Comparison of Sampling Methods Used to Evaluate Forest Soil Bulk Density

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Abstract

*The objective of this study was to compare forest soil bulk density values obtained through conventional sampling methods such as the volumetric ring (VR: diameter 5 cm, length 10 cm) and paraffin sealed clod (PSC), with a variation of the VR, where rectangular boxes (RB) of four different dimensions were used. Sampling transects were established on a machine operating trail located in a beech (*Fagus orientalis *Lipsky) stand in Northern Iran. At each transect, three soil samples were collected at three different locations. Samples from different methods were spaced by a 50 cm distance to avoid direct interactions. The soil class of our study area was Combisols according to the WRB classification with a clay texture. Soil bulk density differed significantly between the three sampling methods. The lowest values were obtained with the RB (average 1.25 g cm^{-3}), followed by the VR (average 1.40 g cm^{-3}), and lastly the PSC (average 1.52 g cm^{-3}). The values obtained with four variations of the RB method ranged from 1.22 to 1.28 g cm^{-3} and were not found significantly different. When soil bulk density was calculated after the removal of the weight and volume of roots included in the samples, the values were determined to be higher than before but with the same range of magnitude. The lowest coefficient of variation was found for RB4 (CV=2.3%), while the highest values were observed for VR and RB1 (CV=5.7%).*

Keywords: paraffin sealed clod, rectangular box, sampling method, soil compaction, volumetric ring

1. Introduction

Forest management practices, such as timber harvesting and off-road timber transportation, have the potential to cause detrimental levels of soil and site disturbances (Kozlowski 1999, Najafi and Solgi 2010, Labelle and Jaeger 2011, Naghdi et al. 2015). The growing mechanization of forest operations combined with higher machine payload increases the magnitude of soil compaction, resulting in a decrease in soil macroporosity (i.e., cavities larger than 0.08 mm in diameter) (Berli et al. 2004, Frey et al. 2009, Solgi et al. 2015a, Solgi et al. 2015b). This decrease, thereby, reduces the rate of exchange of air, water, and solutes (Greacen and Sands 1980, Botta et al. 2007).

In forest operations, the use of dry bulk density as a measure of estimating soil compaction is common (Pires et al. 2005a). Soil dry bulk density is defined as the mass of dry soil particles in a unit volume of soil (Craig 2004). During compaction, solid particles do not change in volume, but are subject to rearrangement, which may be accompanied by bending of clay platelets, changes in the shape of organic matter, and breaking of bonds (Soane and Van Ouwerkerk 1994).

Many studies presented and compared methods to quantify soil bulk density with both modern and conventional sampling procedures (Pires et al. 2005a, Timm et al. 2005). One of the conventional and standard sampling methods used in the majority of studies is the volumetric ring method (Grossman and Reinsch 2002). Standard dimensions and construction material of the volumetric ring are used by some researchers. However, the method is highly dependent upon the specific location where the sample is taken (Lestariningsih et al. 2013). This method is susceptible to error arising from compression and vibrations or shattering of the core, while the cylinder is inserted into the soil profile with external force. According to Pires et al. (2005a), there is a tendency of compaction near the cylinder walls and in the top and the bottom regions of samples taken with the volumetric ring method. Thus, the risk of sample compression increases with decreasing core diameter (Soane and Van Ouwerkerk 1994). Freitag (1971) suggested that the diameter should be selected to give an adequate sample size and that the length should be no more than three times the diameter.

In the forest, trees have high root volumes that occupy the soil space, in particular the topsoil. Under such circumstances, the estimation of bulk density by means of a cylinder is becoming a very difficult process. Parts of tree roots are often included in the core sample, making the sampled soil quantity unsuitable for further analysis. Therefore, a large number of samples must be collected with this method in order to have the required statistical validity of the results, a prerequisite that increases sampling cost.

Another conventional soil sampling method is that of the paraffin sealed clod. In this method, the clod is weighted and its volume is determined by coating it in paraffin wax and immersing it in a volumenometer (Soane and Van Ouwerkerk 1994). The next step includes removal and weighing of the wax. Reliable measurements can be performed especially on cohesive soils, but the method remains time-consuming as care has to be taken to ensure that the wax coats do not penetrate the soil pore system. Van Remortel and Shields (1993) reported that the penetration of some paraffin into the pores of the clods, reduced their measured volume, resulting in higher soil bulk density values.

Apart from the conventional methods, modern methods such as computed tomography and nuclear moisture and density gauge have been introduced to forest soil bulk density measurements (Petrovic et al. 1982, Timm et al. 2005, Labelle and Jaeger 2011). These methods are advantageous in many aspects; the computed tomography provides a detailed analysis of soil bulk density variation along a sample, while the nuclear moisture and density gauge allows for repeated measurements of an identical area without extracting and destructing the soil sample (Timm et al. 2005, Labelle and Jaeger 2011). Despite these important advantages, the cost of this specific equipment can be prohibitive, especially in the case of developing countries and as such the computed tomography and the nuclear moisture and density gauge methods were not targeted during our study. In this view, the rationale behind this research effort was to improve our knowledge on the use of rectangular boxes of different dimensions as an alternative to the widely-used sampling cylinders of the volumetric method. Samples were collected with the volumetric ring, paraffin sealed clod and rectangular box methods, and the respective soil bulk density values were compared with the aim of assisting future research endeavours on the choice of the more appropriate method.

2. Materials and Methods

2.1 Site description

The study was conducted in compartment 41 of the third district of Shenrood forest, Guilan Province, northern Iran (between 36°31′56″ N and 36°32′11″ N latitude and 51°47′49″ E and 51°47′56″ E longitude). The forest is comprised predominantly of oriental beech (*Fagus orientals* Lipsky) with an average canopy cover of 80%, stand density of 170 trees ha^{-1}, mean tree diameter at breast height of 29.7 cm, and mean tree height of 22.9 m. The study area has an elevation of approximately 800 m above sea level and a northerly aspect. The average annual rainfall recorded at the closest national weather station situated about 20 km away from the research site is 970 mm. The maximum mean monthly rainfall of 120 mm usually occurs in October, while the minimum rainfall of 25 mm occurs in August. The mean annual temperature is 15 °C, with the lowest values recorded in February. At the time of skidding, weather conditions were dry and warm with an average soil moisture content of 210 g kg^{-1} (21%). The soil class of our study area in soil classification according to WRB was Combisols. Soil texture in the studied machine operating trail was determined based on particle-size analysis using the Bouyoucos hydrometer method (Kalra and Maynard 1991) and was classified as clay (Table 1).

Table 1 Soil particle size distributions at different depths of the skid trail

Horizon	Depth, cm	Sand, %	Silt, %	Clay, %
A	0–15	26	26	48
B	15–55	23	28	49
C	55–85	21	29	50

The range of particle size in Table 1 was 0.05–2 mm, 0.002–0.05 and <0.002, for sand, silt, and clay, respectively. Soil texture in all three depths was clay.

The soil had not been driven on before the experiment. Ground-based skidding operations were performed with a Timberjack 450 C rubber-tired skidder (Table 2). The rubber-tired skidder was used to extract 3 to 4 m long logs from the felling site to the nearest

Table 2 Technical details of the rubber-tired skidder Timberjack 450 C

Specifications	Timberjack 450C
Weight, kg	10,257
Number of wheels	4
Tire size, mm	775x813
Ground pressure, kPa	221
Engine power, hp	177
Year of manufacture	1998
Manufacturing location	Canada

forest road on machine operating trails in flat terrain. Traffic frequency of the loaded skidder was twelve passes.

2.2 Experimental design and data collection

Soil bulk density was measured with three different methods. The first method of the volumetric ring (hereafter VR) has been extensively used and could be considered as the standard method of soil bulk density measurement. The volumetric ring was made from 1.5 mm thick stainless steel with an inside diameter of 5 cm and a length of 10 cm (Fig. 1).

The second method made use of paraffin sealed clods (hereafter PSC). The sampling procedure in this case consisted of excavating the soil surface down to a depth of 10 cm with a spade. The removed soil clod was wrapped in a plastic film directly after sampling to avoid water loss, and care was taken during the transportation to minimize alterations in the clod structure.

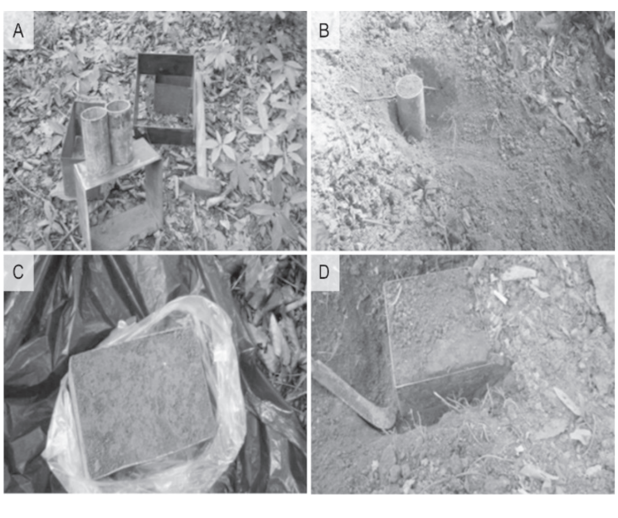

Fig. 1 Different sampling methods used in the study A: Rectangular Boxes and Volumetric Rings; B: Volumetric Rings; C and D: Rectangular Boxes

The third method referred to the use of a rectangular box (hereafter RB) as a means for collecting soil samples. This method resembles the VR, with the exception of the shape of the sampling device (Fig. 1). Four rectangular boxes with different dimensions (RB1: length 20 cm, width 20 cm, height 10 cm, RB2: length 20 cm, width 15 cm, height 10 cm, RB3: length 20 cm, width 10 cm, height 10 cm, and RB4: length 15 cm, width 10 cm, height 10 cm) were used in our study. All rectangular boxes were made from 1.5 mm thick steel. The characteristics of these rectangular boxes are given in Table 3.

Table 3 Inside dimensions of rectangular boxes

Rectangular box	Thickness[a] mm	Length cm	Width cm	Height cm
RB1	1.5	20	20	10
RB2	1.5	20	15	10
RB3	1.5	20	10	10
RB4	1.5	15	10	10

In order to compare the above mentioned methods, a 200 m longitudinal segment was chosen inside the beech stand, along which samples were taken from the soil surface layer (0–10 cm). More specifically, soil samples were collected from eight sampling transects each separated by 25 m and aligned perpendicular to the 200 m long segment. At each transect, 18 samples (three for each method including the different variations of RBs) were collected at three different locations: on the left track, between tracks, and on the right track (Fig. 2). Volumetric ring, clod, and rectangular boxes samples were spaced 50 cm apart to create a buffer zone, thus avoiding possible interactions. A total of 144 soil samples were collected for the analysis.

At the time of sampling (VR and RBs methods), we placed a piece of wood flush on one of the extremity of the rings and boxes and then we inserted those into the soil by hitting the piece of wood with a hammer. Using a piece of wood prevented damaging the top of rings and boxes as to maintain their shape and volume correctly. After extracting the rings and boxes from the soil with minimal disturbance to their contents, the soil samples were trimmed flush with the ring and box end and extruded into plastic bags for transportation to the laboratory. Immediately after sampling, the samples were brought to the laboratory and were

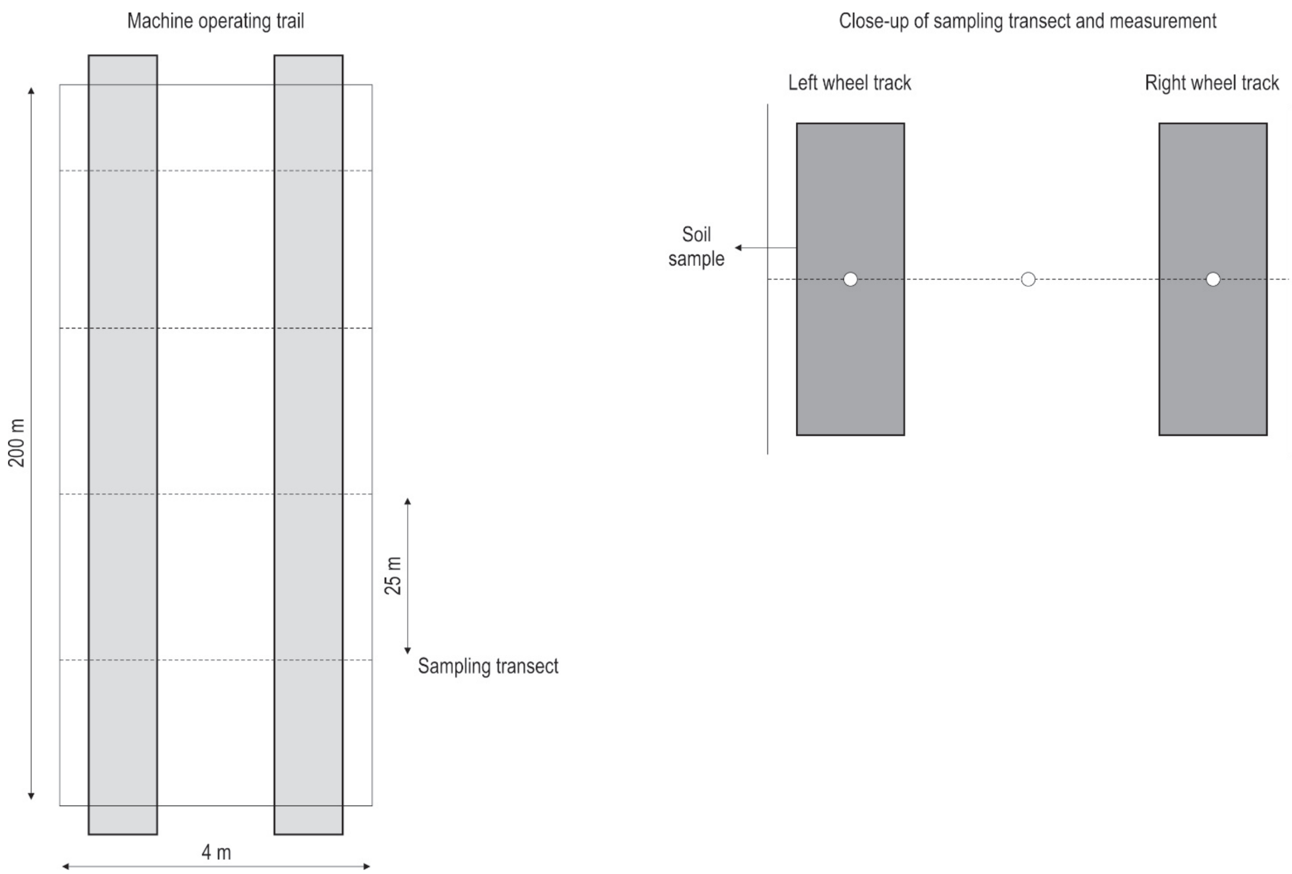

Fig. 2 Schematic of the treatment set-up with the location of sampling transects within the research area

promptly weighed. Soil samples were dried in an oven at 105 ºC (24 h) to obtain the dry weight value. The water content in the soil samples was measured gravimetrically after drying in an oven. However, due to the large amount of wet soil mass in the rectangular boxes, dry soil weight was counted based on a subsampling method in which approximately 300 g of wet soil contained in a rectangular box was measured in the laboratory and oven-dried at 105 ºC (24 h) to obtain the dry weight value (Lestariningsih et al. 2013). For each sample originating from a rectangular box, wet weight and volume of tree roots were determined in a laboratory.

Soil bulk density value from volumetric ring was computed using Eq. (1):

$$\rho_d = \frac{W_d}{V_c} \tag{1}$$

Where:

ρ_d dry bulk density, g cm^{-3}
W_d mass of dry soil, g
V_c volume of soil cores, 196.25 cm^3.

Uncorrected bulk densities from rectangular boxes were computed with Eq. (2):

$$\rho_d = \frac{\left[\frac{(W_t - W_b - W_r)}{(1 + S_{wc})}\right]}{V_t} \tag{2}$$

Corrected bulk densities (for root correction) from rectangular boxes were computed with Eq. (3):

$$\rho_d = \frac{\left[\frac{(W_t - W_b - W_r)}{(1 + S_{wc})}\right]}{(V_t - V_r)} \tag{3}$$

Where:

ρ_d dry bulk density, g cm^{-3}
W_t total mass of rectangular box and soil from the field, g
W_b mass of rectangular box, g
W_r mass of wet root, g
S_{wc} soil water content, g g^{-1}
V_t volume of apparatus, cm^{-3}
V_r volume of roots, cm^{-3}.

Total soil porosity was computed with Eq. (4):

$$AP = \left(1 - \frac{\rho_d}{2.65}\right) \times 100 \qquad (4)$$

Where:

AP total porosity, %

ρ_d dry bulk density (g cm^{-3}), and 2.65 (g cm^{-3}) is the assumed particle density (Najafi et al. 2009).

2.3 Statistical Analysis

Mean values of soil physical properties of each method were compared to those in other methods using Tukey's HSD test (Zar 1999). One-way ANOVA (significance test criterion $\alpha \leq 0.05$), included in the SPSS statistical package version 11.5, was used to compare the soil physical properties among the different methods. Paired *t*-tests were used to analyze soil bulk density data from the »without« and »after« root correction among RBs methods at an α level of 0.05.

3. Results and Discussion

In the context of the study, soil bulk density values were used as indicator of soil compaction in an oriental beech stand. This forest species was chosen because of its importance in the Hyrcanian forest area in Iran, where it covers 16.5% (245 372 ha) of the total forested area and represents approximately 25% of the wood harvested annually (Sagheb Talebi et al. 2014). However, it should be noted that oriental beech has a high density of roots that are located near the soil surface, which increased difficulty during the soil sampling process. The *post-hoc* Tukey test showed that the average values of PSC, VR, and RB differed statistically. However, this was not the case in the RBs, where measurement differences were not statistically significant (Fig. 3). The lowest soil bulk density values were obtained with the RBs in the range of 1.22 to 1.28 g cm^{-3} (average 1.25 g cm^{-3}) and the highest with the PSC method (1.52 g cm^{-3}). The average bulk density value of the VR (1.40 g cm^{-3}) was 11.7% higher than that of RBs and 8.7% lower than that of PSC. This result is in line with Lestariningsih et al. (2013), who also obtained lower soil bulk density values compared to the VR for box dimensions similar to our RB1 configuration. Pires et al. (2004) showed that the VR method induces changes in soil structure during sampling procedures, mainly for small soil samples, causing under- and over-estimated bulk density values. These modifications in bulk density occur due to compaction close to the cylinder walls and, in some cases, at the top and bottom regions of the soil sample. The same problem was observed by Pires et al. (2005b) while working with different soil samplers.

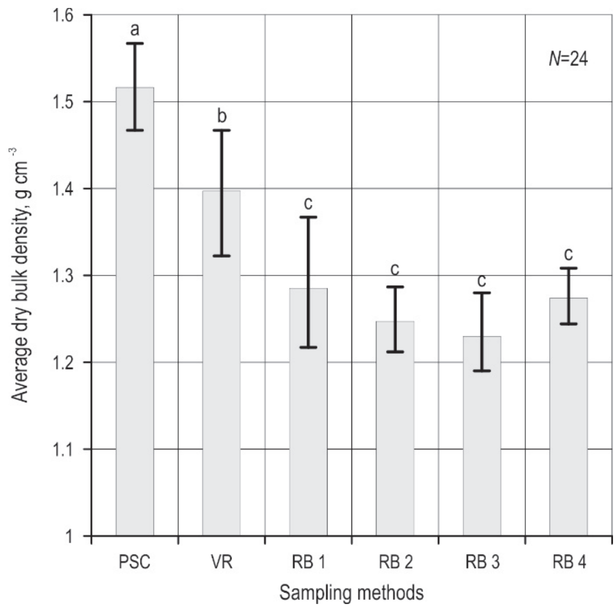

Fig. 3 Comparison of soil dry bulk densities from values determined by different sampling methods (means followed by the same letter are not significantly different at $p=0.05$, error bars indicate standard deviations)

Comparing the sample area can lead to some interesting results. The surface area of VR is 19.63 cm^2, while in the RB method it increases from 150.00 cm^2 (RB4) up to 400.00 cm^2 (RB1). Higher bulk density values in VR could be partly explained by the increased vibration and compression forces associated with this sampling technique and the effect of sampler walls on samples of smaller area. However, this trend has not been verified when comparing the various RB samples. RB1 and RB4 had higher average soil density values than RB2 and RB3. Thus, more research is needed to clarify the reason for this and possibly define the optimum dimensions for the RB method.

The PSC samples were found to be more compacted than those of the VR, confirming the observations made by Van Remortel and Shields (1993) and Timm et al. (2005). Both studies suggest that bulk density obtained with the PSC method are, in general, higher than those collected with the VR method, due to some paraffin penetration into the pores of the clod, causing a reduction of the volume measurement.

In rectangular box methods, when root correction is included (the volume and weight of roots included in the samples were subtracted from the total soil sample size and soil compaction was calculated based on the new data), bulk density values measured with volumetric rings and paraffin sealed clods continue to be higher than those obtained with rectangular boxes

Table 4 Percentage differences between measurements of various RB dimensions, PSC and VR (comparison of soil bulk densities measured with six sampling methods (*N*=24))

		PSC[a]	VR[b]
With root correction	RB1[c]	15.6%	8.3%
	RB2	18.5%	11.5%
	RB3	19.6%	12.7%
	RB4	16.4%	9.2%
Without root correction	RB1	21.1%	14.3%
	RB2	24.3%	17.7%
	RB3	26.2%	19.8%
	RB4	20.8%	13.9%

[a] Paraffin Sealed Clod; [b] Volumetric Ring; [c] Rectangular Boxes

(Table 4). Comparison of the bulk density values by means of the paired sample *t*-test showed that there was a significant difference between bulk density before and after root correction among the same sampling methodologies (Fig. 4). Similar results have been reported by Lestariningsih et al. (2013).

The spatial variability of soil bulk density values, with an error pattern, along the 200 m longitudinal segment for the various sampling methods is present-

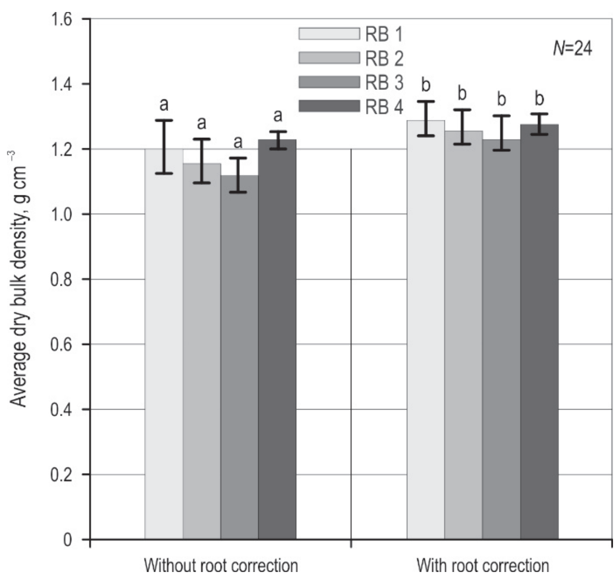

Fig. 4 Average soil dry bulk density before and after root correction for rectangular box methods (means followed by a different letter are significantly different at $p=0.05$, error bars indicate standard deviations)

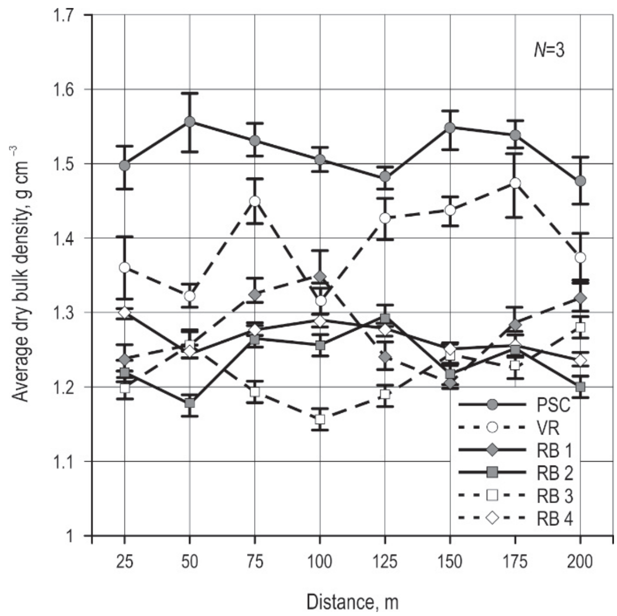

Fig. 5 Distribution of soil dry bulk density values along 200 m longitudinal segment determined by different sampling methods, error bars indicate standard deviations

ed in Fig. 5. Table 5 presents average soil bulk density values determined by each method, the respective standard deviations and coefficients of variation (CV). Soil bulk density values obtained by the RB4 method present the smallest variation in relation to the average value (CV=2.3%), while that obtained by the VR and RB1 methods demonstrated the highest variation (5.7% in both cases). Variation in both methods is at low levels, especially considering the sample size. Statistical analysis revealed that standard deviation value was significantly different between samples from different methods with $p<0.05$. Standard deviation of soil

Table 5 Average soil bulk density values determined by the six different methods and respective standard deviations and coefficients of variation (*N*=24)

Methods	Dry bulk density g cm^{-3}	Standard deviation g cm^{-3}	Coefficient of variation %
PSC	1.52^{a}	0.04	2.6
VR	1.39^{b}	0.08	5.7
RB1	1.28^{c}	0.07	5.7
RB2	1.23^{c}	0.06	4.8
RB3	1.22^{c}	0.06	4.9
RB4	1.27^{c}	0.03	2.3

bulk density values from VR was higher than PSC and RB1 values indicating a larger heterogeneity in the VR samples. This larger heterogeneity could have been induced during the sampling procedure through modifications in soil structure caused by a limited volume of soil sample inside the cylinders, as shown by Pires et al. (2004).

Also, our results showed that the standard deviation of soil bulk density values from the PSC samples were equal to those obtained with the RB1 method. Our finding is similar to that of Timm et al. (2005), who reported a coefficient of variation of 5.9% for soil density values obtained with the volumetric ring method.

Soil bulk density values were obtained for each method using Eq. (4), since for the PSC and VR methods the bulk density values were higher, and consequently the total porosity estimates along the segment were smaller (on average 35% and 46%, respectively). The highest total soil porosity values were obtained with the RBs in the range of 51.76% to 54.27% (on average 52.85%) and the lowest with the PSC method (35.52%), which, according to Kiehl (1979), is within the range of mineral soil porosity variations, usually from 40% to 60%. The average total soil porosity value of the VR (46.13%) was 14.6% lower than that of RBs and 29.8% higher than that of PSC, respectively. This fact shows the importance of the choice of the method for the determination of soil bulk density.

4. Conclusion

In our study, we compared the well-established method of volumetric ring to that of paraffin sealed clod and four rectangular boxes of varying dimensions under forest conditions. Statistical differences in soil dry bulk density have been found between the three general methods but not among the four rectangular boxes, indicating substantial differences between the three general methods. While the volumetric ring is the most commonly used methodology and is supported by a large amount of international literature, there is evidence that it can overestimate soil dry bulk densities due to increased compaction and vibrations during the sampling process, in particular with smaller-sized cylinders.

The rectangular box method yielded promising results when used in the conditions (soil texture, water content and root size/density) observed at our study site. However, these results need to be tested in other conditions, such as different soil texture, soil moisture content, soil depth and soil organic matter content, before drawing general conclusions or giving recommendations.

5. Reference

Berli, M., Kulli, B., Attinger, W., Keller, M., Leuenberger, J., Flühler, H., Springman, S.M., Schulin, R., 2004: Compaction of agricultural and forest subsoils by tracked heavy construction machinery. Soil Till Res 75(1): 37–52.

Botta, G., Pozzolo, O., Bomben, M., Rosatto, H., Rivero, D., Ressia, M., Tourn, M., Soza, E., Vazquez, J., 2007: Traffic alternatives in harvest of soybean (Glycine max L.): effect on yields and soil under direct sowing system. Soil Till Res 96(1–2): 145–154.

Craig, R.F., 2004: Soil Mechanics. Seventh edition. Spon press. British Library Cataloguing in Publication Data, 95 p.

Freitag, D.R., 1971: Methods of measuring soil compaction. In: K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton and G.E. Vanden Berg (Editors), Compaction of Agricultural Soils. Am. Soc. Agric. Eng., St. Joseph, MI, USA, 47–103.

Frey, B., Kremer, J., Rüdt, A., Sciacca, S., Matthies, D., Lüscher, P., 2009: Compaction of forest soils with heavy logging machinery affects soil bacterial community structure. Eur J Soil Biol 45(4): 312–320.

Greacen, E.L., Sands, R., 1980: Compaction of forest soils: a review. Aus J Soil Res 18(2): 163–189.

Grossman, R.B., Reinsch, T.G., 2002: Bulk density and linear extensibility. In: Dane JH, Topp C, Co-editors. Method of soil analysis part 4 physical methods, Madison, Wisconsin: Soil Sci Soc Am Inc, 201–228.

Jourdan, C., Rey, H., 1997: Architecture and development of the oil-palm (*Elae isguineensis* Jacq.) root system. Plant Soil 189(1): 33–48.

Kalra, Y.P., Maynard, D.G., 1991: Methods and manual for forest soil and plant analysis. Forestry Canada, Re NOR-X-319. Northern Forestry Center, 125 p.

Kiehl, E.J., 1979: Manual de edafologia. São Paulo: Agronômica Ceres, 262 p.

Kozlowski, T.T., 1999: Soil compaction and growth of woody plants. Scand J For Res 14(6): 596–619.

Labelle, E.R., Jaeger, D., 2011: Soil compaction caused by cut-to-length forest operations and possible short-term natural rehabilitation of soil density. Soil Sci Soc Am J 75(6): 2314–2329.

Lestariningsih, I.D., Widianto, K.H., 2013: Assessing soil compaction with two different methods of soil bulk density measurement in oil palm plantation soil. Proc Environ Sci 17: 172–178.

Naghdi, R., Solgi, A., Zenner, E.K., 2015: Soil Disturbance Caused by Different Skidding Methods in North Mountainous Forests of Iran. Inter J For Eng 26(3): 212–224.

Najafi, A., Solgi, A., Sadeghi, S.H., 2009: Soil disturbance following four-wheel rubber skidder logging on the steep trail in the north mountainous forest of Iran. Soil Till Res 103(1): 165–169.

Najafi, A., Solgi, A., 2010: Assessing site disturbance using two ground survey methods in a mountain forest. Cro J For Eng 31(1): 47–55.

Pires, L.F., Arthur, R.C.J., Camponez Do Brasil, R.P., Correchel, V., Bacchi, O.O.S., Reichardt, K., 2004: The use of gamma ray computed tomography to investigate soil compaction due to core sampling devices. Braz J Phys 34(3A): 728–731.

Pires, L.F., Pilotto, J.E., Timm, L.C., Bacchil, O.O.S., Reichardt, K., 2005a: Qualitative and quantitative analysis of soil samples by computerized tomography. Publ UEPG Ci Exatas Terra Ci Agr Eng Ponta Grossa 11(2): 7–15.

Pires, L.F., Arthur, R.C.J., Bacchil, O.O.S., 2005b: Assessment of soil sample quality used for density evaluations through computed tomography, International Nuclear Atlantic Conference – INAC 2005, Santos, SP, Brazil, August 28 to September 2, 5 p.

Sagheb Talebi, K., Sajedi, T., Pourhashemi, M., 2014: Forests of Iran a treasure from the past, a hope for the future. Plant and Vegetation. Volume 10. ISBN 978-94-007-7370-7 (Print) 978-94-007-7371-4 (Online), 143 p.

Soane, B.D., Van Ouwerkerk, C., 1994: Soil Compaction in Crop Production. Developments in Agricultural Engineering Series, vol. 11. Elsevier Science, Amsterdam, Netherlands, 643 p.

Solgi, A., Naghdi, R., Tsioras, P.A., Nikooy, M., 2015a: Soil compaction and porosity changes caused during the operation of Timberjack 450C skidder in northern Iran. Cro J For Eng 36(2): 77–85.

Solgi, A., Naghdi, R., Nikooy, M., 2015b: Effects of skidder on soil compaction, forest floor removal and rut formation. Madera y Bosques 21(2): 145–153.

Petrovic, A.H., Siebert, J.E., Lieke, P.E., 1982: Soil bulk density analyses in three dimension by computed tomographic scanning. Soil Sci Soc Am J 46(3): 445–450.

Timm, L.C., Pires, L.F., Reichardt, K., Roveratti, R., Oliveira, J.C.M., Bacchi, O.O.S., 2005: Soil bulk density evaluation by conventional and nuclear methods. Aust J Soil Res 43(1): 97–103.

Van Remortel, R.D., Shields, D.A., 1993: Comparison of clod and core methods for determination of soil bulk density. Commun Soil Sci Plant Ana 24(17–18): 2517–2528.

Zar, J.H., 1999: Biostatistical analysis, 4th edition, Prentice Hall, Upper Saddle River, NJ, USA, 662 p.

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