COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
2018, VOL. 49, NO. 6, 701–707
https://doi.org/10.1080/00103624.2018.1432640

Taylor & Francis
Taylor & Francis Group

Check for updates

Does Sampler Size Affect Southeastern Piedmont Forest Soil Bulk Density Estimation?

T. Adam Coates[a], Thomas A. Waldrop[b], Victor B. Shelburne[c], and Hoke S. Hill[d]

[a]Department of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA, USA; [b]U.S. Department of Agriculture Forest Service Southern Research Station (retired), Clemson University, Clemson, SC, USA; [c]Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC, USA; [d]Department of Mathematical Sciences, Clemson University, Clemson, SC, USA

ABSTRACT

Destructive core sampling is the most recognized technique for soil bulk density estimation to monitor soil compaction. This study was conducted to determine if soil bulk density sampler size would impact value estimates and silvicultural treatment distinctions in southeastern Piedmont forest soils of the Clemson Experimental Forest, Clemson, South Carolina, USA. In 2004, six hundred soils were sampled using both an Oakfield Soil Probe (diameter 2.5 cm) and an AMS, Inc. Slide Hammer (diameter 5.1 cm). The smaller, Oakfield Soil Probe values were greater than the larger, AMS Inc. Slide Hammer values ($p < 0.0001$) and values from both samplers were greater in the thin and burn treatments than the control treatments ($p < 0.007$). Strong correlation of the values between the samplers was also demonstrated ($p < 00001$; $r^2 = 0.62$). These results highlight the utility of the smaller Oakfield Soil Probe when accessibility and intensity may impose sampling constraints.

Abbreviations: AMS=AMS Inc. Slide Hammer; CEF=Clemson Experimental Forest; D_b=soil bulk density; FFS=National Fire and Fire Surrogate Study; OSP=Oakfield Model H Soil Probe; SOC=soil organic carbon

ARTICLE HISTORY
Received 29 August 2017
Accepted 7 December 2017

KEYWORDS
Forest restoration; forest soils; silviculture; soil bulk density; soil compaction

Introduction

Management practices implemented by natural resource professionals often increase soil compaction over the short- or long-term, which leads to increases in soil bulk density (D_b) for a given unit of soil (Ozgoz, Oztekin, and Gunal 2006). Numerous devices and methods have been investigated to obtain estimates of compaction or D_b (Blake and Hartge 1986; Doran and Mielke 1984; Page-Dumroese et al. 1999; Vomocil 1957) including nuclear gauge and conductive methods (Steele et al. 1983), laser scanning (Rossi et al. 2008), and soil penetrometer estimation (Jones and Kunze 2004; Miller, Hazard, and Howes 2001). Destructive soil sampling has long been the method of choice for most professionals interested in obtaining estimates of D_b, however (Page-Dumroese et al. 1999).

In traditional studies of soil for agricultural purposes, destructive D_b samples were obtained using a slide hammer (Throop et al. 2012). The traditional slide hammer consists of a handled device with a coupling on one end, left open for the insertion of a series of rings of various depths. These rings can be added or omitted based on the desired depth of sampling and are generally 4–5 cm in diameter. A weighted slide is oriented along the handle of this device that can slide up the handle and be released to drive the rings into the ground. In total, this instrument can weigh 6.5–9.0 kg on average and samples obtained from the upper 10 cm of mineral soil commonly weigh 1–1.5 kg (wet).

CONTACT T. Adam Coates acoates4@vt.edu Department of Forest Resources and Environmental Conservation, Virginia Tech, 228F Cheatham Hall, 310 West Campus Dr., Blacksburg, VA 24061, USA.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/lcss.

© 2018 Taylor & Francis

Figure 1. The AMS Inc. Slide Hammer used for sampling soils within the Cecil-Lloyd-Madison Association on the Clemson Experimental Forest, Clemson, South Carolina.

Improvements have been made to the more modern versions of slide hammers, as seen through the design of the AMS Inc. Slide Hammer (AMS) (Figure 1). This slide hammer consists of an inner ring that is inserted into an outer, driving ring. The inner ring can be removed once the sample is obtained. A slide is oriented similarly to traditional slide hammers. This instrument weighs approximately 5 kg and samples obtained from this device to the 10 cm soil depth commonly weigh between 0.2–0.4 kg (wet). For a small number of samples in a non-rocky soil, slide hammers are typically the tool of choice, but intensive sampling and/or rocky soils might necessitate a more convenient, lighter piece of equipment.

The choice of sampling equipment was an issue we addressed in the summer of 2004. We were charged with obtaining 1200 D_b samples across a variety of landscapes within the Clemson Experimental Forest (CEF), Clemson, South Carolina as part of the National Fire and Fire Surrogate Study (FFS) (Schwilk et al. 2009). These sites were selected to represent the southeastern Piedmont ecosystem. Soils of the CEF are generally Ultisols classified within the Cecil-Lloyd-Madison association (Sorrells 1984) and are representative of this ecological region. The goal of sampling was to determine if prescribed fire-alone, thinning-alone, or a combination of prescribed fire and thinning had any effect on forest soil properties, including D_b, 3 to 4 years following a single implementation of these treatments. Pre-treatment and 1-year post-treatment samples had been obtained using a traditional slide hammer and a series of rings, but droughty conditions and rocky soils limited the depth and efficiency of sampling with this device. On the first day of scheduled field work in 2004, this piece of equipment broke. Several individuals suggested using an AMS Inc. Slide Hammer to obtain the remaining samples, but a few others suggested a smaller soil probe, such as the Oakfield Model H Soil Probe (OSP) (Figure 2). This tool is less than 2.5 cm in diameter and mineral soil samples extracted to the 10 cm soil depth typically weigh 40–60 g (wet). This type of sampler is most commonly used to obtain small samples for soil testing, which raised concerns regarding the amount of soil this sampler would provide and the adequacy of a small amount of soil for obtaining confident estimates of D_b. A review of the literature indicated that few similar comparisons of tools have been conducted, but evidence suggests that sampling techniques and equipment can influence D_b values (Folegatti, Brasil, and Blanco 2001; Ozgoz, Oztekin, and Gunal 2006; Page-Dumroese et al. 1999). Throop et al. (2012) also suggested that sampler size may impact the estimation of soil organic carbon (SOC) pools in rocky soils.

Figure 2. The Oakfield Model H Soil Probe used for sampling soils within the Cecil-Lloyd-Madison Association on the Clemson Experimental Forest, Clemson, South Carolina.

Our hypotheses were that the samplers would obtain similar estimates of D_b for a given area and that both would be effective at determining differences between the treatment units if differences did exist. We did, however, expect the variability in samples obtained with the AMS to be greater due to sampling in rocky soils.

Methods

The FFS study for the southeastern Piedmont was established in 2000 on the CEF as a randomized complete block design, consisting of four treatments and three blocks (34.6834°N, 82.8374°W). These blocks were designated based on tree size classes (pulpwood-dominated, mixture of pulpwood and sawtimber, and sawtimber-dominated). The four treatments implemented on the CEF were prescribed fire-only, thinning-only, a combination of prescribed fire and thinning, and a control. Ten 20 m × 50 m plots were assigned to each treatment-block unit. Ten 10 m × 10 m subplots were designated within each of the plots and D_b sampling was conducted 5 m outside the boundaries of these subplots to the 10 cm soil depth to avoid any potential disturbance caused by the intensity of research activities conducted in these areas over time (Figure 3). The D_b sampler comparison was conducted for the control and thin and burn treatments, yielding 600 total samples for each sampler, which were averaged to obtain estimates for the 60 plots of interest. Samples were collected and prepared for analysis according to the methods of Page-Dumroese et al. (1999). Briefly, each sample was placed in a paper bag in the field and taken back to the laboratory. During collection and transport, care was taken to insure that no soil exited any of the bags and none of the bags were torn. Any substantial accumulations of rocks or roots were removed from the samples in the laboratory and the volume of these materials was subtracted from the known volume of soil obtained with each sampler (177.21 cm^3 for the AMS and 27.21 cm^3 for the OSP). The bags were then oven-dried at 104°C for 16–24 h and reweighed immediately. The oven-dry weight of these samples was then divided by the known or calculated volume for each soil sample. The D_b values obtained for each of the subplot samples were then averaged to represent each plot.

A paired analysis was used to determine the significance of differences between the samplers using JMP 12 (Version 12, SAS Institute Inc., Cary, NC, USA) at $\alpha = 0.05$. Statistical difference determinations between the treatment areas using each sampler were conducted using t-tests for independent samples to evaluate the utility of each sampler for difference determination between

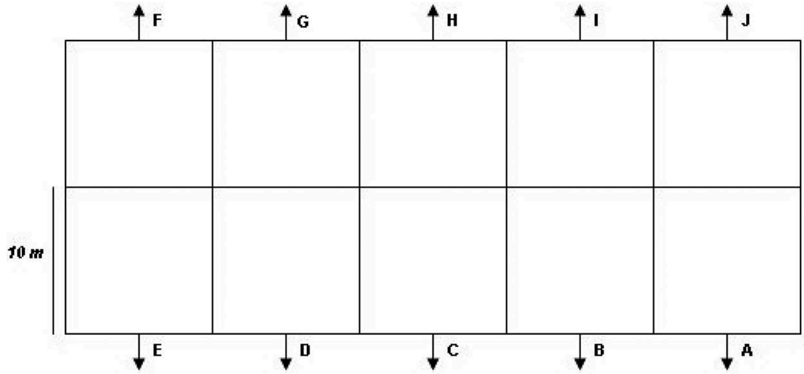

Figure 3. Representation of the subplot designation and bulk density sampling locations utilized on the Clemson Experimental Forest, Clemson, South Carolina for the southeastern Piedmont portion of the National Fire and Fire Surrogate Study.

treatments (α = 0.05). The relationship between the samplers was then evaluated with the 60 plot averages that were obtained for each sampler to predict the AMS D_b using the OSP D_b.

Results and discussion

The OSP estimates of D_b (1.20 g cm^{-3}) within the treatment units were significantly greater than the AMS values (1.31 g cm^{-3}) by 0.11 g cm^{-3} ($p < 0.0001$) (Figure 4). This result agreed with results from a few other studies. Page-Dumroese et al. (1999) found that a small diameter core sampler produced higher estimates of total D_b than a large diameter core sampler at the 10–20 cm soil depth in rocky, forest soils. In a study of core samples in soils with a known, standard D_b, Miller, Hazard, and Howes (2001) determined that smaller soil samplers overestimated D_b when compared to a standard value (up to a 30 cm depth). The higher values generated by samples obtained with smaller core samplers may be related to potential inner compaction created by smaller diameter samplers, like the OSP (Page-Dumroese et al. 1999). There is also less likelihood to encounter rocks and roots using the smaller sampler, so this may elevate D_b values using the small corer in rocky soils (Throop et al.

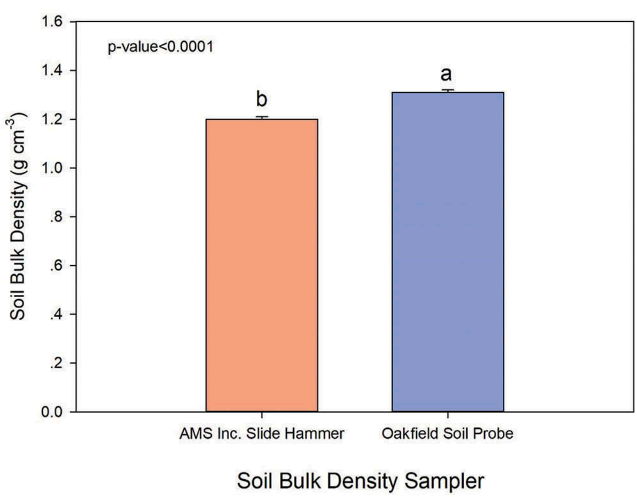

Figure 4. Destructive soil bulk density sampler value comparison on the Clemson Experimental Forest, Clemson, South Carolina (α = 0.05).

2012). Alternatively, Folegatti, Brasil, and Blanco (2001) determined that a Kopecky's Ring assembly (larger core sampler) produced Oxisol samples with higher D_b values than did a smaller core sampler. Cihacek, Foss, and Jacobson (2015) also found that cylindrical samplers differing in diameter from 19 to 31 mm displayed no significant difference in D_b values.

Our pre-supposition was that the AMS values would be more variable than the OSP values based upon the rockiness of the soils we encountered during the course of this study. This was not the case, however, as all standard errors ranged from 0.02–0.04, regardless of sampler. Vincent and Chadwick (1994) suggested that soils with coarse fragments greater than 34% by volume are most accurately assessed using samplers that obtain a larger soil volume. Our soils did not contain coarse fragment volumes of this magnitude.

Both samplers detected differences between the control and thin and burn treatment units (AMS p-value = 0.003; OSP p-value = 0.007) (Figure 5), indicating that soil compaction increased as a result of the thin and burn treatment. In this sense both samplers were capable of addressing the broader experimental question and the same result was determined, regardless of the amount of soil that was obtained as a result of sampling. Through regression analysis of the values obtained with both samplers, it was determined that the OSP and AMS values shared a strong relationship with one another ($p < 0.0001$) and were positively correlated ($r^2 = 0.62$) (Figure 6). This relationship can be represented with the following equation:

$$\text{AMS } D_b = 0.054 + 0.875(\text{OSP } D_b)$$

If it is assumed that smaller core samplers overestimate D_b values (Miller, Hazard, and Howes 2001; Page-Dumroese et al. 1999), this equation may provide a means to more conservatively estimate D_b in these soils. In soils where accessibility and intensity may promote sampling constraints, as was the case in this study, the OSP may be a tool of choice to provide reliable estimates of D_b.

This study might have been enhanced by the addition of soil excavation pits which would have provided an opportunity to extract a known volume of soil at a given depth to provide a standard bulk density value (Miller, Hazard, and Howes 2001; Throop et al. 2012). Given the intensity and number of these treatments, their location, and potential accessibility issues, no pits were created in these areas. Since both samplers are estimates and no particular method has been documented as the absolute best method, it appears that both are valid sampling tools, particularly in cases where the determination of differences among treatment units are concerned and the intensity of sampling

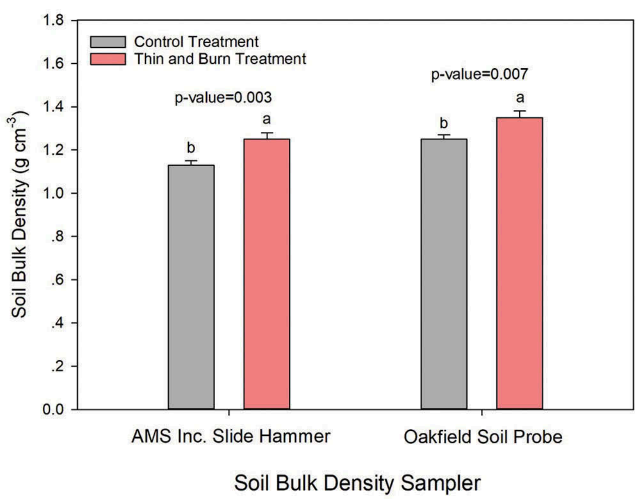

Figure 5. Difference determination for the control and thin and burn treatments using the AMS Inc. Slide Hammer and Oakfield Soil Probe (α = 0.05).

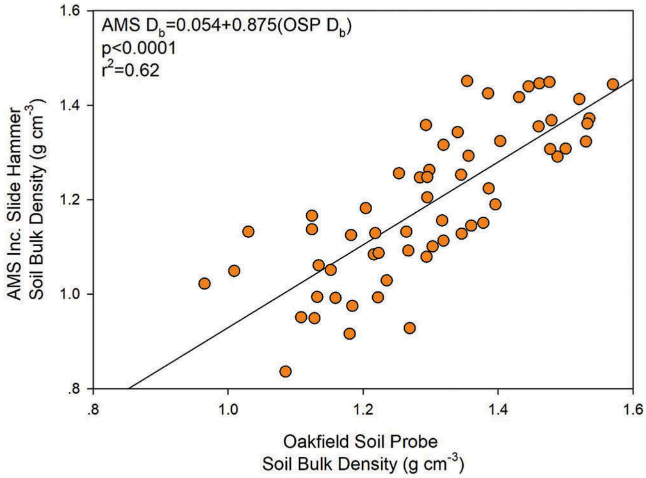

Figure 6. Linear regression analysis for the prediction of the AMS Inc. Slide Hammer soil bulk density values using the Oakfield Soil Probe soil bulk density values (n = 60 plots).

may necessitate a smaller sampling tool and lighter samples. In such cases, the equation presented in Figure 6 may prove valuable to estimate AMS values using OSP values if the individual wishes to report AMS values, given its legacy as the preferred sampling tool.

One item of consideration when obtaining samples for D_b estimation may be related to the use of the excavated samples for purposes beyond D_b estimation, such as SOC or microbiological analyses (Doran and Mielke 1984). Throop et al. (2012) suggested that SOC mass estimates may be affected by core sampler size. The authors concluded that assessing values for the fine earth fraction and coarse fragments may benefit SOC estimation. As interest in long-term carbon sequestration and estimation continues to increase, the selection of sampling equipment and methods to accommodate SOC estimation may be very important. The use of soil coring or extraction devices must be considered for their capacity to provide enough soil to account for the array of tests and analyses desired. For the purposes of this project, the nature of the soils in question, and the number of soil samples needed, we found the smaller core sampler to be advantageous.

Conclusions

Despite its smaller size and sampling portion, the smaller Oakfield Soil Probe obtained values for D_b that were correlated with values obtained with the larger AMS Inc. Slide Hammer. Both samplers were effective at detecting D_b differences between the control and thin and burn treatment units. Even though the OSP obtained higher values than the AMS, both samplers are useful tools. The OSP should be considered as an effective piece of equipment for high intensity sampling in areas that are not easily accessed by roads to maximize the time and efficiency of sampling in the field. More of these samples can be packed and stored in a given area and the amount of soil that is removed from this type of sampling is minimized as well, which minimizes processing time.

Acknowledgments

The authors would like to thank Mr. Graham Marsh and Mr. Brian Welch for their assistance in obtaining these samples from the CEF. Additional thanks goes to Dr. Pete Kapeluck and Mr. Wayne Carroll for their suggestions regarding the use of the OSP from their experiences on the southern Appalachian FFS. The FFS was funded by the U.S. Department of Interior and the USDA Forest Service Joint Fire Science Program. Partial funding was additionally provided by USDA Forest Service Work Unit SRS-4104, Disturbance and Management of Southern Forest Ecosystems.

References

Blake, G. R., and K. H. Hartge. 1986. Bulk density. In *Methods of soil analysis: Part 1 – Physical and mineralogical methods*, ed A. Klute, 363–75. Madison, Wisc: America Agronomy Society.

Cihacek, L. J., L. A. Foss, and K. A. Jacobson. 2015. Comparison of soil sampling devices for soil bulk density determination for carbon sequestration monitoring. *Communications in Soil Science and Plant Analysis* 46:180–84. doi:10.1080/00103624.2014.967857.

Doran, J. W., and L. N. Mielke. 1984. A rapid, low-cost method for determination of soil bulk density. *Soil Science Society of America Journal* 48:717–19. doi:10.2136/sssaj1984.03615995004800040004x.

Folegatti, M. V., R. P. C. Brasil, and F. F. Blanco. 2001. Sampling equipment for soil bulk density determination tested in a kandiudalfic eutrodox and a typic hapludox. *Scientia Agricola* 58:833–38. doi:10.1590/S0103-90162001000400027.

Jones, D., and M. Kunze. 2004. Guide to sampling soil compaction using hand-held soil penetrometers. CEMML TPS 04-1. Center for Environmental Management of Military Lands, Colorado State University, Fort Collins, Colorado. 8p.

Miller, R. E., J. Hazard, and S. Howes. 2001. Precision, accuracy, and efficiency of four tools for measuring soil bulk density or strength. General Technical Report PNW-RP-532. USDA Forest Service Pacific Northwest Research Station, Portland, Oregon. 17p.

Ozgoz, E., T. Oztekin, and H. Gunal. 2006. Assessment of wheel traffic effect on soil compaction using a soil core sampler. *New Zealand Journal of Agricultural Research* 49:299–306. doi:10.1080/00288233.2006.9513720.

Page-Dumroese, D. S., M. F. Jurgensen, R. E. Brown, and G. D. Mroz. 1999. Comparison of methods for determining bulk density of rocky forest soils. *Soil Science Society of America Journal* 63:379–83. doi:10.2136/sssaj1999.03615995006300020016x.

Rossi, A. M., D. R. Hirmas, R. C. Graham, and P. D. Sternberg. 2008. Bulk density determination by automated three-dimensional laser scanning. *Soil Science Society of America Journal* 72:1591–93. doi:10.2136/sssaj2008.0072N.

Schwilk, D. W., J. E. Keeley, E. E. Knapp, J. McIver, J. D. Bailey, C. J. Fettig, C. E. Fielder, R. J. Harrod, J. J. Moghaddas, K. W. Outcalt, C. N. Skinner, S. L. Stephens, T. A. Waldrop, D. A. Yaussy, and A. Youngblood. 2009. The national fire and fire surrogate study: Effects of fuel reduction methods on forest vegetation structure and fuels. *Ecological Applications* 19:285–304. doi:10.1890/07-1747.1.

Sorrells, R. T. 1984. *The clemson experimental forest: Its first fifty years*. Clemson, South Carolina: Clemson University College of Forest and Recreation Resources.

Steele, J. G., J. L. Koger, A. C. Trouse, and D. L. Sirois. 1983. Core versus nuclear gauge methods of determining soil bulk density and moisture content. Research Note SO-285. USDA Forest Service Southern Forest Experiment Station, New Orleans, Louisiana. 5p.

Throop, H. L., S. R. Archer, H. C. Monger, and S. Waltman. 2012. When bulk density methods matter: Implications for estimating soil organic carbon pools in rocky soils. *Journal of Arid Environments* 77:66–71. doi:10.1016/j.jaridenv.2011.08.020.

Vincent, K. R., and O. A. Chadwick. 1994. Synthesizing bulk density for soils with abundant rock fragments. *Soil Science Society of America Journal*, 58:455–64. doi:10.2136/sssaj1994.03615995005800020030x.

Vomocil, J. A. 1957. Measurement of soil bulk density and penetrability: A review of methods. *Advances in Agronomy* 9:159–75.