

**RESEARCH LETTER**

# Sampling probes affect bulk density and soil organic carbon measurements

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**Abstract**

Soil sampling equipment can be a major source of bias in soil organic carbon (SOC) stock estimations. The objective of this study was to evaluate the impact of sampling probes on soil bulk density (BD) and SOC stocks calculated using fixed depth (FD) and equivalent soil mass (ESM) methods. Soil samples were collected to 30 cm using three probes with different diameters and divided into 0–10-, 10–20-, and 20–30-cm layers. The probe with smallest diameter measured higher BD at 0–10 cm in 42% of fields and was significantly different when averaged across fields, while no consistent differences were observed at lower depths. This study shows that sampling probes with different diameters may introduce biases in BD and SOC measurements at individual or combined soil layers when calculated using the FD approach. The ESM approach reduced the differences in mean SOC stocks calculated using different probes.

## 1 | INTRODUCTION

Soil organic carbon (SOC) is an important component and indicator of soil health (McGowen, Sharma, Deng, Zhang, & Warren, 2018). However, estimating SOC stocks is challenging due to spatial and temporal variation in soil properties (Post et al., 2001). Climate, physical, and biological factors affect the variation in SOC at different spatial and temporal scales (VandenBygaart, 2006). The most common approach used to calculate SOC stocks is multiplying SOC concentration in a given layer by corresponding bulk density (BD) and converting it for desired area. In this approach, the surface of the soil is assumed to be fixed. However, the

soil surface and BD are prone to change due to erosion or deposition of material, swelling or compaction, and anthropogenic activities. Errors and biases in soil BD can also arise from sampling equipment and measurement methods that may make comparison of data difficult (Gojts, Van Wesemael, & Crucifix, 2009; Grossman & Reinsch, 2002; Kulmatiski & Beard, 2004). Such errors may result in biased estimations of SOC stocks (Gifford & Roderick, 2003; Wuest, 2009). Moreover, data collection for BD is laborious and time consuming.

To reduce BD-related biases, Ellert and Bettany (1995) proposed the equivalent soil mass (ESM) method to calculate SOC budget for each genetic horizon of soil. In this approach, BD is replaced with ESM per unit area. Zan, Fyles, Girouard, and Samson (2001) later modified this approach by replacing the genetic horizons with soil layers of fixed depth (FD). In 2003, Gifford and Roderrick (2003) proposed an ESM approach on two layers, in which minimum soil mass among

**Abbreviations:** BD, bulk density; ESM, equivalent soil mass; FD, fixed depth; HP, hydraulic probe; PP, push probe; SH, slide hammer probe; SOC, soil organic carbon.

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the cores was used as ESM. Lee, Hopmans, Rolston, Baer, and Six (2009) further modified the ESM method for calculating SOC stock in multiple layers.

While the ESM approach has been widely used for evaluating temporal changes in SOC stocks, data on eliminating the BD errors from different soil sampling probes are limited. We compared three soil sampling probes with different cutting edge diameters for BD and SOC stocks. The objectives of this study were to evaluate the impact of probe type on BD and SOC stock and the utility of the ESM method in reducing variability in SOC stock.

## 2 | MATERIALS AND METHODS

Soil samples were collected from 19 fields located in north-central Oklahoma. The fields were under no-till management with wheat as the main crop. Field boundaries were drawn in ArcMAP 10 and a random point was generated in each field using Random Point Generator using ArcToolbox. Soil samples were taken within 3-m-radius circle around this random point.

The three probes used to collect soil samples were (i) tractor-mounted hydraulic probe (HP, diameter 3.98 cm) (Giddings #25-TS model HDGSRSTS), (ii) push probe (PP, diameter 2.26 cm) (AMS Inc. model 1 1/4" × 24"), and (iii) slide hammer probe (SH, diameter 4.8 cm) (AMS Inc. model 2" × 12"). Five cores were collected with each probe.

Cores were extracted to approximately 33 cm. The soil core was gently removed by pushing it from bottom on to a plastic cradle, where it was segmented into 0–10-, 10–20-, and 20–30-cm layers. The segments were packed in zipper plastic bags and placed in an ice chest until transported and stored in a refrigerator at 4°C. The zipper bags with wet soil were weighed and a subsample of soil (~20 gm) was dried at 110 °C for 24 h to determine moisture content gravimetrically. Dry soil mass along with volume of the core segment was used to determine BD. The remaining soil was transferred to a paper bag and allowed to dry at 65°C for one week and then ground and sieved through a 2-mm sieve. A subsample (0.24–0.25 g) was taken from dried soil to analyze total C using the dry combustion method (Kalembasa & Jenkinson, 1973) using Leco CN analyzer. Inorganic C was determined using a Pressure Calcimeter (Sherrod, Dunn, Peterson, and Kolberg, 2002) for samples with pH greater than 7.2. Soil pH was determined on a 1:1 soil/deionized H<sub>2</sub>O mixture after a 30-min equilibration period. The organic C concentration of samples was calculated as the difference between the total C and inorganic C.

In the FD method, SOC mass in each layer of soil was calculated by multiplying the SOC concentration with the soil mass of the layer (Equations 1 and 2) (Lee et al., 2009):

$$M_i = r_b \times Z \times 10^4 \quad (1)$$

### Core Ideas

- Soil probe selection can significantly affect bulk density measurements.
- Differences in measured bulk density will influence soil organic C stocks measurement within a small area of same field.
- Probe influence was greater when soil organic C was calculated using fixed depth method, while equivalent mass method eliminated this impact.

$$C_{i,\text{fixed}} = f_c \times M \quad (2)$$

where  $M_i$  is the soil mass for  $i$ th soil layer,  $\rho_b$  is the bulk density for corresponding layer,  $Z$  is the depth of  $i$ th layer,  $10^4$  is the conversion factor for soil mass for  $i$ th layer per hectare,  $C_{i,\text{fixed}}$  is the organic C stock for the fixed depth in  $i$ th layer, and  $f_c$  is mass fraction of the organic C.

In the ESM approach, minimum soil mass among the cores for each field was selected as ESM. Therefore, ESM was different for each field. The ESM was adjusted from top layer in other cores (Equation 3), and the extra soil mass from the upper layer was added to the lower layer. Similarly, the lowest mass among cores in the second layer was selected as ESM. The additional soil mass in the second layer was added to the third layer (Equation 4).

$$M_{i,\text{add}} = M_{i,\text{equiv}} - M_i \quad (3)$$

$$C_{i,\text{ESM}} = C_{i,\text{fixed}} + C_{i-1} \times M_{i-1,\text{add}} - C_i \times (M_{i,\text{add}} + M_{i-1,\text{add}}) \quad (4)$$

where  $M_{i,\text{add}}$  is additional soil mass in  $i$ th layer,  $M_{i,\text{equiv}}$  is the minimum soil mass selected for  $i$ th layer,  $C_{i,\text{ESM}}$  is organic C stock in  $i$ th layer (where  $i$  represent soil layer 0–10, 10–20 or 20–30 cm), and  $C_{i-1}$  and  $M_{i-1,\text{add}}$  are the C fraction and additional soil mass from the upper layer. A similar procedure was followed for third layer, and the extra soil in third layer was discarded. The SOC concentration was multiplied with the corresponding ESM to obtain SOC stocks in each layer.

All three probes were treated as treatments with cores serving as replicates and field representing a test site. Therefore, a completely randomized design analysis of variance was performed using the SAS PROC MIXED procedure (SAS Institute, 2011) where the probe was the main fixed treatment effect and field was a random effect. Fisher's protected LSD was used to separate significant differences ( $p < .05$ ) among probes within a field or when averaged across fields.

**TABLE 1** Average bulk density at various depths (0–10, 10–20 and 20–30 cm) in 19 fields for push probe (PP), slide hammer probe (SH), and hydraulic probe (HP)

Field	Bulk density depth								
	PP	SH	HP	PP	SH	HP	PP	SH	HP
	0–10 cm			10–20 cm			20–30 cm		
	g cm <sup>-3</sup>								
1	1.23	1.22	1.30	1.43ab	1.42a	1.52b	1.41	1.41	1.44
2	1.49	1.36	1.49	1.64ab	1.7b	1.51a	1.61	1.56	1.61
3	1.92b	1.17a	1.25a	1.41a	1.54ab	1.55b	1.56	1.52	1.35
4	1.82b	1.34a	1.36a	1.49	1.51	1.46	1.35	1.38	1.42
5	1.56b	1.37a	1.3a	1.35a	1.47ab	1.51b	1.60b	1.44a	1.44ab
6	1.52	1.53	1.54	1.56a	1.59a	1.7b	1.54	1.55	1.59
7	1.63b	1.26a	1.31a	1.50	1.51	1.53	1.5	1.58	1.53
8	1.29b	1.12a	1.29b	1.52	1.58	1.59	1.56	1.58	1.53
9	1.27ab	1.09a	1.36b	1.59b	1.48a	1.63b	1.58	1.61	1.62
10	1.5	1.32	1.48	1.35a	1.56b	1.52b	1.41	1.60	1.55
11	1.58b	1.53b	1.31a	1.54b	1.63c	1.46a	1.68b	1.69b	1.51a
12	1.48b	1.42ab	1.34a	1.47b	1.55c	1.36a	1.50b	1.48b	1.33a
13	1.40ab	1.52b	1.34a	1.68b	1.66b	1.55a	1.69b	1.72b	1.57a
14	1.22	1.28	1.18	1.45b	1.49b	1.32a	1.47b	1.47b	1.39a
15	1.40b	1.46b	1.21a	1.52b	1.49b	1.43a	1.47ab	1.56b	1.4a
16	1.19	1.10	1.23	1.44	1.55	1.52	1.57	1.60	1.51
17	1.34	1.25	1.34	1.63	1.71	1.69	1.83b	1.82b	1.68a
18	1.41	1.33	1.36	1.62b	1.53a	1.61ab	1.73	1.66	1.69
19	1.43	1.43	1.35	1.46	1.44	1.56	1.55	1.53	1.55
Average	1.46b	1.32a	1.33a	1.51a	1.55a	1.53a	1.56b	1.56b	1.53a

Note. Values within a row followed by the same letter or no letter are not significantly different at  $p < .05$  within each depth increment. The average values were pooled across fields and mean separation was conducted for each depth increment.

### 3 | RESULTS AND DISCUSSION

Table 1 shows the impact of the probe on the BD of each layer and the average BD across all the fields. Significant differences were observed in the mean BD at all depths among the probes. Although the differences were not limited to any single probe, PP registered higher BD in the majority of the fields, especially at the 0–10-cm layer. The BD for PP when averaged across all the fields was significantly higher than SH and HP ( $p < .05$ ). Despite statistical difference, variation in average BD among the probes was small (CV < 10%). The average CV across all the fields at all depths was 7.82, 5.95, and 5.67% for PP, SH, and HP, respectively.

Higher BD in PP at surface layer could be the result of compaction of soil during the insertion of the probe in soil (Grossman & Reinsch, 2002). In general, BD tends to increase naturally in no-till systems, where compaction is mostly limited to 5–20-cm depth (Kay & VandenBygaart, 2002). Tebrügge and Düring (1999) found that addition of SOC in no-till systems tends to decrease BD in the 0–3-cm layer, while the susceptibility to compaction declines with depth. The compaction at

the surface layer for PP could be due to exertion of greater pressure on the surface as a result of its smaller cutting edge diameter. Further, Wilson and Warren (2015) reported elevation of BD measurement with increasing soil moisture in soils with shrink–swell properties. In this study, we did not find a correlation between BD and soil moisture. This could be because all the soils in this study were dry during sampling, where volumetric water content ranged from 3 to 18%. Also, volumetric water content remained within  $\pm 1\%$  among the probes within individual fields.

Our results are in agreement with those of Dold, Hatfield, Sauer, Cambardella, and Wacha (2018) and Beem-Miller, Kong, Ogle, and Wolfe (2016), who reported differences in BD measurement using different sampling methods, which consisted of hydraulic sampling and pit sampling. While core length was not measured in our study, Dold et al. (2018) noted error in core length and diameter to be possible sources of BD error. However, the authors reported that correction measures were unable to produce significant results.

Soil organic C concentration declined with depth in all the fields (Table 2). Only 4 or fewer fields exhibited significant

**TABLE 2** Average organic C concentration at various depths (0–10, 10–20, and 20–30 cm) in 19 fields for push probe (PP), slide hammer probe (SH), and hydraulic probe (HP)

Field	Organic C concentration								
	PP	SH	HP	PP	SH	HP	PP	SH	HP
	0–10 cm			10–20 cm			20–30 cm		
	%								
1	0.97	0.94	0.93	0.73	0.73	0.74	0.74b	0.69a	0.64a
2	0.43	0.44	0.40	0.43	0.40	0.42	0.55	0.55	0.53
3	0.73ab	0.82b	0.68a	0.70	0.68	0.68	0.61	0.70	0.66
4	0.81	0.74	0.72	0.84	0.79	0.83	0.58a	0.71ab	0.82b
5	0.41ab	0.58b	0.35a	0.45	0.57	0.47	0.36	0.39	0.38
6	0.62	0.53	0.55	0.36	0.43	0.40	0.55	0.46	0.52
7	0.68	0.71	0.72	0.57	0.59	0.56	0.48	0.51	0.54
8	0.94	1.00	0.96	0.78	0.77	0.78	0.77	0.75	0.76
9	0.85	0.86	0.81	0.60	0.62	0.55	0.52	0.52	0.53
10	0.59	0.60	0.64	0.51	0.48	0.52	0.64	0.62	0.63
11	0.27	0.32	0.31	0.16b	0.08a	0.15b	0.11b	0.04a	0.04a
12	0.92	0.86	0.78	0.66b	0.64ab	0.62a	0.68b	0.61a	0.65ab
13	0.50b	0.44a	0.47ab	0.28	0.25	0.30	0.19b	0.35c	0.09a
14	1.01	1.10	1.01	0.77	0.74	0.74	0.92b	0.86a	0.86a
15	0.97	1.00	1.04	0.73	0.72	0.74	0.89b	0.82a	0.86a
16	0.95	0.99	0.89	0.56	0.54	0.55	0.49	0.48	0.47
17	0.50	0.42	0.49	0.22b	0.18ab	0.15a	0.16	0.13	0.13
18	0.26ab	0.20a	0.33b	0.07	0.08	0.08	0.09b	0.04a	0.06ab
19	0.81	0.89	1.15	0.63	0.62	0.64	0.42ab	0.53b	0.40a
Average	0.70	0.71	0.70	0.53	0.52	0.52	0.51	0.52	0.50

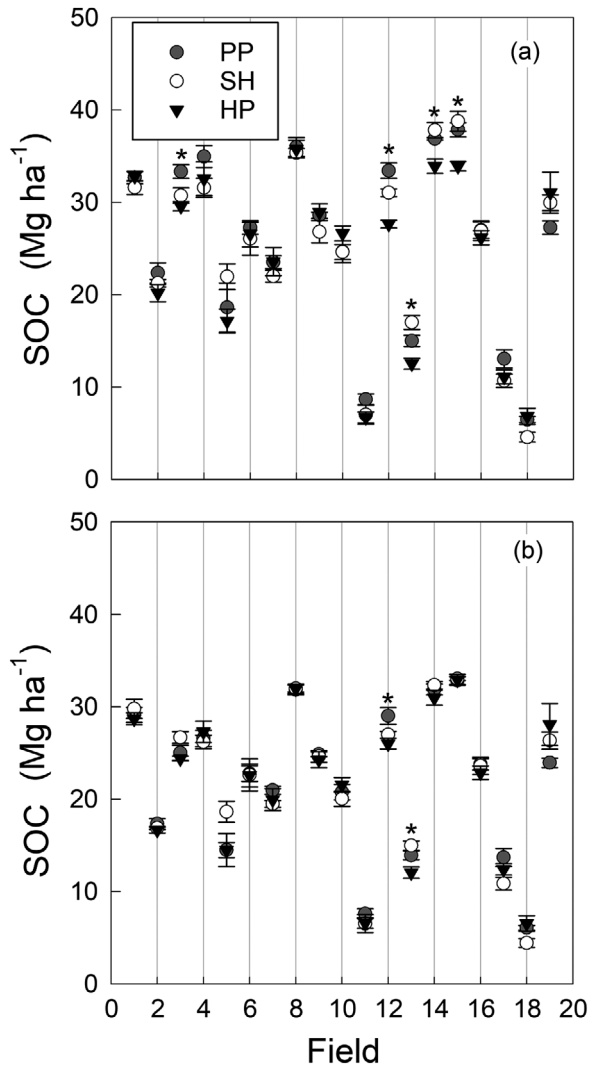
Note. Values within a row followed by the same letter or no letter are not significantly different at  $p < .05$  within each depth increment. The average values were pooled across fields and mean separation was conducted for each depth increment.

differences among probes at the top two layers, while 11 of the 19 fields showed significant difference at the 20–30-cm layer. At the 20–30-cm layer, PP had significantly higher SOC concentration in six fields (Fields 1, 11, 12, 14, 15, and 18), while SH (Fields 13, and 19) and HP (Field 4) were elevated in the remaining fields. Some differences observed could be due to differential compression as discussed above. The differences observed in the subsoil could be caused by differences in contamination of the lower depths with surface soil material. This is supported by the observation that the PP with the smallest diameter (least sample mass) tended to have elevated concentrations at the 20–30-cm depth when significant differences were observed. The error associated with differential contamination of the lower depths should have only minor impacts on the SOC stocks because solid tube probes were used. Despite a statistical difference, the numeric difference in average SOC concentration remained small (<10%) among the probes.

Figure 1 shows cumulative SOC stocks calculated for each probe in each field using the FD and ESM methods. The difference among the probes was greater in the FD method as compared to the ESM method. Analysis of variance showed significant effect of probes in SOC stocks of Fields 3, 12, 13,

14, and 15 in the FD approach, where PP and SH registered significantly higher SOC than HP. The fields with significant impact of probe on SOC stocks also showed significant differences in BD and SOC concentration (Table 1 and 2). However, note that not all the fields with significant differences in BD or SOC (at individual layers) manifested significant difference in 0–30-cm SOC stocks, indicating that in some cases the SOC concentration and BD balanced the calculation of SOC stocks. Furthermore, the differences in BD and SOC concentrations in the surface can be diluted when combined with lower depths for the SOC stock estimate.

The probe impact on SOC stocks was limited to Fields 12 and 13 when the ESM method was used (Figure 1). Since the mass of soil was fixed for each layer, differences in SOC concentration are the source of differences in SOC stocks (Wuest, 2009). Specifically, in Field 12, the PP resulted in consistently larger SOC concentrations, while in Field 13, the SH resulted in SOC concentration that was two and three times larger than that in the PP and HP in the 20–30-cm depth. These differences can only be explained by human error in operating these two manual probes at these two field sites. The use of the ESM method brought parity to the SOC stocks measured with the



**FIGURE 1** Cumulative soil organic C (SOC) in push probe (PP), slide hammer probe (SH), and hydraulic probe (HP) samples for (a) fixed depth (FD) of 30 cm and (b) the equivalent soil mass method (ESM). Asterisks in plots (a) and (b) denote fields with significant probe impact ( $p < .05$ )

three probes for 90% of the sites, which is an improvement over the FD method, but these data highlight the fact that human error cannot be fully eliminated and that the quality of sample collection protocol is important.

There was no significant difference in mean CV among the probes at individual or cumulative depths for the FD or ESM method. The average CV among the probes for cumulative SOC stocks was 13.9 and 12.1% in the FD and ESM method, respectively. Average CV was 15.1, 15.5, and 17.7% for FD and 14.6, 11.6, and 15.1% for ESM at 0–10-, 10–20- and 20–30-cm depth, respectively. Although marginal, the reduction in error by the ESM method is in agreement with the findings of Beem-Miller et al. (2016), Wuest (2009), and Dold et al. (2018).

## 4 | SUMMARY

This study evaluated three soil sampling probes of different cutting edge diameters and between the FD and ESM approaches for calculating SOC stocks. The small-diameter PP tended to compact the surface layer of soil, thus giving significantly higher BD measurements than SH and HP. Differences among probes for BD measurements tended to decrease with depth, while difference in SOC increased. This study shows that different probes used for soil core sampling could result in different BD measurements and may affect the calculation of SOC stock when using the FD approach. However, the ESM method reduced differences among mean SOC stocks across different probes such that parity was observed in 90% of the sites.

Sampling equipment is not the only potential source of error in SOC stock measurements. Factors such as gradual versus abrupt (as assumed in linear interpolation) changes in SOC as a function of depth can potentially affect these measurements as well. Measurement of core depth, removing plant residue from the surface before sampling, time of the sampling, selection of the fixed mass to be used, and management history of the land all add to the uncertainties related to quantifying SOC stocks. Although these issues were beyond the scope of this study, further investigation into these factors is needed to improve consistence in SOC stock measurement protocols.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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