# EFFECTS OF ORGANIC MATTER AMENDMENT ON AGGREGATE STABILITY OF SOME AGRICULTURAL SOILS IN SEMI ARID REGION OF NIGERIA

# ABSTRACT

Soil aggregate stability is important in understanding the structural behaviour of soils. Soil aggregate stability is therefore an important index of soil productivity. The effect of chicken dung on aggregate stability of three (3) agricultural soils of Borno state namely sandy loam, sandy clay and clay soils was investigated in a laboratory experiment using a rainfall simulator. Chicken dung was added to these soils at 2% (w/w) and the aggregate sizes of 2-4 mm and 6-8 mm were prepared by sieving. These aggregate sizes were weighed and subjected to simulated rainfall for rainfall durations of 1, 2, 3, 4, 5, 10, 15, 20, 25 and 30 minutes using a rainfall simulator at an intensity of 226.6 mm/hr. The aggregate stability of the three (3) sails were calculated using the wet sieving method. The result revealed that 2% chicken dung incorporation did not influence stability of sandy loam soils, but improved the stability of the structure of both sizes of sandy clay and clay soils relative to the "controls”. The degree of stability however, varied with few soil types and aggregate sizes. Aggregate size of 2-4 mm showed poor resistance to rain drop forces as the rainfall depth increases compared to the aggregate size of 6-8 mm, but both performed better than the control. This implies that smaller sized aggregates are more vulnerable to detachment and transport irrespective of soil type. Clay soil aggregates were more stable than sandy clay soil irrespective of aggregate sizes. The use of chicken dung is hereby recommended to stabilise soil against erosion hazards.

Key words: Aggregate stability, rainfall simulation, chicken dung, erosion

# INTRODUCTION

Soi I is a very complex system made of heterogeneous mixture of solid, liquid and gases. The solid phase of the soil is of particular interests to farmers and agricultural related specialists; its geometry and chemical composition determines the soil structure, texture, and conductivities to both heat and fluids. The maintenance of stable soil surface conditions is important to the conservation of soil (Stroud et al., 2023). Soil aggregate often gets disintegrated when subjected to any imbalance in soil-moisture continuum (Sonsri and Watanabe, 2023). This in turn affects crop productivity and depresses farmers and national economy. Soil aggregate stability is therefore a very important index of soil productivity (Lal, 2004). It is determined by factor such as soil moisture content, particle size distribution and quality and type of organic matter content. Organic matter is an important determinant of soil aggregate formation and stability (Bach and Hofmockel, 2014).

A soil surface exposed to rainfall is subjected to processes of wetting and drop impact which can lead to the formation of a seal during the rainfall, reducing infiltration and increasing erosion by increasing runoff (Panel et al., 2003). Soil aggregate breakdown caused by rainfall is a critical part of soil erosion (Xu et al, 2021; Shan et al., 2018). The raindrops break up soil aggregates, although raindrops also have a sorting effect on the aggregate fraction size (An et al., 2021): macroaggregates are split, and microaggregates are transported, which results in a redistribution of the aggregate size, and the destruction of the topsoil structure during rainfall. Zhao et al. (2022) and Vaezi et al. (2018) also reported that the broken and transported small aggregates block the surface-soil pores, form crusts and enhance the turbulence intensity of the thin-layer runoff, which results in the enhanced soil-erosion capacity by rainfall. Therefore, aggregate breakdown and transportation under rainfall have an important impact on changes in the soil structure. The study of aggregate breakdown and transportation under rainfall has mainly focused on raindrop detachment and splash transport (Sophie et al., 2020; Li et al., 2021)). Liu et al. (2016) conducted simulation rainfall experiments (rainfall intensity: 90 mm h−1; rainfall duration: 45 min) in a cylindrical container with drainage holes, and the splash erosion was relatively stable in the later period of rainfall. It was found that the total mass of the splash erosion increased as a power function (rainfall intensity: 58 mm h−1; rainfall duration: 61 min). The mass of splashes would increase with the increasing rainfall duration. Legout et al. (2005) found that the splash erosion mass and mean weight diameter (MWD) of silty clay loam were the maximum only at a near transport distance. However, most researchers believe that the higher the MWD of splash erosion aggregates, the smaller the splash erosion amount should be.

The formation of soil aggregates is on basis of complex interactions between soil particles and the divergent biotic and abiotic binding agents. These may include adsorption of organic matter to clay minerals, microbial occlusion within aggregates, gluing particles by water, clay particles, humic substances, root exudates, fungal hyphae, etc., and cementation of fine particles by inorganic materials such as carbonates and iron or aluminum oxides (Pihlap et al., 2021). Based on the aggregate hierarchy model, soil organic matter is a significant contributor to the aggregate formation and stability (Six et al., 2004). Since soil organic matter content is influenced by management practices in agricultural systems, the size of the organic matter pool may also vary. Previous studies have shown that the application of organic amendments (such as chicken dung) is a potential source of organic matter in the soil. Hence, the application of organic amendment is expected to enhance soil aggregate formation and stability as an effective interparticle binding agent that would improve the mechanical strength of soil aggregates (Six and Pastian., 2014, Mizuta et al., 2015, Jiang et al., 2017) through the supply of organic matter to the soil.

The application of farmyard manure (FYM) to arable soils has been a management practice for many centuries and is associated with a stabilized soil. Research has shown that that both FYM and straw-amended plots had improved mean weight diameter (MWD) of soil (Blair et al., 2006). There are new sources of organic matter for field applications. It is apparent therefore that, study that would improve soil aggregate stability would serve as a means of finding ways of improving food production, environmental protection, and better social life. Information on the effectiveness of chicken dung application in soil stabilisation is inadequate in the region for practical planning and management of soils. Soil aggregate stability also is one factor that has not received adequate attention, especially in the semi-arid region of Nigeria, therefore, the present study is aimed at examining the effects of organic material (Chicken dung) incorporation on the soil aggregate stability of some agricultural soils under varied rainfall depths.

**MATERIALS AND METHODS**

**Location and Treatments**

A rainfall simulator experiment was conducted to determine the effect of raindrop on dispersing soil aggregate. The experiment was conducted at the Department of Agricultural and Environmental Resource Engineering, Faculty of Engineering, University of Maiduguri. The experiment involved three different soil textures (sandy, sandy clay and clay soil texture) incorporated with and without chicken dung organic material.

**Experimental Procedure**

Three soils classified using the USDA textural triangle as sandy, sandy clay and clay were used for the study. These soils represent majority of the agricultural soils of north-eastern region of Nigeria (Kindersley, 1999). The samples were collected from the top l m of soil profiles in two selected locations in Borno State and air dried. A chicken dung organic material was added at 2% (w/w) to each of the samples. The samples were worked through manually and subjected to horizontal shaking in a specially constructed tray. This made the soils to form aggregates of varying sizes. The so-formed aggregates were then sieved in specially prepared sieves in a similar fashion with the normal mechanical sieve analysis of soil samples into (A) 2-4 mm and (B) 6-8 mm diameters. The sub-samples were then labelled as SA, SB, SCA, SCB, CA and CB. Where A and B refer to samples belonging to aggregates sizes 2-4 mm and 6-8 mm in diameter, respectively and S, SC and C refer to sandy. sandy clay and clay soils. The control (untreated) samples were labelled SCAc, SCBc, CAc and CBc. Subscript ‘c’ refers to control sample without the organic material. No control sample for sandy soil due to their inability to form aggregate sizes. Each of the samples was filled into a 90 cm x 20cm deep metal core and their antecedent moisture contents were determined following the gravimetric method (Yaji, 2003) and placed directly below the perforated box of the rainfall simulator. Rain was then allowed to fall from the box at an intensity of 228.6mm/hr for varying durations of 1, 2, 3, 4, 5, 10, 15, 20, 25 and 30 minutes. After each rainfall simulation, each of the core was emptied and sieved in a dispersing liquid medium (sodium hexametaphosphate) to clearly distinguish between a stone and a range of sandy particles.

Measuring cylinders were also kept in between the core to collect water, from which the depth, d (mm) of rain that fell was calculated using d = x/A; where x = volume of the rain and A = area of the cylinders (mm2).

The weights of stones and sand were then subtracted from the original weights of the aggregates adopting (Lal, 1990); and the percentage soil aggregate stability (SAS) was calculated.

SAS = 100

W here:

Wa = weight of aggregate retained after rainfall simulation (g)

WS = weight of stone (g}

Wt = tota1 (original) weight of the sample (g)

**Description of Rainfall Simulator**

A rainfall simulator assembly (Atiwrucha, 1988), consisted of a perforated box of 65 cm x 45 cm x 20 cm made of 1 mm thick galvanized iron sheet and raised by two adjustable stands was used for the experiment. The perforations were 3 mm wide and 10 mm apart. A 56 cm internal diameter (d) and 90 cm deep container which serve as overhead water tank was also raised to a height of 3.0 m beside the simulator. Water was pumped mechanically from a borehole or a reservoir into the overhead tank via a 25 cm diameter flexible hose. Water was delivered into the simulator from the overhead tank via another flexible hose of the same size. The apparatus simulates rainfall at a height of 2.65 m

**Simulator Calibration**

The simulated rain was allowed to fall for 15 seconds. Five-1000 ml Cylinders were randomly placed under the perforated box to collect the simulated rainfall. The average depth of rain that felt was calculated for each of the selected period from which the intensity (I) and the Kinetic Energy (KE) of the rain that fell were computed adopting Hudson (1965) method:

Isr = d/t and

KEsr = 8.95 + 8.44 log Isr.

Where Isr = intensity of the simulated rainfall (mm/hr), d = depth of the rain (mm) and t = duration of the rainfall (hr) and KEsr = kinetic energy of the simulated raindrop ((Jm-2 mm-1).

A stopwatch was used to measure the rainfall duration KEsr = the Kinetic Energy of the simulated rain (Jm-2 mm-1).

**RESULTS AND DISCUSSION**

In the course of the experiment, all sandy soil sample dispersed completely, showing zero degree of aggregation. This implies that the 2% percent organic material was grossly inadequate to stabilise sandy soils. It has been demonstrated that chicken dung organic material cannot stabilise sandy soils, there is need therefore to increase the quantity of organic material, change the type of organic material, or use it in conjunction with another organic material. Generally, the percentage of soil aggregate stability of both the sand clay and clay soils studied exhibited a reciprocal relationship with depth of rainfall irrespective of the aggregate sizes and with or without organic material incorporation (Table l).

**Table 1: Percentage aggregate stability of sandy clay and clay soils**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rainfall Duration (mins) | Rainfall Depth  (mm) | SCA | SCAc | SCB | SCBc | CA | CAc | CB | CBc |
| 1 | 3.81 | 12.20 | 3.80 | 20.75 | 55.13 | 14.00 | 2.10 | 65.25 | 8.12 |
| 2 | 7.62 | 11.20 | 2.87 | 18.75 | 50.62 | 13.10 | 1.18 | 60.75 | 6.13 |
| 3 | 11.43 | 10.75 | 2.70 | 16.90 | 23.66 | 11.60 | 0.76 | 33.90 | 2.23 |
| 4 | 15.24 | 8.00 | 1.79 | 15.45 | 20.84 | 10.75 | 0.48 | 31.00 | 1.57 |
| 5 | 19.05 | 6.30 | 1.57 | 10.82 | 13.98 | 9. 10 | 0.32 | 23.05 | 0.92 |
| 10 | 38.10 | 5.25 | 1.23 | 8.14 | 7.73 | 6.25 | 0.27 | 17.75 | 0.81 |
| 15 | 57.l5 | 4.10 | 0.00 | 6.18 | 6.17 | 5.35 | 0.00 | 16.20 | 0.24 |
| 20 | 76.20 | 3.10 | 0.00 | 5.14 | 3.72 | 4.25 | 0.00 | l3.7S | 0.21 |
| 25 | 95,25 | 1.60 | 0.00 | 4.21 | 1.63 | 3.62 | 0.00 | 11.65 | 0.00 |
| 30 | 114.15 | 1.75 | 0.00 | 2.10 | 0.00 | 1.52 | 0.00 | 5.25 | 0.00 |
| CV | - | 61.46 | 101.42 | 61.52 | 111.34 | 54.52 | 133.22 | 71.49 | 139.45 |

Key: SCA = sandy clay (2-4 mm) with chicken dung, SCAc = sandy clay (2-4 mm) without chicken dung, SCB = sandy clay (6-8 mm) with chicken dung, SCBc = sandy clay (6-8 mm) without chicken dung, CA = clay (2-4 mm) with chicken dung, CAc = clay (2-4 mm) without chicken dung, CB = clay (6-8 mm) with chicken dung, CBc = clay (6-8 mm) without chicken dung.

The chicken dung incorporation had however, improved the stability of the structure of both the soils relative to the controls. The degree of stability however, varied with the soil type and aggregate sizes. Aggregate sizes 2-4 mm of both the soils showed poor resistance to rain drop forces as the rainfall depth increases compared to the aggregate size 6-8 mm (Table 1), but both performed far better than the control samples. For example, from 10th minute of rainfall, aggregate sizes 2-4 mm of sandy clay without the organic amendment got dispersed completely. Aggregate sizes 6-8 mm of sandy clay soil without amendment though not completely dispersed were mostly carried away compared to those of clay soil. This was attributed to insufficient organic material content in the smaller aggregate sizes that is responsible for organic-inorganic linkage (Pihlap et al., 2021). This implies that small sized aggregates are more vulnerable to detachment and transportation even by light rain drops and that clay soils are more resistant to detaching forces of water. These observations are buttressed by reports of Lal (2004), Six et al. (2004), Six and Paustian (2014). Mizuta et al. (2015) and Jiang et al. (2017). Furthermore, it was observed that clay soil aggregates were more stable than sandy clay soils irrespective of aggregate sizes (Table 2). It can be seen that even at 30th minute of rainfall with correspondingly highest depth of rainfall, there was over 100% increase in stability of clay soils over sandy clay soils in 2-4 mm aggregate sizes. This increase in stability was up to 150% in 6-8 mm aggregate sizes. Smaller aggregates are therefore more vulnerable to erosion, irrespective of soil type. This conforms the reports of Vaezi et al. (2018) and that of Zhao et al. (2022). This demonstrates the dangers associated with fine tillage and advocates for the need to till soils roughly with moderately larger clods to permit adequate infiltration of water and reduced soil erosion. This suggests that sandy clay and clay soils should not be tilted finely as this will encourage high erodibility, water logging, reduced infiltration and permeability and hence lower water holding capacities, This would result into crop yield depression and environmental degradation.

**Table 2: Comparing aggregate stability (%) within the same aggregate size**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Rainfall Duration (mins)** | **Rainfall depth (mm)** | **CA** | **SCA** | **% difference** | **CB** | **SCB** | **% difference** |
| 1 | 3.81 | 14.00 | 12.20 | 14.75 | 65.25 | 20.75 | 214.46 |
| 2 | 7.62 | 13.10 | 11.20 | 16.96 | 60.75 | 18.75 | 224.00 |
| 3 | 11.43 | 11.60 | 10.75 | 7.91 | 33.90 | 16.90 | 100.59 |
| 4 | 15.24 | 10.75 | 8.00 | 34.38 | 31.00 | 15.45 | 100.64 |
| 5 | 19.05 | 9.10 | 6.30 | 44.44 | 23.05 | 10.82 | 113.30 |
| 10 | 38.10 | 6.25 | 5.25 | 19.05 | 17.75 | 8.14 | 118.06 |
| 15 | 57.l5 | 5.35 | 4.10 | 30.49 | 16.20 | 6.18 | 162.14 |
| 20 | 76.20 | 4.25 | 3.10 | 37.10 | l3.75 | 5.24 | 162.4 |
| 25 | 95,25 | 3.62 | 1.60 | 126.25 | 11.65 | 4.21 | 176.72 |
| 30 | 114.15 | 1.52 | 0.75 | 102.67 | 5.25 | 2.10 | 150.00 |
| **CV** |  | 54.52 | 61.46 | **-** | 71.49 | 61.52 | **-** |

Key: SCA = sandy clay (2-4 mm), SCB = sandy clay (6-8 mm), CA = clay (2-4 mm), CB = clay (6-8 mm).

**CONCLUSION**

Soil aggregate stability as an essential parameter that directly or indirectly influences soil productivity was investigated together with addition of chicken dung organic material to influence the stability. The study revealed that incorporation of the chicken dung organic material into sandy clay and clay soils have resulted into a tremendous success towards stabilising the aggregate of both the soils, but not sandy soils. The success was however higher in clay than with sandy clay soil. For better soil aggregate stability of sandy clay, organic material addition has to be more than 2% (w/w). Also, it has been found that finely tilted soils are more prone to erosion danger with or without a stabilising agent irrespective of soil type. It is recommended here that chicken dung can be used to stabilize soils against erosion hazards. It can be recommended that further research be conducted with higher percentages of chicken dung and in conjunction with other types of organic material to assess their effectiveness in stabilising soils.

**REFERENCES**

# An, J.; Wu, Y.Z.; Wu, X.Y.; Wang, L.Z.; Xiao, P.Q. (2021). Soil aggregates loss affected by raindrop impact and runoff under surface hydrologic conditions within contour ridge systems. Soil Tillage Res., 209, 104937.

# 

# Bach, E.M. and Hofmockel, K. S. (2014). Soil aggregate isolation method affects measures of intra-aggregate extracellular enzyme activity. Soil Biology and Biochemistry, 69: 54-62. <https://doi.org/10.1016/j.soilbio.2013.10.033>

Blair, N, Faulkner, R. D., Till, A. R. and Poulton, P. R. (2006). Long-term management impacts on soil C, N and physical fertility Part I: Broadbalk experiment. Soil and Tillage Research, 91: 30-38.

# Jiang, P. M., Wang, X., Liusui, Y., Han, C., Zhao, C., and Liu, H. (2017). Variation of soil aggregation and intra-aggregate carbon by long-term fertilization with aggregate formation in a grey desert soil. Catena, 149(1): <https://doi.org/10.1016/j.catena.2016.10.021>[Get rights and content](https://s100.copyright.com/AppDispatchServlet?publisherName=ELS&contentID=S0341816216304398&orderBeanReset=true)

Lal, R. (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science, 304: 1623-1627. <https://doi.org/10.1126/science.1097396>

# Legout, C.; Leguédois, S.; Bissonnais, Y.L.; Issa, M. (2005). Splash distance and size distributions for various soils. Geoderma, 124, 279–292.

# Li, H.R.; Liu, G.; Gu, J.; Chen, H.; Shi, H.Q.; Abd Elbasit Mohamed, A.M.; Hu, F.N. (2021). Response of soil aggregates disintegration to the different content of organic carbon and its fraction during splash erosion. Hydrol. Process.1, 35, 14060.

# Liu, T.; Luo, J.; Zhang, Z.C.; Li, T.X.; He, S.Q. (2016). Effects of rainfall intensity on splash erosion and its spatial distribution under maize canopy. Nat. Hazards Rev., 84, 233–247.

Mizuta, K. Taguchi, S. and Sato, S. (2015). Soil aggregate formation and stability induced by starch and cellulose. Soil Biology and Biochemistry, 87: 90-96. https:// doi.org/10.1016/j.soilbio.2015.04.011

Panel, M., Ramos, C., Nacci, S. and Pla, I. (2023). Effect of raindrop impact and its relationship with aggregate stability to different disaggregation forces. Catena, 53(4): <https://doi.org/10.1016/S0341-8162(03)00086-9>[Get rights and content](https://s100.copyright.com/AppDispatchServlet?publisherName=ELS&contentID=S0341816203000869&orderBeanReset=true)

Pihlap, E., Steffens, M., and Kögel-Knabner, I. (2021). Initial soil aggregate formation and stabilisation in soils developed from calcareous loess. Geoderma, 385. <https://doi.org/10.1016/j.geoderma.2020.114854>[Get rights and content](https://s100.copyright.com/AppDispatchServlet?publisherName=ELS&contentID=S0016706120326094&orderBeanReset=true)

# Shen, H.-O.; Wen, L.-L.; He, Y.-F.; Hu, W.; Li, H.-L.; Che, X.-C.; Li, X. (2018). Rainfall and inflow effects on soil erosion for hillslopes dominated by sheet erosion or rill erosion in the Chinese Mollisol region. J. Mt. Sci., 15, 2182–2191.

Six, J. and Paustian, K. (2014). Aggregate -associated soil organic matter as an ecosystem property and a measurement tool. Soil Biology and Biotechnology, 68: A4-A9. <https://doi.org/10.1016/j.soilbio.2013.06.014>

Six, J., Bossuyt, H., Degryze, S. and Denef, K. (2004). A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil and Tillage Research, 79(1): 7-31.

Sonsri, P., K. and Watanabe, A. (2023). Insight into the formation and stability of soil aggregates in relation to the structural properties of dissolved organic matter from various organic amendments. Soil and Tillage Research, 232: <https://doi.org/10.1016/j.still.2023.105774>[Get rights and content](https://s100.copyright.com/AppDispatchServlet?publisherName=ELS&contentID=S0167198723001411&orderBeanReset=true)

# Sophie, L.; Olivier, P.; Cédric, L.; Yves, L.B. (2005). Splash Projection Distance for Aggregated Soils. Soil Sci. Soc. Am. J., 69, 30–37.

Stroud, J. L., Kemp, S. J., and Sturrock, C. J. (2023). The effect of organic matter amendments on soil surface stability in conventionally cultivated arable fields. Soil Use and Management, 40(1): <https://doi.org/10.1111/sum.12985>

# Vaezi, A.R.; Eslami, S.F.; Keesstra, S. (2018). Interrill erodibility in relation to aggregate size class in a semi-arid soil under simulated rainfalls. Catena, 167, 385–398.

# Xu, L.; Zhang, D.; Proshad, R.; Chen, Y.-L.; Huang, T.-F.; Ugurlu, A. (2021). Effects of soil conservation practices on soil erosion and the size selectivity of eroded sediment on cultivated slopes. J. Mt. Sci., 18, 1222–1234.

# Zhao, Y.; Wang, H.; Chen, X.; Fu, Y. (2022). Effect of Rainfall on Soil Aggregate Breakdown and Transportation on Cultivated Land in the Black Soil Region of Northeast China. Sustainability 14, 11028. https://doi.org/10.3390/ su141711028