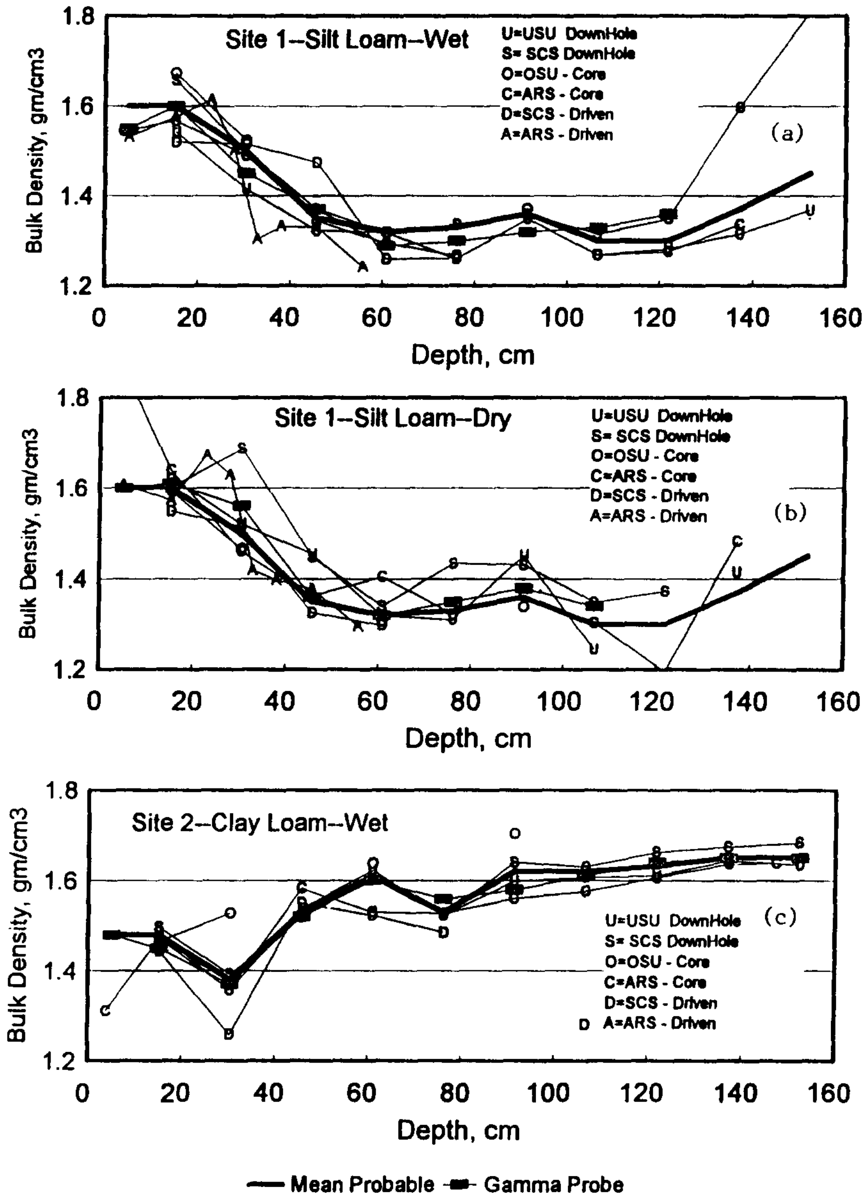

Figure 1. Comparison of Bulk Densities Sampled by Various Sampling Methods: a) Site 1 Wet; b) Site 1 Dry; c) Site 2 Wet.

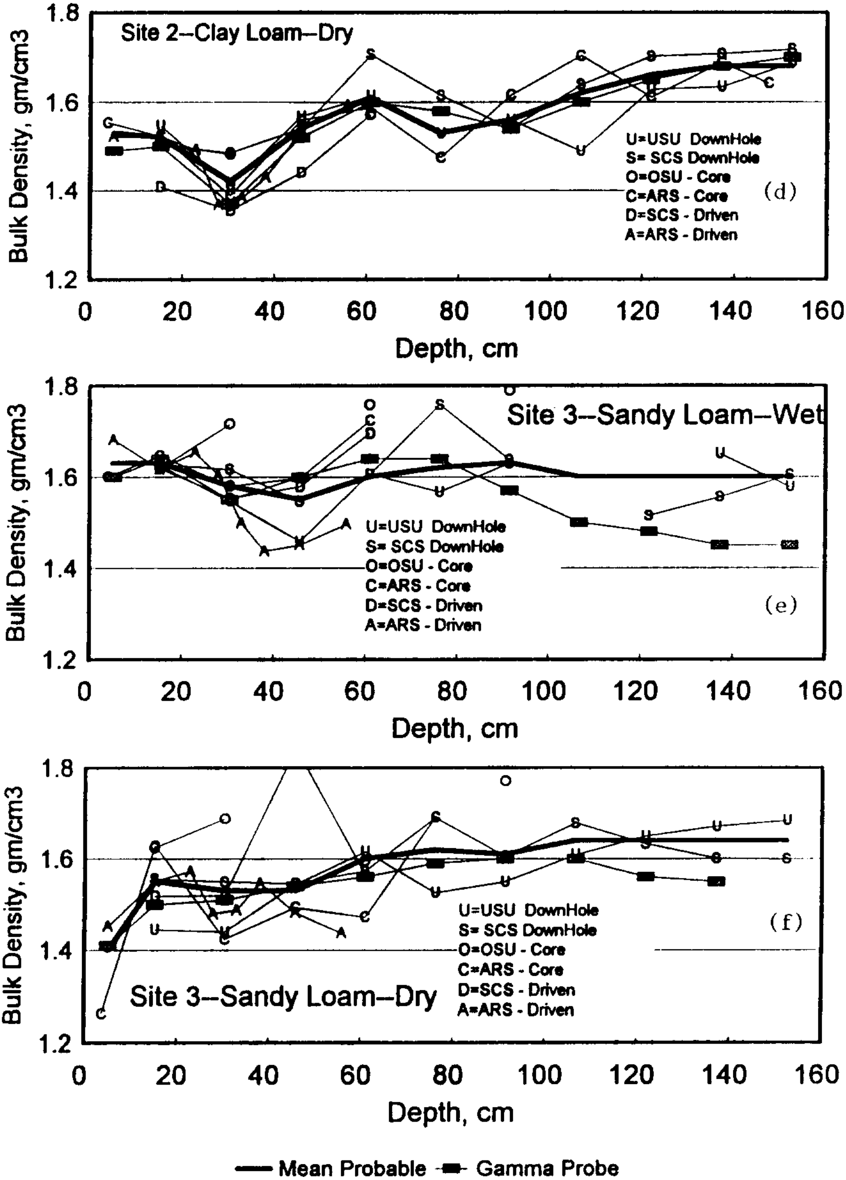

Figure 1, continued. Comparison of Bulk Densities Sampled by Various Sampling Methods: d) Site 2 Dry; e) Site 3 Wet; f) Site 3 Dry.