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Assessing soil compaction with two different methods of soil bulk density measurement in oil palm plantation soil

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Abstract

Method comparison of soil bulk density value as an indicator of soil compaction was studied in oil palm plantation soil, as oil palm tree has high root occupancy in the soil and is estimated has high difficulty in soil bulk density sampling process. The study was compared the value of soil bulk density extracted by volumetric cylinder and rectangular box. The samples were obtained from one, five, ten, and fifteen-year age of oil palm plantation as well as natural forest. Sampling processing were conducted at front stack zone, circle zone and harvesting zone with 0-10 cm, 10-20 cm, and 20-30 cm of soil depth. Soil bulk density measured from volumetric cylinder is 6.83% higher than measured from rectangular box with root correction. Being compared to soil bulk density from rectangular box without root correction, bulk density from volumetric cylinder is 8.42% higher. Oil palm root evidence trapped in the rectangular box show a significant difference impact to the bulk density value in which the value with root corrected was higher than uncorrected one. The biomass of oil palm root in the rectangular box was found higher in fifteen years ages, indicated the difficulty of soil sampling using this apparatus compared to five and ten years age of oil palm plantation. Comparing sensitivity of the apparatus revealed that rectangular box confirmed the heterogeneous condition in the field than volumetric cylinder. Sensitivity of both apparatus was significantly difference in loamy and clay loam soil texture, while the sensitivity in sandy loam soil was not significantly different from loamy and clay loam soil texture.

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Keywords: Soil compaction; Bulk density; Sampling method; Oil palm plantation; Volumetric cylinder; Rectangular box

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1. Introduction

Soil compaction has been recognized as one of the factors that reduce crop production. It is now considered to be a multi-disciplinary problem in which machine, soil, crop, and weather interactions play an important role and which may have serious economic and environmental consequences in the world agriculture [1]. Soil compaction that closely related to soil pore and soil bulk density had widely studied as indicator of land use quality or other environmental objective [2]. Soil bulk density defines as the weight of clastic and other solid material per unit volume of soil. The value of soil bulk density ranged between 1.0 g cm^{-3} to 2.65 g cm^{-3}. A compacted soil achieves bulk density in excess of 2.3 g cm^{-3} [3]. Depend on some factors affecting soil bulk density, most mineral soil value ranged between 1.1 g cm^{-3} and 1.6 g cm^{-3} [4].

Many studies revealed methods to quantify soil bulk density with both modern and conventional procedure [5][6]. One of the conventional and standard methods that still uses in many studies is volumetric ring method [7]. Standard dimension and material of volumetric ring used by some researches, however, is vary depend on the specific location where the sample will be taken. This difference brings some consequences to other soil properties value measured with volumetric ring even there are not enough researches reveal it. A research in large and small column show the result that dispersivity of small column with 5.1 cm of internal diameter and 30 cm of length was 1 cm while large column with 0.945 m of internal diameter and 6 m of length was 5 cm [8]. Dispersivity is the function of mechanical dispersion coefficient and pore water velocity [9]. Since pore water velocity is approximated by the ratio of Darcian fluid flux density and volumetric water content, the value of dispersivity then approximately linear with the value of flux density. Hence, the difference dimension in soil column brings different value in water movement in the same soil.

The study was objected to compare the value of soil bulk density in two difference apparatus based on the standard method of volumetric ring. Sampling was conducted in oil palm plantation soil. The study site was selected based on condition that the root system of oil palm tree has a big occupation in the soil space. Horizontal primary root of oil palm increases steadily even after 11 years after it planted. The horizontal primary root has downwardly growing vertical roots with 0.5 to 2 meters of length and highly branched [10]. This is the reason why the roots will highly takes place in the soil and brings consequences to the difficulty of sampling for soil bulk density measurement with volumetric ring method.

2. Materials and methods

2.1. Site description

The research was conducted in oil palm plantation of Astra Agro Lestari Co. Ltd. located in Pangkalan Lada, Kota Waringin Barat district, Central Kalimantan, Indonesia. Average rainfall in the plantation field from 2000 to 2010 was 2469 mm $year^{-1}$. Soil type in the field sampling area can be divided as Ultisols, Inceptisols and Entisols [11], with Ultisols occupied about 50% of the study area. Average altitude of the research area is 30 m above sea level with flat to wavy of soil surface condition.

2.2. Soil bulk density apparatus and its additional equipment

Soil bulk density was measured with two different apparatus. The first apparatus is volumetric cylinder generally used in standard method of soil bulk density measurement. The second apparatus is rectangular box. The volumetric cylinder was made from stainless steel material with 1 mm of thickness and 5 cm of internal diameter and height. Rectangular box was made from iron steel with 1.5 mm of thickness, 20 cm of length and width and 10 cm of height. Both apparatus was sharpened about 0.5 cm for rectangular box and 0.3 cm for volumetric cylinder from its base to make it easy penetrate to the soil. Rubber hammer, wooden board, garden scissor, chisel, knife, blade, hoe and spade are the additional equipment used to help the apparatus inserted into the soil.

2.3. Soil sampling

Soil samples were obtained from 1, 5, 10, 15 years old of oil palm plantation field and natural forest. For natural forest sampling, randomized method was used to select the site with six replications. For oil palm plantation soil, samples were obtained from harvesting path zone, circle zone and front stack zone. Harvesting path zone is a path for the labor or mechanical engine commonly used for fertilizing, harvesting, or other agronomic activity for oil palm trees. Circle zone is the area for spreading fertilizer in each individual plant with 1 m width around the staple crops. Front stack zone is the lane for pile up pruned branch and leaves of oil palm. The sketch is illustrated in figure 1. Sampling in every age of oil palm was repeated 4 times. The samples were acquired from 0-10 cm, 10-20 cm and 20-30 cm of soil depth in each site.

Rectangular box and volumetric cylinder were inserted with very careful manner to minimize soil failure in the box due to the clash effect. Garden scissor, blade and chisel were used to cut the oil palm root that was blocking transverse the base of the apparatus. For rectangular box, the outer part of box was down warding unearthed to help the rectangular box inserted into the soil. After all the volume of rectangular box was full with soil, spade and hoe were used to help uplift the sample from the soil ground. Volumetric cylinder sample was taken adjacent to the rectangular box site of sampling.

All the samples in the volumetric cylinder obtained from the field were taken to the laboratory and were weighed to acquire its dry weight. However, due to the large amount of wet soil mass in rectangular box, dry weight soil was counted based on sub sampling method in which just about 300 g of wet soil trapped in rectangular box was measured in the laboratory to get the dry weight value. The oil palm root was sorted in the field and was weigh its wet biomass and volume in the laboratory.

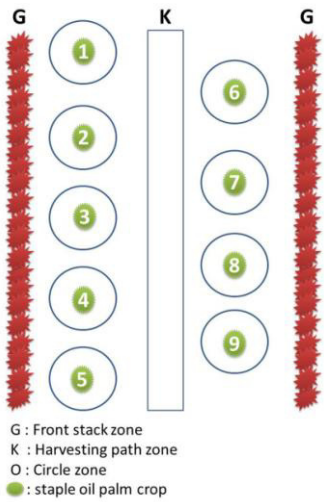


Figure 1. Sampling sketch in oil palm plantation plot

2.4. Calculation and data processing

Soil bulk density values from volumetric cylinder were calculated from the mass of a unit volume of dry soil as describes in the calculation formula bellow.

$$Bulk\ Density = {Wd}/{Vt}$$

Uncorrected bulk densities from rectangular box were calculated with the equation bellow:

$$Bulk\ density = \frac{\left((Wt - Wb - Wr) / (1 + Swc) \right)}{Vt}$$

For root corrected bulk density measured from rectangular box, the equation will be:

$$Bulk\ density = \frac{\left((Wt - Wb - Wr) / (1 + Swc) \right)}{(Vt - Vr)}$$

Wd = *Weight of oven dry soil (g)*
Wt = *Total weight of rectangular box and soil from the field (g)*
Wb = *Weight of rectangular box (g)*
Wr = *Weight of wet root (g)*
Swc = *Soil water content* ($g\ g^{-1}$)
Vt = *Volume of apparatus* (cm^{-3})
Vr = *Volume of root* (cm^{-3})

The effect of sample failure due to the harshness of the soil toward the data validity was anticipated by analyze the data from the samples that have more than 0.25 $g\ g^{-1}$ of water content. Dry soil is strong and brittle and generally only vulnerable either towards rapid wetting. An increase in water content reduces soil strength and produces friable soil which is widely regarded as its most desirable state [12].

3. Result and discussion

3.1. Bulk density from volumetric cylinder and rectangular box

The difference value of bulk density measured from volumetric cylinder and rectangular box is shown in figure 2. The data used for rectangular box is the bulk density data that had been corrected with the weight and volume of the root in the sample. Bulk density measured from volumetric cylinder is 6.83% higher than bulk density from rectangular box. Compared to the bulk density from rectangular box without root correction, bulk density from volumetric cylinder is 8.42% higher. Statistical analysis of the data revealed that both methods generate a significance difference of bulk density value with 95% of confident interval.

The data revealed that the samples measured with volumetric cylindrical were more compacted than measured with rectangular box. Rectangular box volume which is 44 times larger than volumetric cylinder more accommodated the soil variety condition. It indicates that sample failure due to the collision in sampling processing in the oil palm plantation soil was higher in the small volume than in the bigger one. Justification toward the best apparatus for bulk density measurement, however very depended on the other factors such as sampling timing and carrying practicality of the apparatus to the field that was not measured in this study.

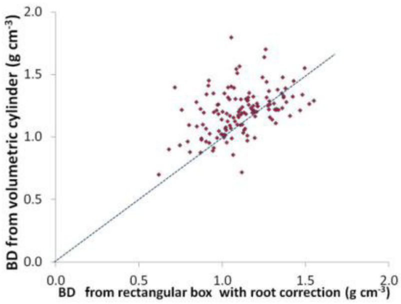
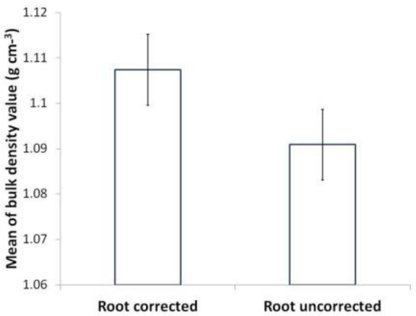


Figure 2. Comparison of bulk density from rectangular box and volumetric cylinder

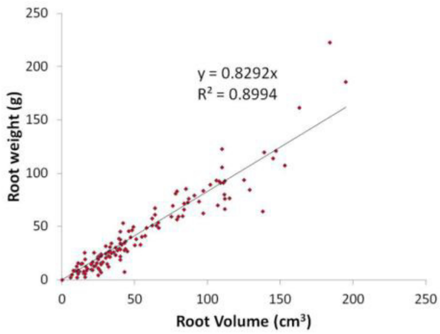
3.2. Influence of oil palm root to the bulk density value

Influence of oil palm root to the value of soil bulk density was tested by calculating the volume and weight of oil palm root trapped in the rectangular box. Bulk density was calculated with the new value of soil volume after reduced by the root volume. Correlation analysis of root volume and soil bulk density measured from rectangular box without root correction result -0.148 of r^2 value. Root volume and soil bulk density from rectangular box with root correction indicates -0.070 of r^2 value. The low correlation between root volume and soil bulk density value reveals that the calculation for soil bulk density was not considering root volume, as the volume occupied by the root should be fill with the soil. The relation between root weight and its volume trapped in rectangular box in the samples showed in figure 3b, in which explained that root was a fresh biomass and was not form space in the soil that affect soil bulk density value.

The root evidence trapped in the rectangular box however revealed a different value of soil bulk density. Comparison of both values with paired sample t test showed that there was a significant difference between bulk density before and after root correction from the soil sample (figure 3a).



(a)



(b)

Figure 3. (a) standard error bar graph of bulk density after and before root correction; (b) regression between root volume and root weight

3.3. Trapped oil palm root in every age of oil palm plantation

Wet biomass of oil palm root trapped in the rectangular box in each age of oil palm plantation is used to explain sampling difficulty. Oil palm root evidence from five and ten years oil palm plantation sample is not significantly different. However, both of them show a significant difference value compared to fifteen years old oil palm plantation with $p<0.05$. The samples from one year oil palm plantation do not include in this comparison due to the evidence of other materials from residual logging process. The highest amount of root occurrence in the rectangular box shows in the fifteen years old oil palm plantation samples, in which indicates the most difficulty effort to sampling with this method.

Figure 4. Root evidence trapped in the rectangular box in oil palm plantation samples

3.4. Sensitivity of the apparatus

Sensitivity of the apparatus reflects the capability of the tool to measure the parameter both in controlled and uncontrolled condition that affects soil bulk density value. Soil bulk density is closely related to soil organic matter and soil texture condition. Soils from different texture have different inherent bulk density [13], and addition of 10% by volume of fine-grained peat in five different soil texture resulted 1.64 to 1.75 g cm^{-3} for the pure minerals samples and 1.59 to 1.61 g cm^{-3} for the amended samples [14]. Due to the high variety of soil condition in the field, examination of the apparatus sensitivity was conducted based on the uncontrolled condition in which standard deviation value of soil bulk density from volumetric cylinder and rectangular box was used to be compared.

Table 1. Standard deviation of bulk density values in rectangular box and volumetric cylinder

Soil texture	**Soil depth (cm)**	**Standard deviation of bulk density values**	
		Rectangular box	**Volumetric cylinder**
Loamy	00-10	0.22	0.15
	10-20	0.23	0.19
Clay loam	00-10	0.20	0.13
	10-20	0.16	0.14
Sandy loam	00-10	0.13	0.13
	10-20	0.22	0.20

The examination was conducted in loamy, clay loam, and sandy loam soil. In every soil texture the samples was selected from different oil palm age, zone, soil depths and soil organic matter content. Soil organic matter content in the samples from loamy and sandy loam is range from moderate to high, while from clay loam is low to high [15]. Statistical analysis revealed that standard deviation value was significantly different between samples from loamy and clay loam texture, however, in sandy loam sample it was not significantly different with the samples from loamy and clay loam texture with $p<0.05$. Standard deviation of soil bulk density values from rectangular box was higher than volumetric cylinder, indicates that rectangular box confirmed the heterogeneous condition in the field than volumetric cylinder.

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References

[1] Soane BD, Van Ouwerkerk C. Soil compaciton problems in world agriculture. In: Soane BD, Van Ouwerkerk C, editors. *Soil compaction in crop production,* Amsterdam: Elsevier Science & Technology; 1994, p. 1-21

[2] Mattsson B, Cederberg C, Blix L. Agricultural land use in life cycle assessment (LCA): Case studies of three vegetable oil crops. *J of Clear Production* 2000;**8**:283-292

[3] Schaetzl RJ, Anderson S. *Soils: genesis and geomorphology*. New York: Cambridge University Press; 2005

[4] Manrique LA, Jones CA. Bulk density of soils in relation to soil physical and chemical properties. *Soil Sci. Soc. Am. J.* 1991;**55:**476-481

[5] Rossi AM, Hirmas DR, Graham RC, Sternberg PD. Bulk density determination by automated three-dimensional laser scanning. *Soil Scie. Soc. Am. J.* 2008;**72**:1591-1593

[6] Timm LC, Pires LF, Reichardt K, Roveratti R, Oliveira JCM, Bacchi OOS. Soil bulk density evaluation by conventional and nuclear methods. *J. Soil Research.* 2005;**43(1)**:97-103

[7] Grossman RB, Reinsch TG. Bulk density and linear extensibility. In: Dane JH, Topp C, Co-editors. *Method of soil analysis part 4 – physical methods,* Madison, Wisconsin: Soil Science Society of America Inc; 2002

[8] Wierenga PJ, Van Genuchten MTh. Solute transport through small and large unsaturated soil columns. *Ground Water.* 1989;**27(1)**:35-42

[9] Van Genuchten MTh, Wierenga PJ. Solute dispersion coefficients and retardation factors. In: Klute A. *Methods of soil analysis part 1.Physical and mineralogical method (2nd edition)*, Madison Wisconsin: American Society of Agronomi Inc. and Soil Science Society of America Inc.; 1986

[10] Jourdan C, Rey H. Architecture and development of the oil-palm (*Elaeis guineensis* Jacq.) root system. *Plant and Soil.*1997;**189**:33-48

[11] Soil survey staff of USDA. Keys to soil taxonomy (tenth edition). Washington: U.S. Government printing office; 2006

[12] Muray RS, Grant CD. The impact of irrigation on soil structure. Canberra: The national program for sustainable irrigation (Land and Water Australia); 2007

[13] Hairiah K, Van Noorwidjk M, Weise S. Sustainability of tropical land use systems after forest conversion. In: Palm CA, Vosti SA, Sanchez PA, Ericksen PJ, editors. *Slash and burn agriculture the search for alternatives,* New York: Columbia University Press; 2005, p. 143-169

[14] Wesseling JG, Stoof CR, Ritsema CJ, Oostindie K, Dekker LW. The effect of soil texture and organic amendment on the hydrological behaviour of coarsed-textured soils. *Soil Use and Management* 2009; **25**:274-283

[15] Baldock JA, Skjemstat JO. Soil organic carbon/soil organic matter. In: Peveril K.I, Sparrow LA, Reuter DJ, eds. *Soil analysis: An interpretation manual,* Melbourne: CSIRO Publishing; 1999, p. 159-170