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Soil Cracking Depth as Influenced By Soil Physical Properties

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Abstract

Knowledge of the tendency of soils to change volume as moisture content changes and regional distribution of expansive soils are of great importance. Therefore it is expected that they exhibit soil cracks. To achieve this fact, bulk soil samples were collected from the surface layer (0.00– 0.30m) of five locations that are distributed throughout the Sulaimani governorate and its surrounding. Standard procedures were applied to perform physical, chemical and geotechnical properties of the investigated soils. The effect of five soil types and four levels of normal bulk density (100, 107, 114, and 121%) on soil crack depth was analyzed by complete randomized design. 40 metal pots each with a diameter of 25cm and 23cm in height were used to carry out this study at six periods of time. The average depth of crack at several random points along the length of the cracks was measured by inserting a 2mm steel rod. Relationships among soil cracks depth with the clay content, organic matter, and liquid limit at all levels of bulk density were positive, while it was negative with sand content. Stronger correlations for all studied properties were obtained in the highest state of bulk density. As bulk density increased the difference of cracks depth decreased; when bulk density increased from 100% to 121% of the normal the soil cracks depth decreases by 28.5%. This results in clay content, sand content, liquid limits, and organic matter to have less effect on crack depth at 121% of normal state of bulk density.

Introduction

Soil cracks are an important physical property of soil in Vertisols that swell while wetting then shrink while drying [1], the consequences of swell-shrink action of clay soils at most undesirable for both agricultural and engineering uses [2], In agriculture, soil shrinkage cracking can effect on plant growth and yield parameters by allows rapid transport of nutrients and pesticides with water to the subsoil where they are both unreachable to surface or shallow rooting plants and can contaminate the local groundwater resource [3; 4; and 5], while in engineering projects can damage building foundations, roads, [2], utilities and septic tanks which depends on the frequency, size, rate [6; and 7] and orientations [1] of crack development. These developments create a zone of weakness in a soil mass and reduce its overall strength and stability [8]. Since, cracking initiates when tensile stresses generated by increasing suctions exceed the soil strength, which in itself, is controlled by soil water content [9]. Also, there are many factors can affect the increment of soil cracking such as clay content, mineral composition, layer thickness and size, boundary conditions, wetting and drying cycles [10; 11; 12; 13; and 14]. Also, the soil cracking increases or decreases as result of the effect of grown crops, bulk density, groundwater and soil moisture characteristics of soils [15] particles size distribution, exchangeable cations [16] organic matter, cation exchange capacity [17; and 18] soil indices [19]. Mohanty et al. (2006) [5] studied the cracking behavour of a Vertisol at the research farm of the Indian Institute of Soil Science and observed that each of the crack parameters [length, width and depth] were significantly and positively correlated with bulk density.

As the amount of clay per unit dry volume increases, the amount of water that can be absorbed by the clay particles and the amount of potential swell also increases [20]; while, when coarser fractions of the soil are brought into contact external volume of the soil aggregate does not change appreciably with further water withdrawal [16]; also they concluded that only factor which gave a very close correlation to cracks parameters is clay content. Due to that when the percentage of clay is higher than 5% by mass, soils with smectite minerals, like montmorillonite, exhibit the most profound swelling properties. Potentially expansive soils can typically be classified in the laboratory by their consistency indices. Inorganic clays of high plasticity, generally those with liquid limits more than 50% and plasticity index exceeding 30%, usually have very high swelling capacity [21]. Also, Navar et al. (2001) [22] pointed out that changes in soil moisture content strongly influence the tensile strength of Vertisols dominated by kaoline and smectite clays. Bandyopadhyay et al. (2003) [7] revealed that the gravimetric water content of the soil surface layer accounted for more than 85% variation in width, area and volume of cracks and for 50% variation in the depth and length of the cracks.

The problems of cracking can be reduced when the tendency of a soil to shrink and swell are known, that accurately requires both the knowledge of which soil properties affect swelling and shrinking, and the value of these parameters [23]. Due to limits study on the impact of these soil properties on soil cracking this caused impossibilities in using these soil properties in predicting soil crack parameters; also, caused difficulties or impossible sustainability of agricultural production with minimum environmental degradation in Vertisols. Maulood (2015) [24] summarized that the apparent and micro cracks of soil decreased with decreasing liquid limit by adding limestone powder in various amount as a managing and improving brick cracks. Daniel and Wu (1993) [25] observed that the amount of shrinkage and cracks lowered with higher compaction effort [i.e., cracking in compacted clays can be minimized by using high compactive effort near optimum water content]. Albrecht and Benson (2001) [12] confirmed the results of [25] and showed that the shrinkage and cracks were function to the volumetric water content, when a soil samples is compacted dry to the same dry unit mass as a soil sample compacted wet, the drier sample undergoes smaller shrinkage and cracks. Also, management of Vertisols for agricultural production such as fertilizer use, crop selection, soil tillage, irrigation, and reducing soil erosion which happens more compared to other soil group [26; and 27].

For this purpose the current study was carried out to study the effect of soil physical properties on soil cracks under four levels on bulk density which contribute in shrinking and swelling process and cracks development.

Materials and Methods

Sample preparation:

Expansive area of fine texture soils occurs in the wide plains of Sulaimani governorate and in the other areas surrounding these plains. The clay content often exceeds 35% and the clay fraction contains a large proportion of expanding clay minerals. Therefore it is expected that they exhibit appreciable swell-shrink potential. To achieve this fact bulk surface samples at a depth varying between (0 - 30cm) of five sites were collected in the Sulaimani governorate and around it. The soils were air-dried, ground to pass through a 2mm sieve and stored in plastic containers until used for laboratory analysis. Also undisturbed soil samples were taken from each soil using steel cores 5.6cm in diameter by 4cm long to determine normal state of compaction. The cores were driven into the soil at or near field capacity with the aid of a core sampler. The cores were then taken out by a special spade, trimmed and the ends were covered with a thin layer of wax to prevent desiccation.

Experimental design:

Complete randomized design [CRD] experiment was conducted to evaluate the effect of five soils and four levels of bulk density on soil crack depth as result of decreasing of soil moisture content at six periods of time [the experiment starts from soil moisture at the field capacity to under the wilting point] by two replication [5 soil types * 4 levels of bulk density * 2 replication * 6 periods]. Therefore, 240 data were taken for each of soil moisture content and soil cracks depth.

Soil compaction [remoded] procedure:

Percentage of clay in the five soils ranged between 16 and 55% (table, 1), calculated mass of soil packed in 40 metal pots each with a diameter of 25cm and 23cm in height under four levels of soil compaction. Prior to packing, soil moisture content of the soils were raised to nearly optimum water content by adding required amount of water using a special sprayer. The samples were then thoroughly mixed by hands, kept in a polyethylene bags and stored in cool place for a period of 24 hr, to ensure soil water distribution.

The compaction (remolded) was performed with the aid of metal packer and the objective was to achieve (100, 107, 114, and 121%) of narmal state of soil bulk density. Later on the water was added to the pots to restore the soil water content to nearly field capacity. The soil inside the pots were then subjected to four cycles of wetting and drying.

Measurements of soil moisture content and crack depth:

The average depth of crack at several random points along the length of the cracks was measured by inserting a 2mm steel rod until it countered resistance to further penetration; the soil moisture content was measured with measuring soil crack depth.

Table-1: Some properties of soils.

Locations	Sand (%)	Silt (%)	Clay (%)	OM (%)	LL (%)	BD (g cm^{-3})
Chwarqwrna	50	34	16	1.5	28	1.51
Bakrajow	9	45	46	2.3	49	1.30
Sangasar	10	35	55	2.4	54	1.30
Qlyasan	7	49	44	2.2	46	1.31
Chamchamal	13	47	40	2.0	41	1.32

Results and Discussion

Effect of clay content on soil cracks depth

Relationships between soil cracks depth and clay content is shown in figure (1). Generally at both levels of bulk density (100%BD and 121%BD) soil cracks depth trended to increase with increasing clay content. This is in agreement with [28]. Also the results is in agreement with the result of [29] found that the swelling percent, swelling pressure and percent of linear shrinkage were linearly and very significant related to clay content (R^2 = 0.857, 0.879 and 0.961 respectively).

Different soil cracks depth versus clay content functions were obtained from each level of bulk density, with a stronger correlation obtained in 121%BD as shown in figure (1). This result was in agreement with [12] findings which confirmed the results of [25]. This shows the importance of compaction process to decrease soil cracks depth in the same clay content and other impact factors. When bulk density increased from 100%BD to 121%BD (i.e., if compaction adjustment factor increases from normal state to hard state or more) only soil cracks depth decreases by 28.5%, figure (1).

Soil compaction process causes the particles to become denser due to the smaller particle filling the spaces, and this causes them to entrap, hence they cannot function freely. This results in the behaviors of the soil to change such as (increasing soil strength and reducing soil settlement). The changes that were stated above affect the relationships between soil cracks depth and clay content as shown in figure (1).

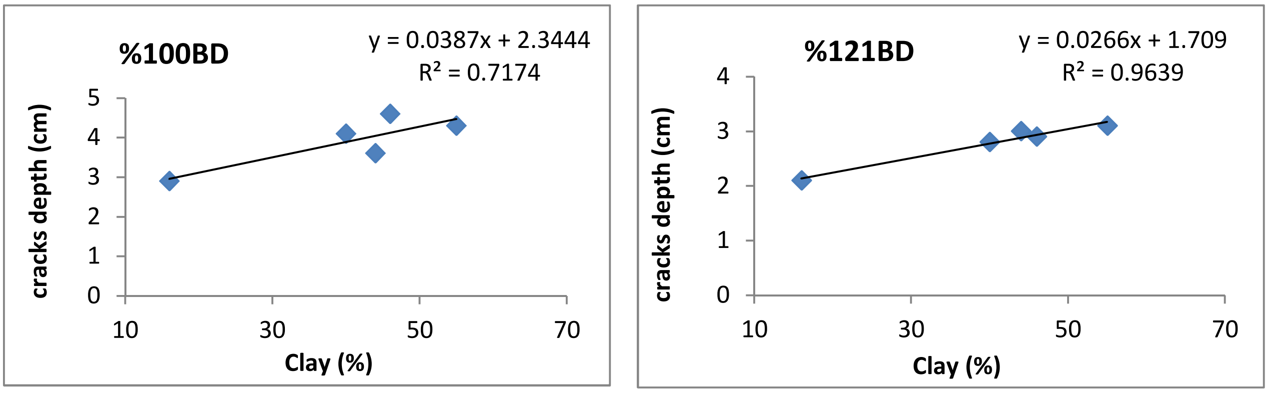

Figure-1: *Relationship of cracks depth with clay content at %100 and %121 of normal bulk density.*

Effect of sand content on soil cracks depth

Concerning sand fraction, at both levels of bulk density (100%BD and 121%BD) soil cracks depth tended to decrease with increasing sand content as shown in figure (2), wherefore it has an opposite effect on cracks depth compared to the others studied parameters. In the light of this result, sand can be added by the percentages which are necessary for decreasing cracks depth, as it is known sand is a component which will not decompose like some other materials which decay in the soil after a short time when adding them to the soil with the purpose of reducing cracks depth. This is in agreement with [30] showed that the shrinkage and cracking can be minimized by stimulating clay soil with the coarse-particles. For this case [25] proposed to use clayey sand with a low hydraulic conductivity and low shrinkage values.

Different correlations of soil cracks depth with sand content were revealed from each level of bulk density, with a stronger correlation obtained in 121%BD (Figure, 2). The same figure show that increasing bulk density from 100%BD to 121%BD, these results in the crack depth to decline by 28.5% may be due to the same causes which have been mentioned in the previous section.

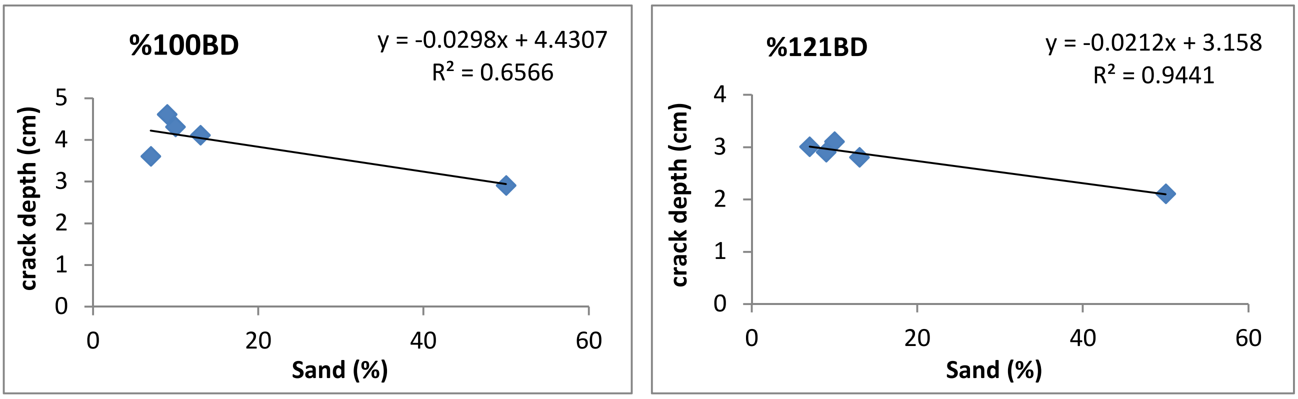

Figure-2: *Relationship of cracks depth with sand content at %100 and %121 of normal bulk density.*

Effect of liquid limit on soil cracks depth

Similarly to fines fraction, it is found that there is a strong and posititve correlation between the degree of soil cracking and the liquid limit (Figure, 3). The liquid limit increases with the increase of clay content of the soil. So it is considered a rough measure of the strength of clay [31; and 32]. Meanwhile, the extreme crack properties are detected in the soils with the largest fines fraction and highest plasticity index [33; and 34]. Also the results is in agreement with the result of [29] found that the percent of linear shrinkage was linearly and very significant related to liquid limit (R^2 = 0.951). Also, figure (3) indicates that there was a decrease in cracks depth by 28.5% with increasing bulk density from 100% to 121% of normal state.

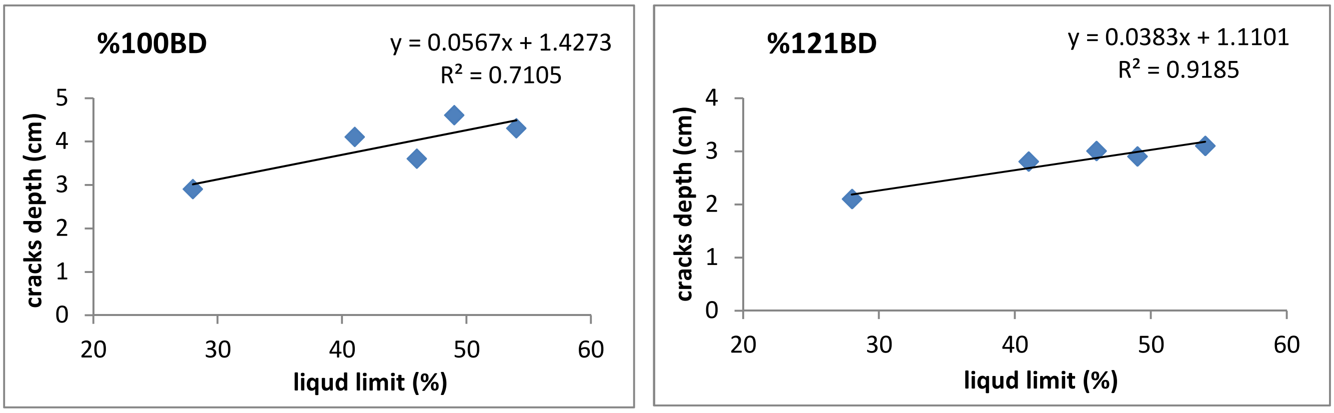

Figure-3: *Relationship of cracks depth with liquid limit at %100 and %121 of normal bulk density*

Effect of organic matter on soil cracks depth

Correlation between soil cracks depth and organic matter at two levels of bulk density are shown in figure (4), in both state (100%BD and 121%BD) soil cracks depth tended to increase with increasing organic matter. The results is in agreement with the result of [29] found that the swelling percent and swelling pressure were linearly and significant related to organic matter (R^2 = 0.635 and 0.601 respectively). Usually soil organic matter has a positive effect on soil physical properties which include soil structural improvement [35] and decreasing soil temperature. While soil compaction has a negative effect (contrary of organic matter), therefore when bulk density increased from 100%BD to 121%BD, the soil cracks depth decreases by 28.5%, figure (4).

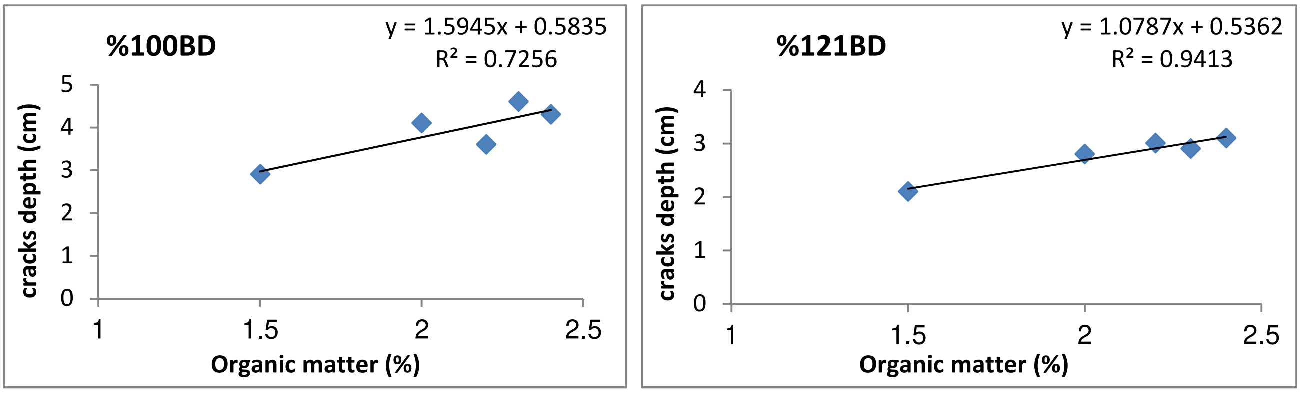

Figure-4: *Relationship of cracks depth with* organic matter *at %100 and %121 of normal bulk density*

Effect of soil types on cracks depth

The effect of soil types on cracks depth is shown in figure (5). The highest value of cracks depth appears in Sangasar soil. The value is approximately (2.44 cm). At the same time, this soil has the highest value of clay, liquid limit and organic matter, with the value of (55, 54, and 2.4%) respectively as shown in Table 1. However the lowest cracks depth appears in Chwarqwrna soil its value is around (1.44 cm), also it has the lowest value of clay, liquid limit, organic matter and their values are (16, 28, and 1.5%) respectively, (Table, 1). This confirms the fact that the properties of soil cracks have a strong linear relationship with clay, liquid limit, and organic matter (figures, 1, 3, and 4).

The percentage of clay in the studied soils is more than %40, except for Chwarqwrna soil , which is 16% as shown in table 1, also the value of sand is low in the soils which is lower than 15%, with the exception of Chwarqwrna soil which is 50%, because of these two characteristics there is no significant difference among the soils except Chwarqwrna soil, which differed significantly with the rest of the soils as shown in figure (5). Moreover each of the figures (1, and 2) show the relationship between crack depth with each of clay and sand are positive and negative respectively.

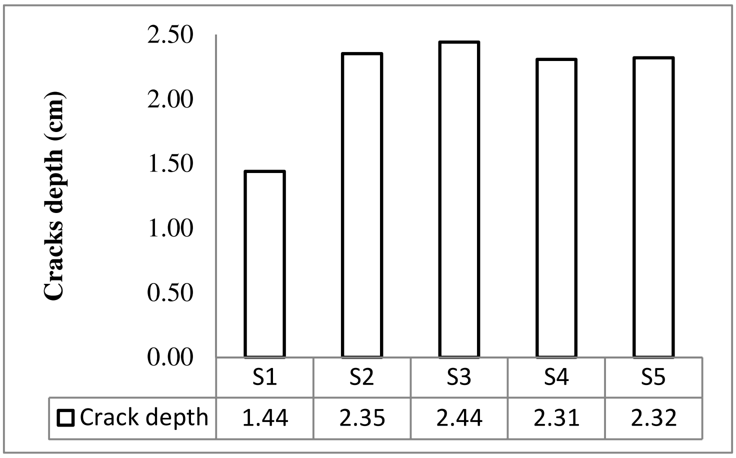

Figure-5: Cracks depth in different soil types.

Effect of soil bulk density on cracks depth

The effect of four levels bulk density on cracks depth is shown in figure (6). As bulk density increases the difference of cracks depth decreases (e.g., the difference of cracks depth between 100%BD and 107%BD is higher than the difference of cracks depth between 114%BD and 121%BD) as shown in figure 6. This results in clay content, sand content, liquid limits, and organic matter to have less effect on crack depth. This is the reason for decreasing cracks depth by 28.5%, when bulk density increased from 100%BD to 121%BD, with applying functions which resulted from the relationships among clay, liquid limit and organic matter with crack depth as shown in figure (1, 2, 3, and 4). Soil compaction has relatively more destructive effects on clayey soils as they have more binding of soil aggregates than sandy soils [36]. The cause of this may be the degradation of soil structure. it occurs when bulk density increases, this result in soils to have less porosity due to external applied load [37; and 38]. Also, Whalley et al. (1995) [39] reported that the Compaction can adversely affect nearly all physical, biological and chemical properties and its behaviors and functions. The large aggregates break into medium and small aggregates as a result of compaction. By increasing compactive effort more (i.e., increase bulk density from 114%BD to 121%BD) the medium aggregates collapse into small aggregates. Due to that a negative relation between bulk density and crack depth appears as shown in figure (7), and this is in agreement with [40] showed that the shrinkage of soil aggregates increased with increase in compaction of soil aggregates, but decreased for those with smaller aggregates due to difference in amount of aggregate rearrangement. Reeve et al. (1980) [18] Found a close relationship between bulk density and total volume reduction. The correlation coefficients were – 0.85 and – 0.86 for topsoil and subsoil respectively.

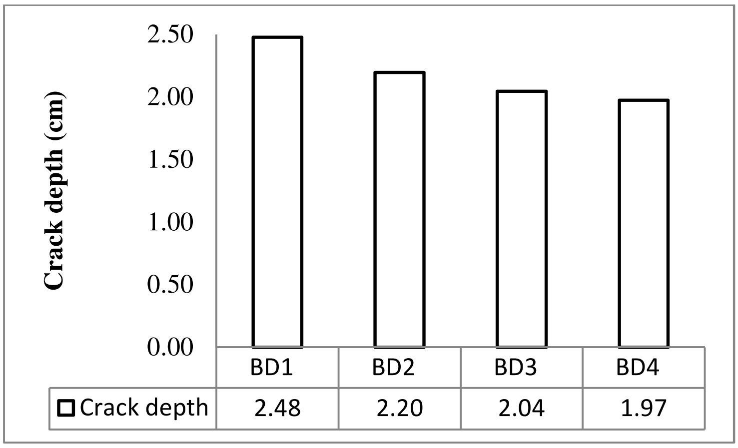

Figure-6: Soil cracks depth in different levels of bulk density

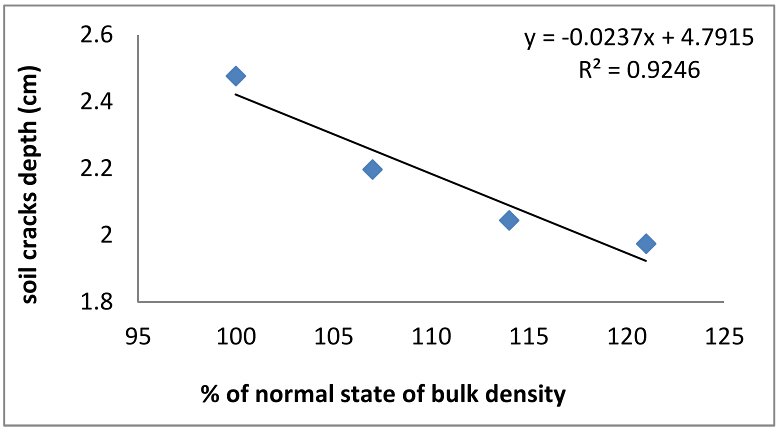

Figure-7: Levels of bulk density versus soil cracks depth.

Conclusions

- The difference of cracks depth between 100%BD and 107% BD is higher than the difference of cracks depth between 114%BD and 121%BD.
- The effectiveness of bulk density on crack depth is much higher than the other properties in case of 121% BD which decreased by 28.5%.
- Increasing bulk density to highest level results in clay content, sand content, liquid limits, and organic matter to have less effect on crack depth.
- Increases of bulk density makes stronger correlations among clay content, sand content, liquid limit, and organic matter within highest state of bulk density.

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