# EFFECT OF BIOCHAR APPLICATION ON FRIABILITY OF SOILS WITH DIFFERENT TEXTURE

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**Abstract** - A green house experiment was done to examine the effect of biochar on soil friability. The interrelations between soil properties and soil friability was also been studied. Three soils with different texture were used in the study. The soil was air dried, crushed and packed in a 28 kg plastic pot (15 cm diameter). The soil was applied with: (i) control (without any soil amendment), (ii) biochar, (iii) Ammonium enriched biochar. The soils was then planted with maize and harvested after the end of vegetative growth. The soil was fallowed for one month, and again planted with waize until the end of vegetative growth. After harvesting the second maize, soil samples were taken for laboratory analysis. The results show that biochar application influenced Plastic Limit and Liquid limit of kaolinite and illite clay soil, but not with Liquid Limit. Acitivity of soil dominated with monmorilonite clay mineral decreased with biochar application. Biochar application improved wet soil aggregate stability. The friability of all soils improved with biochar application. Soil friability positively correlated with soil organic matter and wet soil aggregate stability.

**Key words** - Soil amendment, Atterberg limits, soil consistency, soil activity, soil tillage

## I. INTRODUCTION

The important of soil friability has a long time been realized. Soil friability is a key soil physical property to obtain valuable information on the ease of producing a favorable seed—and root beds during tillage operations [1]. Furthermore, Munkholm[1] pointed out that soil friability is a crucial soil property in relation to the ability of soil to support plant growthand to minimize the energy required for tillage. In spite of the important of soil friability property, the progress of soil friability theory is going very slow. The topic has been put by Christensen [2], but for years the measurement is only qualitative as done by Bodman[3] based on the consistency theory. Utomo and Dexter [4] come through this breakthrough by proposing a new quantitative method to measure soil friability. Utomo and Dexter [4] defined soil friability as "the tendency of amass of unconfined soil to break down and crumble under applied stress into a particularsize range of smaller fragments".
A soil called a good soil tilth "usually is loose, friable and wellgranulated" [5]. This qualitative statement of a "crumb structure" as the optimal environment for plant growth is supported by empirical data by Braunack and Dexter [5]. Therefore, a friable soil is characterized by an ease of fragmentation of undesirably large aggregates/clods and adifficulty in fragmentation of minor stable aggregates into undesirable small elements. Soil friability is influenced by basic soil properties, especially soil water content [4, 6] and soil bulk density [7]. Soil friability is also strongly influence by clay content [8], clay type [9], and exchangeable cation [10].
Avillaet al. [9] pointed out that soil friability is not a static characteristic, but very dynamic. Soil friability has been found to be influence by soil tillage system [11] and irrigation [12]. The significant influence of cropping system and management on soil friability has been demonstrated by Reis et al.[11]. This is reasonable, because cropping system and management will influence soil organic matter content. It has been shown by Schjønninget al. [13] that soil organic matter content strongly influence soil friability. The important of soil organic matter on soil structure formation and stabilization has been widely understood [14]. Soil organic matter plays as a main bonding material in soils structure formation [15]. It forms complexes with primary mineral particles and secondary structural units, and will enhance the formation of soil flaws or cracks. Then based on the crack theory developed by Grifith [16]the soil will break up easier.

The effect of application of organic amendment, such as organic manure, on soil fertility and productivity has been has been for centuries acknowledged [17]. Organic amendments are usually applied in a large amount, and due to a very rapid decomposition it should be repeat every planting season, and therefore most farmers reluctant to apply organic amendment for their soil [18].

Lately, a lot research has shown that organic soil amendment called "biochar" very resistant to decomposition [19]. Many research have shown that biochar application improved soil fertility and crop yield [20, 21]. The positive effect of biochar application on soil structure and soil bulk density has been shown by Chan et al.[20] and Islamiet al.[22]. However, there was no study reported the effect of biochar application on soil friability. The study reported here was aimed to examine the effect of soil organic amendment, especially biochar, on soil friability. The interrelation between soil friability and other soil properties will also be studied.

## II. Materials and Method

Three soil type were used in this study. They were montmorilonitic clay from Lamongan, East Java; mixture of Illitic-kaolinitic clay loam from Malang, East Java and and illitic loam from Kupang, East Nusa Tenggara, Indonesia. The soil was air dried, and than crushed and packed in a 28 kg plastic pot ( 15 cm diameter). The soil was then treated with: (i) control, (ii) biochar, (iii) Ammonium enriched biochar.
Biochar was made from corn cob and done according to the technique described by Masuliliet al.[18], and biochar enrichment was done according the technique described by Wisnubroto et al.[21]. Some properties of the soil and organic amendment used in the experiment are presented in Table 1.

**Table 1.Some properties of soils and biochar used in the experiment**

| Soil | Soil and biochar properties | | | | | |
|---|---|---|---|---|---|---|
| | pH | C (%) | N (%) | CEC cmol/kg | Sand (%) | Clay (%) |
| Illite-loamy soil | 7.52 | 1.32 | 0.12 | 12.28 | 32.15 | 22.85 |
| Illite- loamy soil | 6.46 | 1.30 | 0.14 | 14.96 | 24.35 | 32.60 |
| Montmorolonite-Clayey soil | 7.02 | 1.65 | 0.14 | 28.28 | 22.30 | 55.65 |
| CCbiochar | 8.14 | 47.06 | 0.00 | 14.75 | - | - |
| CCbiochar$NH_4^+$ | 7.65 | 48.04 | 3.60 | 16.55 | - | - |

The soils was then planted with maize, growed in a green house, and harvested after the end of vegetative growth. The soil was fallowed for one month, and again planted with waize until the end of vegetative growth. During maize growing soil water content was maintained at field capacity. After harvesting the second maize, soil sample was taken and then processed for laboratory analysis.
Soil organic matter was measured with Walkley and Black Method, Atterberg limits was determined with Cassagandre method[24]. Wet soil aggregate stability was determined by wet sieving method according to the technique described by Utomo and Dexter [25], and dry soil aggregate stability with dry sieving [26]. The result was expressed as the mean weight diameter (MWD) of the stable aggregate with equation of:

$$MWD = \sum_{i=1}^{n} diwi.. \quad (1)$$

Where $d_i$ is the mean diameter of any particular size range of aggregates separated by sieving, and $iw_i$ is the weight of aggregates in that size range as a fraction of the total dry weight.
Soil friability was determined by the method of Utomo and Dexter [4]. Soil aggregates of 2,0 – 4,0; 4,0 – 8,0; 8,0 –12,5 dan 12,5 – 19,0 mm were capillary wetted until saturated in a sand bath, and then dried to the potential matrix of – 50; - 100, - 300; and – 1000 kPa, after which the tensile strength was measured with the method of Dexter [27]. Soil friability was expressed as "k' index of equation (2):

$$\log_e V = a + k \log_e S \quad (2)$$

Here: V is soil aggregate volume, and S is the soil agregate tensile strength

## III. RESULTS AND DISCUSSION

The experimental result presented in Table 2 show that Atterberg Limits were significantly influenced by clay content and clay type. A soil with higher clay content possessed a higher Plastic and Liquid Limit; Monmorilonite dominated soil had a higher PL and LL compared to that of kaolinite and Illite dominated soil.

**Table 2. Effect of biochar application on Atterberg Limits and soil activity**

| Treatment | | Soil properties | | | |
|---|---|---|---|---|---|
| Soil | Biochar | PL (%) | LL (%) | PI (%) | Activity |
| Illite-loamy soil | Non biochar | 18.43 a | 27.45 a | 9.02 a | 48.94 a |
| | CCbiochar | 20.32 ab | 31.64 b | 11.32 b | 50.95 ab |
| | CCbiochar $NH_4^+$ | 21.46 b | 31.86 b | 10.40 ab | 48.46 a |
| Illite-kaolinite -Loamy soil | Non biochar | 19.80 a | 31.35 b | 11.55 bc | 58.33 b |
| | CCbiochar | 24.23 c | 36.37 c | 12.14 c | 50.10 ab |
| | CCbiochar $NH_4^+$ | 23.95 c | 37.28 c | 13.33 c | 55.57 ab |
| Montmorilonite-Clayey soil | Non biochar | 38.04 d | 116.56 d | 78.52 d | 206.41 c |
| | CCbiochar | 40.92 e | 116.18 d | 75.26 d | 183.92 d |
| | CCbiochar $NH_4^+$ | 41.56 e | 117.46 d | 75.90 d | 182.62 d |

*)means followed by the same letters in the same column is not significantly different (p=0.05)

The results in Table 2 also show that biochar application increased Plastic Limit (PL) and Liquid Limit (LL) and Plasticity Index(PI) of illite and kaolinite loamy soil. For montmorilonite clayey soil, however, biochar application influenced Plastic Limit, but not with Liquid Limit. Furthermore, biochar application increased the activity of kaolinite and illite loamy soil, but decreased the activity of monmorilonite clayey soil. Soil activity was calculated by dividing Plasticity Index with clay content.

Liquid Limit, Plastic Limit and soil activity is influenced by specific surface [28]; and specific surface is influenced by particle size and clay mineral type. Since monmorilonite much smaller than kaolinite and illite, it is reasonable that montmorilonite clayey soil possessed a higher Plastic and Liquid Limits than illite or kaoliniet-illite loamy soil. The increase of Atterbergs Limits with increasing clay content has also been shown by Polidori[29]. The effect of biochar application on Atterberg Limits can be explained from soil organic matter content. The result in Table 3 show that biochar application increased soil organic matter content. A correlation analysis (by excluding montmorilonite clayey soil)

show that Plastic Limit positively correlated with soil organic matter content (r = 0.89). Moradi[30] found that in addition to clay content and type, Atterberg Limits was significantly influenced by soil organic matter content.

Biochar application increased wet soil aggregate stability of loamy soil, but not with montmorilonite clayey soil. Dry soil aggregate stability, however, was only influenced by soil type. A correlation analysis was done for examining the effect of soil organic matter with soil aggregate stability. In this analysis, to eliminate the effect of clay type, the montmorilonite clayey soil was excluded. The result shows that only wet soil aggregate stability which significantly correlated with soil organic matter content (r=0.83).The increase of wet soil aggregate stability in biochar treated soil was a logic consequence of increasing soil organic carbon in the soil (Table 3). As has been discussed before, soil organic matter is the main bonding for soil aggregate formation [15].

**Table 3. Effect of biochar application on soil carbon and soil aggregate stability**

| Treatment | | Soil properties | | |
|---|---|---|---|---|
| | | | MWD (mm) | |
| Soil | Biochar | C (%) | Wet stability | Dry stability |
| Illite loamy soil | Non biochar | 0.95a | 1.56 a | 2.48 a |
| | CCbiochar | 1.45b | 2.16 b | 3.34 a |
| | CCbiochar $NH_4^+$ | 1.50b | 2.05 ab | 3.56 a |
| Illite- kaolinite Loamy soil | Non biochar | 1.32a | 1.55 a | 2.98 a |
| | CCbiochar | 1.78b | 2.25 b | 3.56 a |
| | CCbiochar $NH_4^+$ | 1.86b | 2.35 b | 3.16 a |
| Montmorilonite clayey soil | Non biochar | 1.55 a | 2.89 c | 4.88 b |
| | CCbiochar | 2.05 b | 2.81 c | 4.95 b |
| | CCbiochar $NH_4^+$ | 1.96 b | 2.91c | 5.31 b |

*)means followed by the same letters in the same column is not significantly different (p=0.05)

The results presented in Table 4 show that , by using Imhoff's (2002) classification, the friable condition (k = 0.20 – 0.50) occurred at soil matrix potential (ϒm) in between – 100 kPa to – 300 kPa. Gravimetric soil water content at these matrix water potential were: 16 to 23% for illite loamy soil; 18 to 25% for illite-kaolinite loamy soil; and 33 to 37% for montmorilonite clayey soil.

It is interesting to notice that for monmorilonite clayey soil, after reaching of about field capacity (ϒm) - 300 kPa, friabilility indeks, k, decreased with decreasing matrix water potential. The result in Table 4 show that at matric water potential (ϒm) of – 300 kPa, friability index of montmorilonite clayey soil was 0.26, 0.37 and 0.42 for the control, biochar and $NH_4^+$enriched biochar treatment respectively. These k values decreased to 0.19; 0.21 and 0.20 at matrix potential (ϒm ) – 1000 kPa (see also Figure 1).For illite and illite-kaolinite loamy soils, on the other hand, a different phenomenon occurred. The friability index, k, of these soil increased steadily with decreasing matric water potential. At matrix potential (ϒm of – 1000 kPa, their friability index, k, were more than 0.5, which according to Imhoff's [8] classification belongs to very friable.

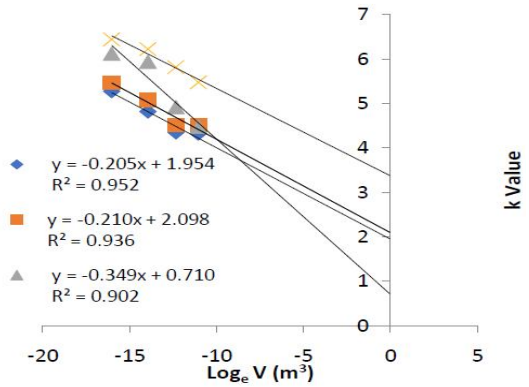



**Figure 1. Effect of $NH_4$-enriched biochar application on $Log_e$ V-S relationship of montmorilonite-clayey soil at different matrix water potential (♦) – 50 kPa; (■)-100 kPa; (-300) kPa; (▲) - 1000 kPa**

To examine the effect of soil basic properties on friability index, the k value was correlated with soil organic matter content, soil aggregate stability and plastic limit. In this analysis, the montmorilonite clay soil was excluded. The result shows that friability index significantly correlated with soil organic matter content (r= 0.72); plastic limit (r= 0.72); wet soil aggregate stability (r = 0.58), but not with dry soil aggregate stability (r=0.47). As has been discussed before, soil organic matter will enhance the formation of soil structure, which in turn will propagate the flaw formation. Therefore, in accordance with the Grifith theory [16], these will reduce the strength of the larger clods, and hence increase the k value.

**Table 4. Effect of biochar application on friability index, k, of soils with different texture at matrix water potential of -50; -100; -300 and – 1000 kPa.**

| Treatment | | k value at ϒm (-kPa) of | | | |
|---|---|---|---|---|---|
| Soil | biochar | 50 | 100 | 300 | 1000 |
| Illite- soil | Control | 0.16 | 0.26 | 0.30 | 0.52 |
| | Biochar | 0.21 | 0.32 | 0.37 | 0.53 |
| | Biochar -NH4 | 0.19 | 0.32 | 0.42 | 0.51 |
| Illite-kaolinite loamy soil | Control | 0.15 | 0.29 | 0.34 | 0.51 |
| | Biochar | 0.18 | 0.35 | 0.37 | 0.58 |
| | Biochar -NH4 | 0.20 | 0.36 | 0.42 | 0.60 |
| Montmorilonite-clayey soil | Control | 0.18 | 0.19 | 0.26 | 0.19 |
| | Biochar | 0.22 | 0.27 | 0.33 | 0.21 |
| | Biochar -NH4 | 0.20 | 0.23 | 0.35 | 0.20 |

## CONCLUSION

The results discussed in section 3 show that biochar application influenced Plastic Limit and Liquid limit of kaolinite and illite clay soil, but not with Liquid Limit. Acitivity of soil dominated with monmorilonite clay mineral decreased with biochar application. Biochar application improved wet soil aggregate stability. The friability of all soils improved with biochar application.Soil friability positively correlated with soil organic matter and wet soil aggregate stability.

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## REFERENCES

[1] Munkhohm, L.J. "Soil friability: A review of the concept, assessment and effects of soil properties and management", Geoderma Vol. 167-168, pp. 236–246, 2011.

[2] Christensen, O. "An index of friability of soils", Soil Science Vol. 29, pp. 119–138, 1930.

[3] Bodman, G.B. "Methods of measuring soil consistency", Soil Science Vol. 68, pp. 37-56, 1949.

[4] Utomo, W.H. and Dexter, A.R. "Soil friability", Journal of Soil Science Vol.33, pp.203-213, 1981.

[5] Karlen, D.L., Erbach, D.C., Kaspar, T.C., Colvin, T.S., Berry, E.C. and Timmons, D.R."Soil tilth: a review of past perceptions and future needs", Soil Science Society American JournalVol. 54, pp. 153–161, 1990.

[6] Braunack, M.V. and Dexter, A.R. "Soil aggregation in seed bed, 2: Effect of aggregate size on plant growth" Soil andTillage Research Vol. 14, pp. 281-298, 1989.

[7] Watts, C.W. and Dexter, A.R."Soil friability: theory, measurement and the effects of management and organic carbon content", European Journal Soil Science Vol. 49, pp. 73–84, 1998.

[8] Imhoff, S., Da Silva, A. P., & Dexter, A. "Factors contributing to the tensile strength and friability of Oxisols", Soil Science Society of America Journal Vol. 66(5), pp. 1656-1661, 2002.

[9] Avila, E.A. P., Leiva, F.R. and Madriñán. R.M. "Friability and its relationship with clay and organic carbon in soils cultivated with sugar cane",Agronomía Colombiana Vol. 33, pp. 365-372, 2015.

[10] Munkholm, L.J., Perfect, E. and Grove, J."Incorporation of water content in the Weibull model for soil aggregate strength", Soil Science Society American Journal Vol. 71, pp. 682–691, 2007.

[11] Reis, D.A., Rodrigues de Lima, C.L., Pauletto, E.A., Dupont, P.B. and Pillon. C.N. "Tensile strength and friability of an Alfisol under agricultural management systems", Science Agriculture Vol. 71, pp. 163-168, 2013.

[12] Koehn, A.C., Lersch, G.A., Busscher, W.J., Evans, D.E., King, B.A., Stieneke, D.L. and Sojka, R.E. "Aggregate tensile strengthand friability characteristics of furrow and sprinkler irriigated field in Southern Idaho" Communication in Soil Science and Plant Analysis Vol. 45, pp. 2712 -2720, 2014.

[13] Schjønning, P., Elmholt, S., Munkholm, L.J., Debosz, K. "Soil quality aspects ofhumid sandy loams as influenced by organic and conventional long-term management" Agriculture Ecosystem and Environment Vol. 88, pp. 195–214, 2002.

[14] Harris, R.F., Chesters, G. and Allen, O.N. "Dynamics of soil aggregation",Advances in Agronomy Vol. 18, pp. 108–169, 1966.

[15] Tisdall, J.M. and Oades, J.M. "Organic matter and water-stable aggregates in soils", Journal of Soil Science Vol. 33, pp. 141-161, 1982.

[16] Grifith, A.A. "The phenomena of rupture and flow in solids". Philosophical Transactions of the Royal Society of London(London) A 2211, pp. 163-198, 1921.

[17] Amanullah, M., Vaiyapuri, K.,Satyamoorthi,K. Pazhanivelan S. and Alagesan, A. "Nutrient uptake and tuber yield of cassava (Manihot esculenta) and soil fertility as influenced by organic manure",Journal of Agronomy Vol. 6, pp. 183-187, 2007.

[18] Masulili, A., Utomo, W.H. and Syekhfani, MS. "Rice Husk Biochar for Rice Based Cropping System in Acid Soil 1. The Characteristics of Rice Husk Biochar and Its Influence on the Properties of Acid Sulfate Soils and Rice Growth in West Kalimantan, Indonesia", Journal of Agricultural Science (Canada) Vol. 3, pp. 25-33, 2010.

[19] Lehman, J. "A handful of Carbon", Nature Vol. 447, pp. 143-144, 2007.

[20] Chan, K.Y., van Zwieten, B.L., Meszaros, I., Downie, D. and Joseph, S. "Using poultry litter biochars as soil amendments", Australian Journal of Soil Research Vol. 46,pp. 437–444, 2008.

[21] Sukartono, Utomo, W.H., Kusuma, Z. and Nugroho,W. H. "Soil fertility status and maize (Zea mays) yield after biochar application on sandy soils of North Lombok, Indonesia", Journal of Tropical Agriculture Vol. 49, pp. 47-53, 2011.

[22] Islami, T. Guritno˙B., Basuki, N. and Suryanto, A. "Biochar for cassava based cropping system in the degraded lands of East Java, Indonesia", Journal of Tropical Agriculture Vol. 49, pp. 40-46, 2011.

[23] Wisnubroto, E.I., Utomo W.H. and Soelistyari H.T. "Biochar as a carrier for nitrogen plant nutrition: 1. The release of nitrogen from biochar enriched with Ammonium Sulfate and Nitrate Acid", International Journal of Applied Engineering ResearchVol. 17, pp. 1035-1042, 2017.

[24] Department of Transportation. "Geotechnical Test Method: GTM7", Department of Transportation, State of New York, New York. 16 pp., 2015.

[25] Utomo, W.H. and Dexter, A.R. "Changes in aggregate water stability induced by wetting and drying cycles in non-saturated soil", Journal Soil Science Vol. 34, pp. 623-627, 1982.

[26] Chepil, W.S. "Field structure of cultivated soils with special reference to erodibility by wind", Soil Science America Proceeding Vol. 17, pp. 175-180, 1953.

[27] Dexter, A. R., and Kroesbergen, B. "Methodology for determination of tensile strength of soil aggregates. Journal of Agricultural Engineering Research Vol. 31(2), pp. 139-147, 1985.

[28] Dolinar, B. "Correlation between surface area and Atterberg limits of fine-grained soils", Clay and Clay Minerals Vol. 55, pp. 519-523, 2007.

[29] Polidori, E. "Relationship between the atterberg limits and clay content",Soils and Foundations (Tokyo), pp. 887-896, 2007.

[30] Moradi, S. "Impacts of organic carbon on consistency limits indifferent soil textures", International Journal of Agriculture and Crop Sciences Vol. 5, pp. 1381-1388, 2013.

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