Revista Ciência Agronômica, v. 50, n. 1, p. 27-37, jan-mar, 2019
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Use of PVC pipes to determine bulk density for irrigation management[1]

Uso de tubo PVC para determinação da densidade do solo visando o manejo da irrigação

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ABSTRACT - Irrigation has a great importance in the production of food, and it is responsible for consuming a large part of the water used by human activities. This makes the rational management of water use fundamental for sustainable food production. For this purpose, the determination of bulk density is important and needs to be obtained with the simplest, least onerous methods possible, while maintaining precision and accuracy. Therefore, the objective of this work was to evaluate the use of PVC pipes of different dimensions to determine bulk density. For comparison purposes, the volumetric ring, paraffin clod, beaker and excavation methods were also used. Deformed and undisturbed soil samples of different granulometries were collected at the depths of 0.025-0.075, 0.050-0.100, 0.075-0.125 and 0.100-0.150 m. The PVC pipes had diameters of 0.040, 0.050, 0.060 and 0.075 m and heights of 0.10, 0.15, 0.20 and 0.25 m. The bulk density results for each PVC pipe dimension were compared with those of the traditional methods by the unpaired t-test at 5% significance. For soils with a clayey or very clayey texture, the 0.040 m diameter and 0.15 m high PVC pipe presented the best results, with values closer to those of the standard method. For soils with a medium and sandy texture, the best results were found when a PVC pipe with a diameter of 0.060 m and a height of 0.15 m was used.

Key words: Water use. Irrigated agriculture. Soil management.

RESUMO - A irrigação tem grande importância para a produção de alimentos, sendo responsável por consumir grande parcela da água usada nas atividades humanas. Isto torna fundamental o manejo racional do uso da água. Para tal, a determinação da densidade do solo é importante e precisa ser realizada de forma simples e menos honerosa possível, mantendo-se a precisão e exatidão. Desta forma, o objetivo deste trabalho foi avaliar o uso de tubos de PVC de diferentes dimensões para determinação da densidade do solo. Para comparação, foram utilizados também os métodos do anel volumétrico, torrão parafinado, proveta e escavação. Amostras deformadas e indeformadas de solos de diferentes granulometrias foram coletadas nas profundidades de 0,025-0,075; 0,050-0,100; 0,075-0,125 e 0,100 a 0,150 m. Os tubos de PVC utilizados tinham diâmetros de 0,040; 0,050; 0,060 e 0,075 m e alturas de 0,10; 0,15; 0,20 e 0,25 m. Os resultados da densidade do solo de cada dimensão de tubo de PVC foram comparados com os dos métodos tradicionais pelo teste t não pareado, a 5% de significância. Para solos de textura argilosa ou muito argilosa, o tubo de PVC de 0,040 m de diâmetro e 0,15 m de altura foi o que apresentou os melhores resultados, com valores mais próximos ao método padrão. Já para solos de textura média e arenosa, os melhores resultados foram encontrados quando se utilizou o tubo de PVC de 0,060 m de diâmetro e 0,15 m de altura.

Palavras-chave: Uso da água. Agricultura irrigada. Manejo do solo.

DOI: 10.5935/1806-6690.20190004
*Author for correspondence
Received for publication on 26/05/2017; approved on 22/05/2018

[1]Parte da Dissertação do primeiro autor apresentada ao Programa de Pós-Graduação em Engenharia Agrícola da Universidade Federal de Viçosa/UFV, Viçosa-MG, Brasil

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INTRODUCTION

Soil is one the key factors supporting agricultural production, and its inadequate management can result in changes in chemical, physical and biological properties. From the physical point of view, bulk density is one of the most widely used attribute to change the quality of soil use and management systems (GUEDES *et al*., 2012; PIRES; ROSA; TIMM, 2011; XU; HE; YU, 2016). Among the many attributes that interfere with soil irrigation management and plant growth, bulk density can be considered the most important, and it is very important to determine bulk density in irrigation and drainage projects. Bulk density is affected by compaction degree, soil structure (JORGE *et al*., 2012; STEFANOSKI *et al*., 2013; VASCONCELOS *et al*., 2010), management and crop types (LIMA *et al*., 2013; MENDONÇA *et al*., 2013; VASCONCELOS *et al*., 2014).

The available water in the soil is the amount of water between the field capacity and wilting point. To determine this amount, the humidity values at the field capacity and wilting point are estimated from the soil water retention characteristic curve. The soil water retention capacity is the effect of management practices and the soil textural composition, mineralogy, organic matter content, and structure; the final property, structure, is the most important and can be evaluated by bulk density (LI *et al*., 2016; LOSS *et al*., 2009; MARTINS *et al*., 2009).

Studies investigating bulk density determination methods have shown there are disadvantages to the use of the volumetric ring method, which is considered the standard method (GROSSMAN; REINSCH, 2002), and have reported uncertainties in the determination of bulk density by this method due to the possibility of soil compaction at the time of sampling (PIRES; ROSA; TIMM, 2011).

To facilitate the collection of soil samples by farmers, it is necessary to develop new sampling techniques to determine bulk density, such as the use of PVC pipes. This technique was developed to support the use of an irrigameter (OLIVEIRA; RAMOS, 2008), equipment used in irrigation management.

Bulk density values are used to scale or calibrate the different equipment and/or software used for irrigation management. However, it is important to use simple sampling methods that do not incur high costs to determine bulk density, so that farmers can perform the sampling procedure. It is worth noting that the possible benefit of using the PVC method is that it can collect undisturbed samples of soils with different textures, while taking advantage of materials commonly found in rural areas at an affordable cost. Thus, the aim of this work was to evaluate the use of PVC pipes with different dimensions for the determination of bulk density and to compare the PVC method with traditional methods for bulk density measurements.

MATERIAL AND METHODS

Soil samples were collected in three areas with soils of different granulometries (Tables 1 and 2):

a) Soil of very clayey texture collected in the Experimental Irrigation and Drainage Area of the Federal University of Viçosa, which is located in the municipality of Viçosa-MG, with geographical coordinates of 20°46’05” S and 42°51’44” W and an altitude of 651 m. The climate of the region, according to the Köppen classification, is “Cwa”, a subtropical climate with a rainy summer and dry winter. The soil sampled is an Red-Yellow Ultisol (CONTIN, 2008). The soil was under a coffee crop in the fruiting phase at the time of collection.

b) Soil of sandy loam texture collected in an area near the intersection of BRs 040 and 365, which is located in the municipality of João Pinheiro-MG, with geographical coordinates of 18°00’43” S and 45°37’02” W and an altitude of 752 m. The regional climate is Aw, which is characterized by well-defined dry and rainy seasons. The soil sampled is a Red-Yellow Oxisol, typical A moderate (NUNES *et al*., 2004). At the time of collection, the soybean crop had just been harvested.

c) Soil of sandy texture collected 50 km from the municipality of Jaiba-MG, with the geographical coordinates of 14°53’14” S and 43°55’08” W and an altitude of 456 m. The regional climate is tropical, alternately dry and humid, and the soil sampled is a Fluvisol (REIS *et al*., 2015) under early-stage pumpkin cultivation.

The soil water retention curves are shown in Figure 1. The curves were adjusted by the Van Genuchten equation using SWRC software (DOURADO NETO *et al*., 2001).

The bulk density determination was performed using the PVC pipe (PVC), volumetric ring (Ring), paraffin clod (Clod) and excavation (Exc) methods, with undisturbed samples, and the beaker method (Beaker), with deformed samples. With the exception of the PVC pipe, all other methods used are described in Embrapa (2011). To determine bulk density with the Ring method, sampling was performed at depths of 0.025-0.075, 0.050-0.100, 0.075-0.125 and 0.100-0.150 m. For each type of soil and depth, ten replications were performed. For the Clod method, clods were collected at the above-listed

Table 1 - Results of the granulometric analysis of different soil samples

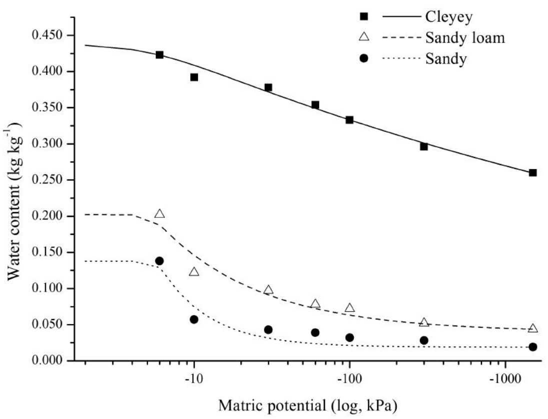
Sampled soil	Coarse sand	Thin sand	Silt	Clay	Textural class
	---------- kg kg^{-1} ----------				
Red-Yellow Ultisol	0.142	0.087	0.159	0.612	Very clayey
Red-Yellow Oxisol	0.437	0.396	0.035	0.132	Sandy loam
Fluvisol	0.526	0.367	0.052	0.055	Sandy

Table 2 - Physical characteristics related to the structure of the sampled soils

Textural class	Pd[1] g cm^{-3}	TP[2]	Ma[3]	Mi[4]	Ko[5] cm h^{-1}
		---------- m^3 m^{-3} ----------			
Very clayey	2.45	0.526	0.088	0.439	3.302
Sandy loam	2.61	0.473	0.157	0.316	5.226
Sandy	2.61	0.404	0.143	0.262	7.358

[1.]Particle density; [2.]Total porosity (TP = 1 - Sd/Pd); [3.]Macroporosity; [4.]Microporosity; [5.]Hydraulic conductivity

Figure 1 - Soil water retention curves adjusted for clayey, sandy loam and sandy soils



depths, with ten replicates per depth. In this work, the Clod method was used only in the evaluation of very clayey soil. For sandy and sandy loam soils, when it was not possible to use the Clod method, the Beaker method was used.

It should be noted that the depths sampled by the volumetric ring, paraffin clod, excavation and beaker methods correspond to half the lengths used for the PVC pipe method, since the profiles of the studied soils had a homogeneous structure.

The bulk density measurements by the PVC method were obtained by preaching the pipe until the upper edge was at the same level as the soil surface. The upper edge of the PVC pipe was sealed with tape and excavated laterally, allowing access to its lower end. With a spatula, the area around the pipe was cleaned by removing the soil on the external walls of the pipe. The bottom of the pipe was also sealed with adhesive tape to prevent soil loss. The PVC pipes used in the work were brown and had nominal diameters of 0.040, 0.050, 0.060 and 0.075 m, denominated by the names PVC 40, PVC 50, PVC 60 and PVC 75, respectively, and thicknesses, according to the diameter, of 0.0050, 0.0067 and 0.0087 m, respectively. The heights of the PVC pipes were 0.10, 0.15, 0.20 and 0.25 m, and the pipes were bevelled on one side to facilitate penetration into the soil. The samples were collected with soil moistures close to the field capacity.

In the laboratory, the samples were transferred from the pipes to aluminum containers, dried in a forced circulation oven at 105 ºC for a minimum of 24 hours and then weighed. Bulk density was obtained by the ratio of dry soil mass to the total internal volume of the PVC pipe.

The determination of bulk density by the Clod method was performed by collecting clods with variable volumes, which were air dried and waterproofed in liquid paraffin, according to the method of Embrapa (2011). The clod volume was determined by the volume of water displaced when the clod was immersed. Bulk density was calculated by the ratio of the dry soil mass to the clod volume.

Bulk density was obtained by the Beaker method according to the methodology described by Embrapa (2011). Deformed soil samples were taken at the depths listed above, dried in a forced air circulation oven at 105 °C for 24 h and sieved with a mesh of 0.002 m. Bulk density was calculated by the ratio of the dry soil mass to the Beaker volume.

For the determination of bulk density via the Ring method (standard method), the undisturbed soil samples were collected with stainless steel rings with a diameter and height of approximately 0.05 m, which had been spiked into the soil with the aid of an Uhland soil sampler. Bulk density was calculated by the ratio of the dry soil mass to the Ring volume.

The excavation method with the volumetric ring, hereafter called the excavation method (EXC), is an adaptation of the volumetric ring method that was used in order to obtain soil samples with a minimal disturbance to their natural structure. In this method, the deformation of the samples due to collection errors is minimized, thus providing greater credibility in terms of the accuracy of the obtained results. The collection of the samples was conducted in the laboratory, after the collection of soil blocks in the field with dimensions of 0.30 x 0.30 x 0.20 m, in accordance with all procedures described in ABNT NBR-9604, which were proposed for the collection of clods in order to preserve soil structure.

A Kopeck ring of known diameter and height was placed on the soil block, and the soil was excavated around the cylinder, without exerting pressure on the ring, to avoid compaction and to adjust the soil throughout its volume.

The comparison of the obtained results was performed by the unpaired t-test at 5% significance. The comparison of the bulk density measurements from the Ring, Clod and PVC methods was performed by comparing Ring and Clod samples from depths of 0.025-0.075, 0.050-0.100, 0.075-0.125 and 0.100-0.150 m with PVC samples from pipes of 0.10, 0.15, 0.20 and 0.25 m in height, respectively, as the soil profile was considered homogeneous.

RESULTS AND DISCUSSION

Very clayey soil

The bulk density values obtained by the EXC and PVC methods, for the different pipe diameters and the depths of 0.10, 0.15 and 0.20 m, generally did not differ significantly (Figure 2). The bulk density measurements of the EXC method ranged from 1.02 to 1.05 g cm^{-3}, while those of the PVC method ranged from 0.93 to 1.09 g cm^{-3}. It is noteworthy that only three depths were sampled for the EXC method, due to limitations imposed by the height of the collected block.

The difference between the mean bulk density values determined by the EXC and PVC methods was low (1.5%), indicating that the procedure adopted for the PVC pipe method prevented sample compaction, since there is no possibility of compaction in the EXC method.

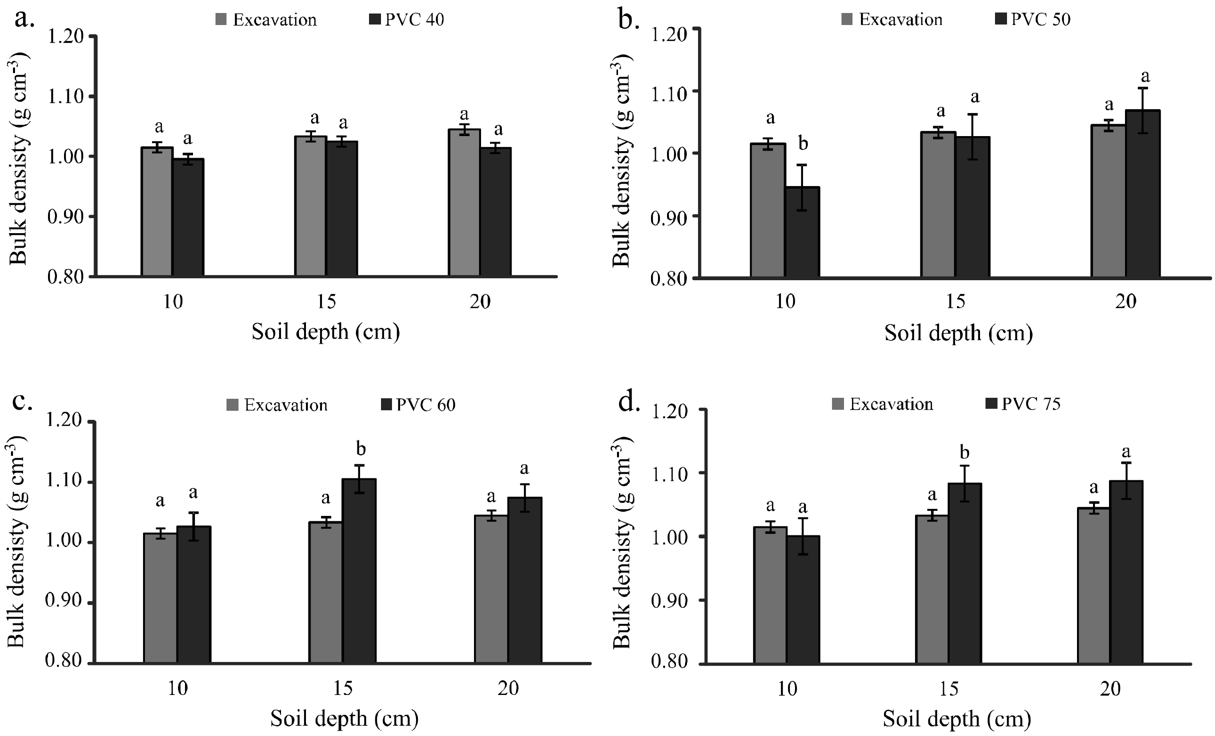
The bulk density values obtained by the Ring and PVC methods (Figure 3) at the four depths evaluated presented significant differences. The highest mean density was 1.13 g cm^{-3} for the Ring method, while the highest mean density was 1.04 g cm^{-3} for the PVC method. It is possible that the use of PVC, with thick walls that can withstand blows during its introduction into the soil, causes a greater destructuring of the sample, thus reducing the value of bulk density. However, the densities are within the range usually reported by the literature for clayey soils, with values ranging from 1.11 to 1.16 g cm^{-3} using a volumetric ring (GONÇALVES *et al*., 2013).

The Ring and PVC methods showed a gradual increase in bulk density with increasing depth (Figure 3), corroborating the results of Reichert *et al*. (2009), in which the bulk density was higher in the layer from 0.10 to 0.15 m depth compared to the layer from zero to 0.05 m depth under different soil management systems. Tavares *et al*. (2012) reports that bulk density generally increases with profile depth, because the pressure exerted by the upper layer on the underlying layers causes densification phenomenon, thus reducing porosity. The movement of thinner material from the upper to lower horizons, by elution, also contributes to reducing porous spaces and increasing bulk density with depth (TAVARES *et al*., 2012).

The fact that the Ring method presented higher values than the PVC method can be justified by the possible soil compaction in the sampling process. Blake and Hartge (1986) corroborate this analysis, stating that probable compaction occurs by soil-ring friction when the ring penetrates the soil. In this respect, the PVC method presents advantages, since, even though compacting may occur, it is minimized because the volume used to calculate the bulk density is the total volume of the PVC pipe, not the volume based on the soil height inside the pipe, since the PVC pipe may not be completely filled (Figure 4).

The comparison of the bulk density results obtained by the Clod and PVC methods showed significant differences for all the diameters and depths sampled (Figure 5). The higher soils density values

Figure 2 - Bulk density determined by the excavation (EXC) and PVC pipe (PVC) methods for very clayey soil: a) EXC and PVC 40; b) EXC and PVC 50; c) EXC and PVC 60; and d) EXC and PVC 75



Columns followed by same letter, for each depth, do not differ by Student´s t-test at 5% significance

Figure 3 - Soil density determined by the volumetric ring (Ring) and PVC pipe (PVC) methods for very clayey soil: a) Ring and PVC 40; b) Ring and PVC 50; c) Ring and PVC 60; and d) Ring and PVC 75

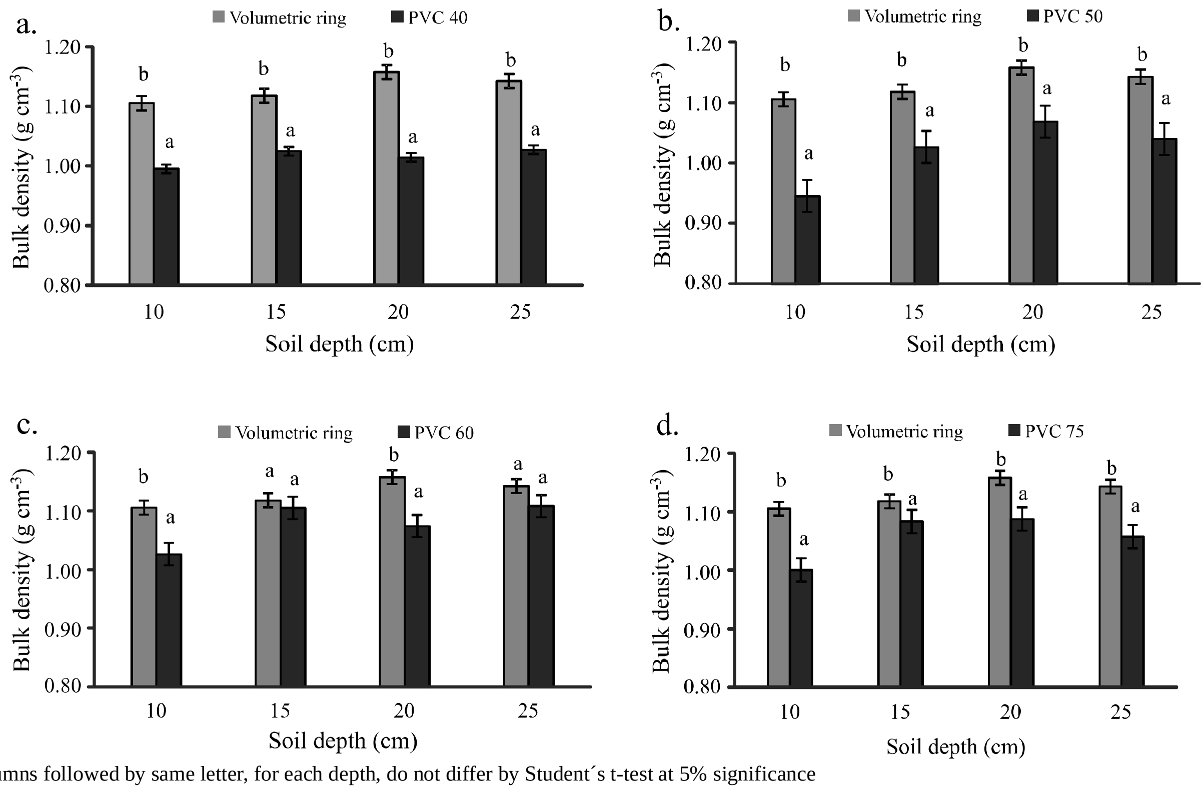


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Figure 4 - Soil sampling through the PVC pipe method: a) no soil compaction and b) soil compaction

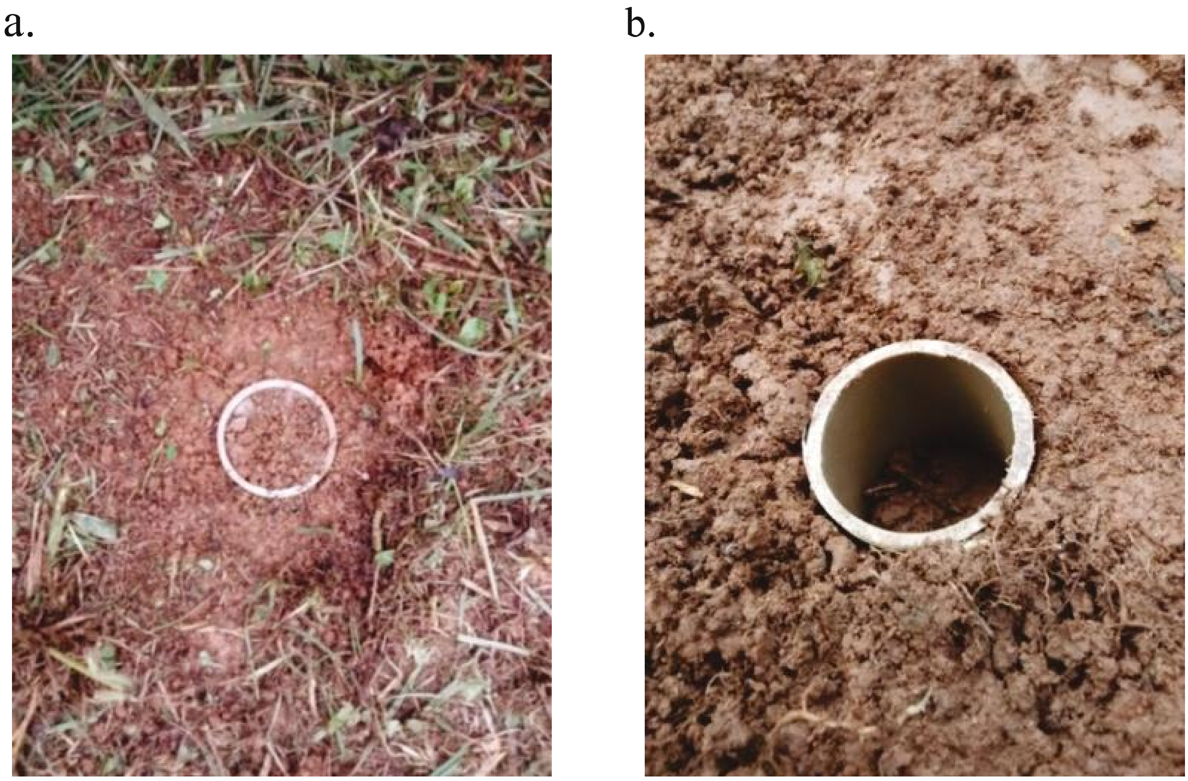
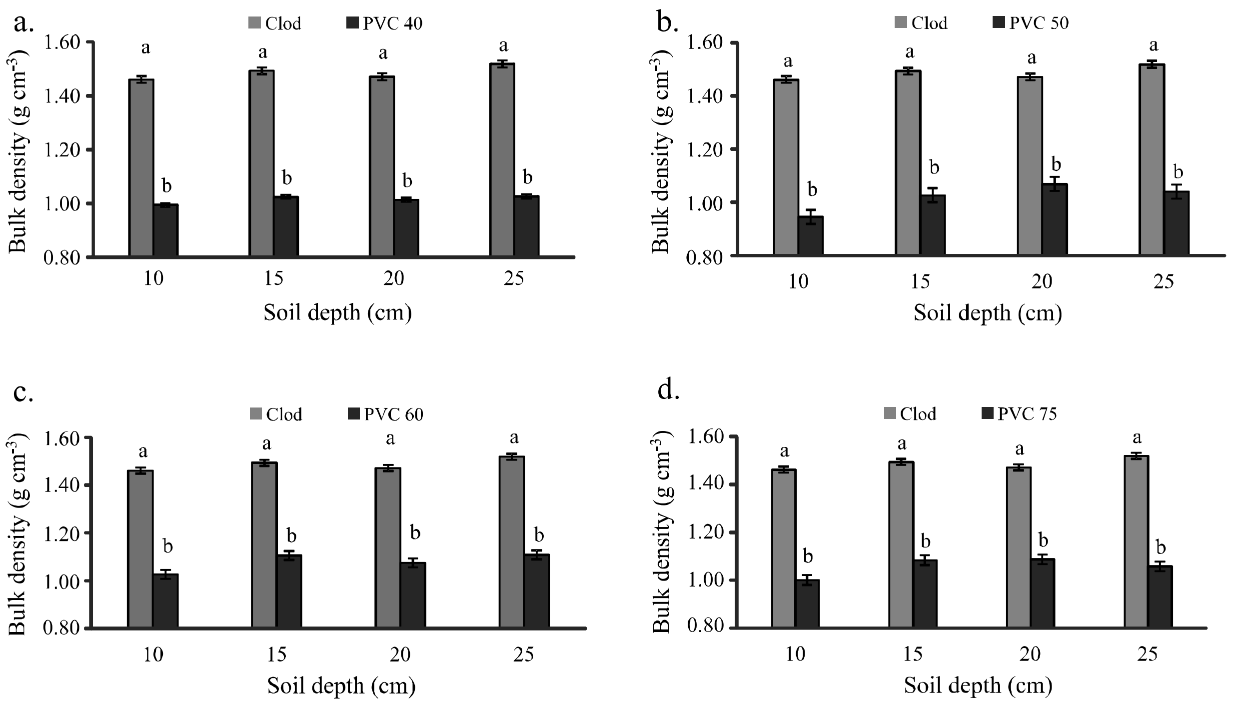


Figure 5 - Bulk density determined by the paraffin clod (PC) and PVC pipe (PVC) methods for very clayey soil: a) Clod and PVC 40; b) Clod and PVC 50; c) Clod and PVC 60; and d) Clod and PVC 75



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obtained by the Clod method may be associated with the segregation, at the moment of the collection, of the clods in soils that were mobilized, resulting in higher density values, since existing macropores between the clods are disregarded (SILVA; REICHERT; REINERT, 2000). The bulk density values determined by the Clod method ranged from 1.43 to 1.52 g cm^{-3}, while the soil densities derived via the PVC pipe method varied from 0.93 to 1.11 g cm^{-3}.

The results found by the EXC and Ring methods, at three depths (Figure 6a), showed significant differences. The bulk density values obtained by the volumetric ring method were always higher than those obtained by the EXC method. In terms of amplitude, the soil densities measured by EXC ranged from 1.02 to 1.05 g cm^{-3}, whereas those measured by Ring ranged from 1.11 to 1.15 g cm^{-3}. In the same way, the bulk density values obtained by the Clod method were significantly different from those obtained by the Ring method (Figure 6b). Pires, Rosa and Timm (2011) also observed that the paraffin clod method obtained higher density values than the volumetric ring method in Nitossolo Vermelho Eutrófico soil under conventional management. Klein (2010) also observed higher values of bulk density by the paraffin clod compared than by the volumetric ring method. The bulk density ranged from 1.02 to 1.05 g cm^{-3} for the EXC method, from 1.11 to 1.15 g cm^{-3} for the Ring method and from 1.43 to 1.52 g cm^{-3} for the Clod method.

Silva, Reichert and Reinert (2000) compared the paraffin clod and volumetric ring methods for surface samples of an Argissolo Vermelho Distrófico Arênico soil, with differences of 0.14 g cm^{-3} between the two methodologies. The authors emphasized that comparisons should be avoided between management systems that use different methods to determine bulk density. For Pires, Timm and Rose (2011), the density values obtained by the paraffin clod method were generally 0.15 g cm^{-3} higher than those obtained by the Ring method. The values found by the Clod method in this study were, on average, 0.35 g cm^{-3} higher than those found by the Ring method (Figure 6).

Even if the PVC pipe 0.040 m in diameter and 0.15 m in height had yielded the best results, the other PVC pipes could also be used; however, they sample a greater volume of soil, making it more difficult to handle the material.

Sandy and sandy loam soils

The bulk density values determined with the Ring and PVC methods in the sandy soil samples were highly variable. The soil densities measured by the Ring method ranged from 1.43 to 1.63 g cm^{-3}, while those measured by the PVC method ranged from 1.45 to 1.70 g cm^{-3}.

The bulk density value determined by the 0.060 m PVC pipe (PVC 60) was the most similar to that determined by the Ring method, evidencing a significant difference only at the depth of 0.15 m (Figure 7). It is important to note that the highest values of bulk density were observed at the greatest depths. This is due to the low concentration of organic matter and the effect of densification. Some authors report that plant roots have the capacity to increase the amount of pores in the soil, improving its physical quality and directly influencing the density and porosity of the soil at the surface (MENDONÇA *et al*., 2013; VASCONCELOS *et al*., 2014).

Figure 6 - Bulk density determined by the volumetric ring (Ring), excavation (EXC) and paraffin clod (Clod) methods for very clayey soil: a) EXC and Ring; and b) Clod and Ring

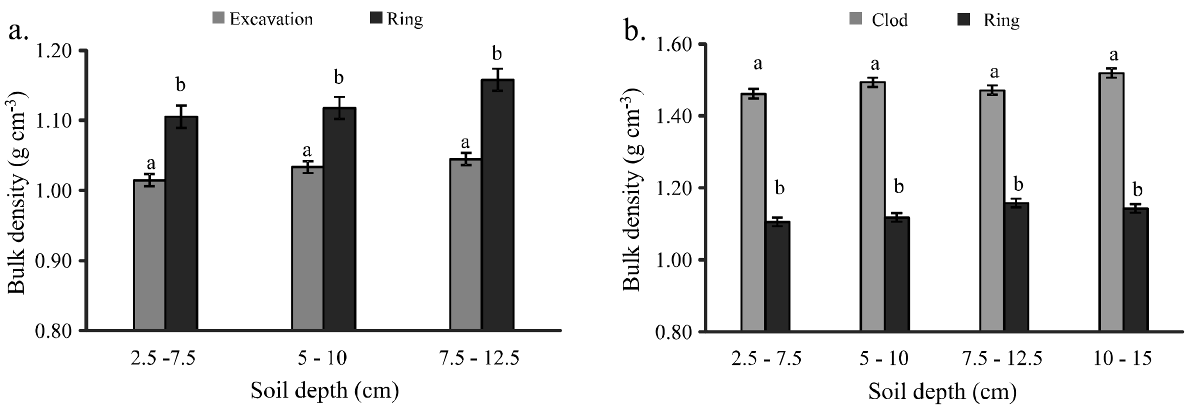

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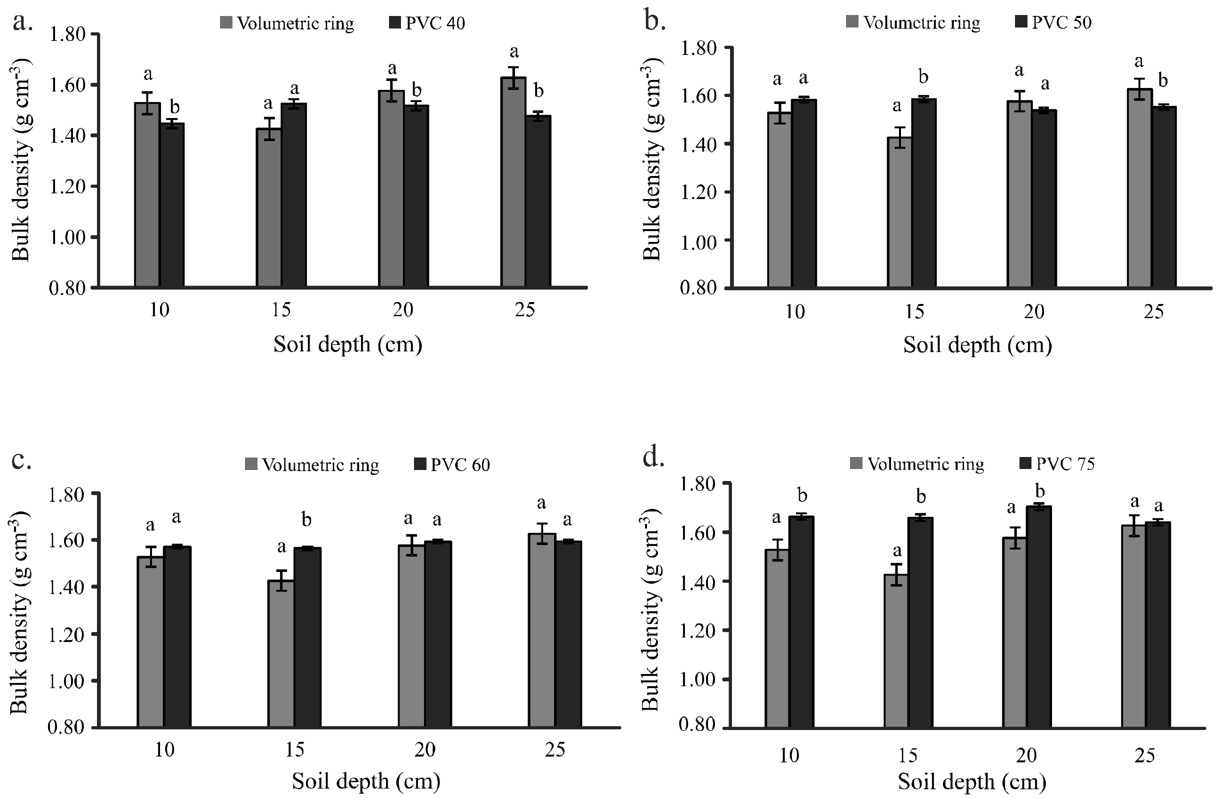
Figure 7 - Bulk density determined by the volumetric ring (Ring) and PVC pipe (PVC) methods for sandy soil: a) Ring and PVC 40; b) Ring and PVC 50; c) Ring and PVC 60; and d) Ring and PVC 75



Columns followed by same letter, for each depth, do not differ by Student´s t-test at 5% significance

For the soil of João Pinheiro (Figure 8), with sandy loam texture, similar behavior was observed. There was underestimation of the bulk density by the PVC method with the use of diameters of 0.040 and 0.050 m in comparison to the Ring, therefore PVC pipes with these dimensions are not recommended. This effect was minimized as the pipe diameter increased (0.060 and 0.075 m). Bulk density by the Ring method ranged from 1.59 to 1.77 g cm^{-3}, while in the PVC method the variation was 1.44 to 1.63 g cm^{-3}.

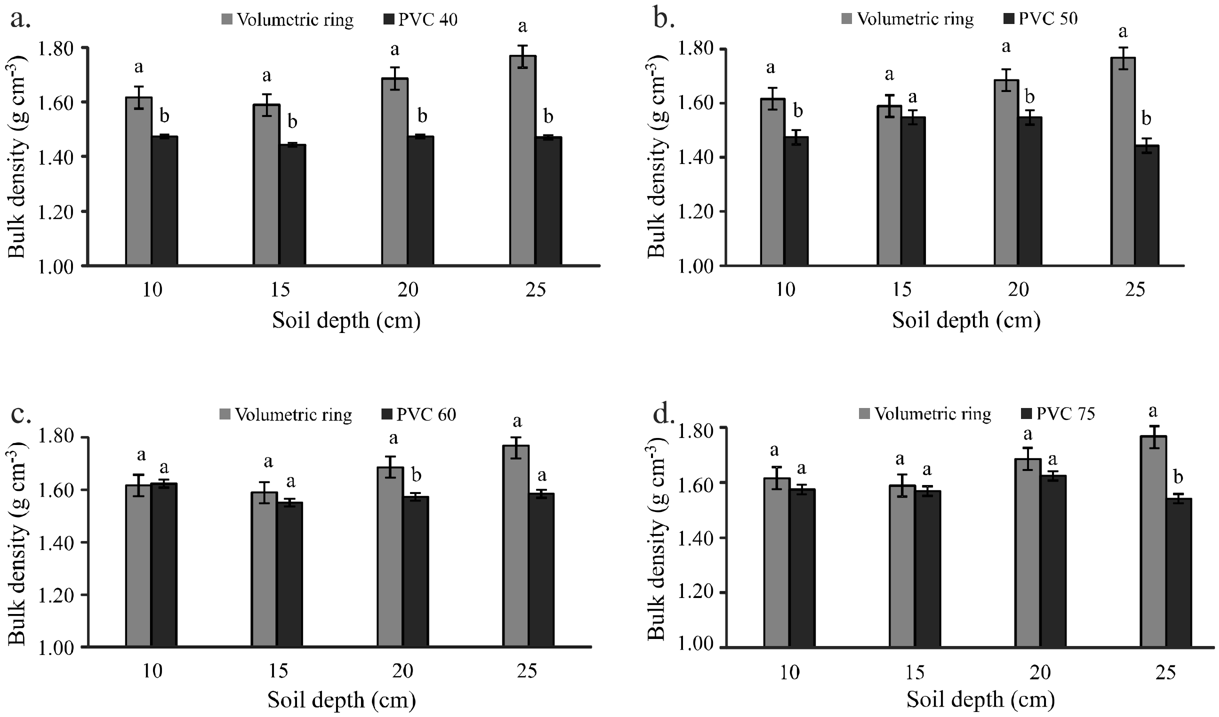
Generally, the bulk density values obtained by the Beaker and PVC methods for sandy soil did not differ significantly when the 0.040 m diameter pipe was used. There were significant differences between the Beaker PVC methods results when pipes with diameters greater than 0.040 m were used (Figure 9). This indicates that the PVC method overestimated the bulk density. The bulk density estimated by the Beaker method ranged from 1.43 to 1.49 g cm^{-3}, while that estimated by the PVC method ranged from 1.44 to 1.69 g cm^{-3}.

The same behavior was observed for the sandy loam soil samples, where the Beaker method underestimated the bulk density (Figure 10), with a variation of 1.41 to 1.44 g cm^{-3}, while in the PVC method, was 1.43 to 1.63 g cm^{-3}.

When comparing the values of sandy bulk density obtained by the Beaker and Ring methods, the Beaker method underestimated the bulk density values. Only at the depth of 0.05 to 0.10 m was there no significant difference between the methods (Figure 11). The bulk density estimated by the Ring method ranged from 1.44 to 1.61 g cm^{-3}, whereas that estimated by the Beaker method ranged from 1.43 to 1.49 g cm^{-3}.

For sandy loam soil, the soil densities estimated by the Beaker and Ring methods differed at all depths evaluated (Figure 12). The Ring method bulk density ranged from 1.59 to 1.77 g cm^{-3}, and the Beaker method soil density ranged from 1.41 to 1.44 g cm^{-3}. For this type of soil, the PVC pipes that obtained bulk density values similar to those found by the Ring method were 0.060 and 0.075 m in diameter, with heights of 0.10, 0.15 and 0.20 m.

Figure 8 - Bulk density determined by the volumetric ring (Ring) and PVC pipe (PVC) methods for sandy loam soil: a) Ring and PVC 40; b) Ring and PVC 50; c) Ring and PVC 60; and d) Ring and PVC 75



Columns followed by same letter, for each depth, do not differ by Student´s t-test at 5% significance

Figure 9 - Bulk density determined by the beaker (Beaker) and PVC pipe (PVC) methods for sandy soil: a) Beaker and PVC 40; b) Beaker and PVC 50; c) Beaker and PVC 60; and d) Beaker and PVC 75

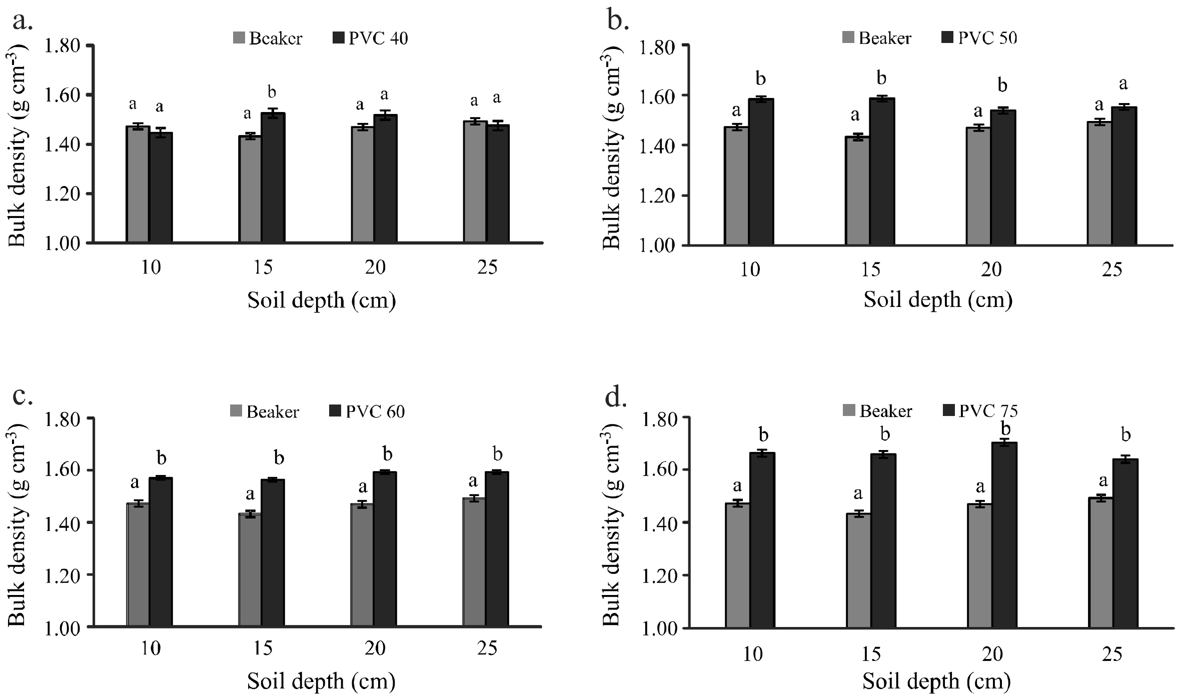


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Figure 10 - Bulk density determined by the beaker (Beaker) and PVC pipe (PVC) methods for sandy loam soil: a) Beaker and PVC 40; b) Beaker and PVC 50; c) Beaker and PVC 60; and d) Beaker and PVC 75

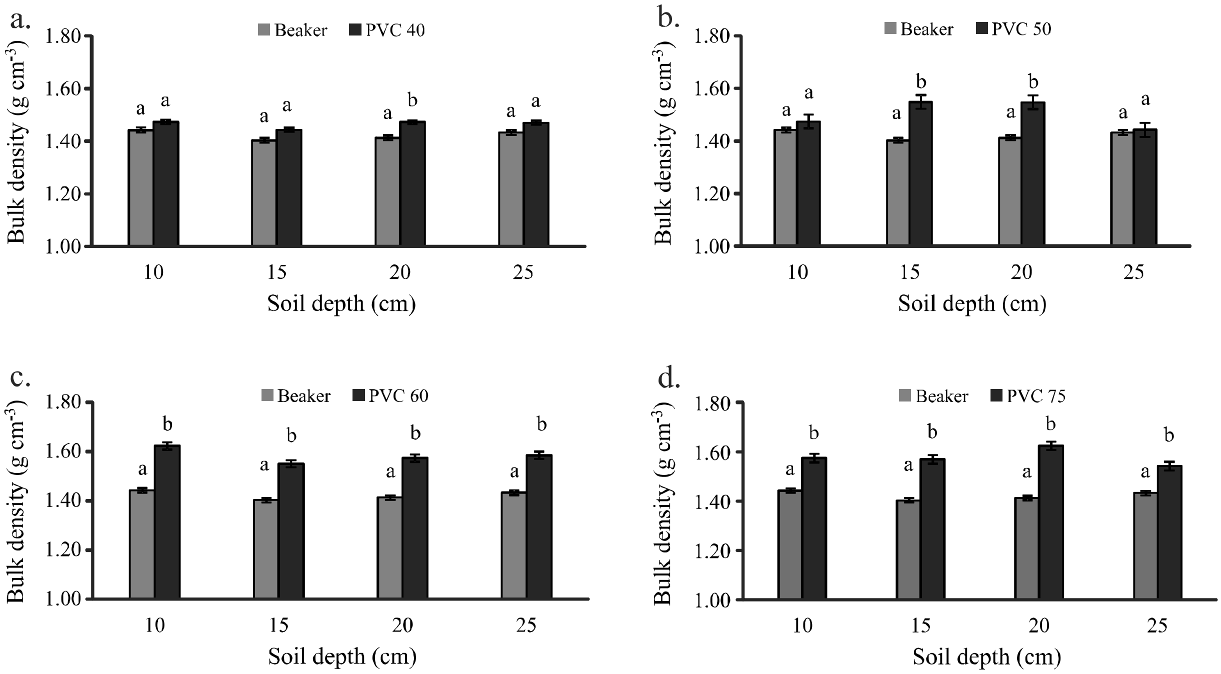

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Figure 11 - Comparison between the beaker (Beaker) and volumetric ring (Ring) methods for the determination of bulk density in sandy soil

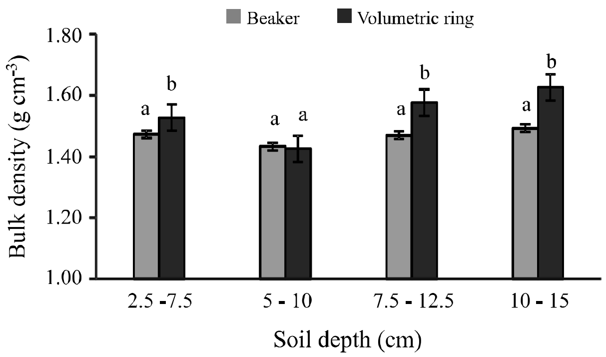

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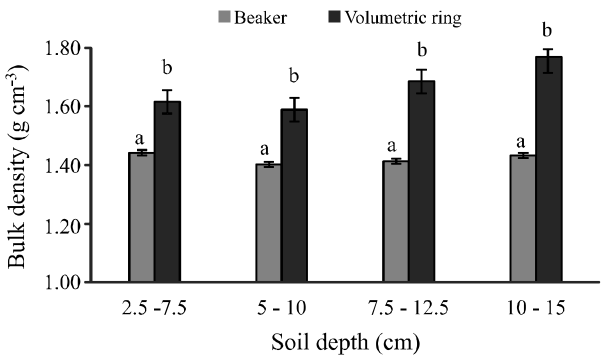
Figure 12 - Comparison between the beaker (Beaker) and volumetric ring (Ring) methods for the determination of bulk density in sandy loam soil



Columns followed by same letter, for each depth, do not differ by Student´s t-test at 5% significance

CONCLUSIONS

1. The PVC pipe method can be used for the sampling of soil and the determination of bulk density, and it is compatible with soils of different granulometry. The use of PVC pipes to determine bulk density represents a method that can be used with great ease and accessibility by small producers, enabling better soil management;
2. Considering the excavation method to be more accurate because it poses no risk of sample compaction, a PVC pipe with a diameter of 0.040 m and a height of 0.15 m is recommended for the PVC method.
3. For soils with a clayey or very clayey texture, among all the methods and PVC pipes tested, the PVC pipe with a diameter of 0.040 m and a height of 0.15 m

presented bulk density results closer to those of the excavation method; therefore, it is considered the most accurate;

4. For soils of medium and sandy texture, among all methods, the Beaker method and the PVC method with a PVC pipe of 0.060 m in diameter and height of 0.15 m presented bulk density results closer to those of the excavation method.

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