



SOIL AGGREGATE STABILITY AND CHEMICAL PROPERTIES: EFFECTS OF DIFFERENT SIZE FRACTIONS OF BLACK SOLDIER FLY DERIVED COMPOST

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Abstract

An incubation experiment was carried out to observe the effects of black soldier fly larvae derived compost (BSC) on aggregate stability with respect to mean weight diameter (MWD) and the changes in soil organic matter (OM), exchangeable calcium (Ca) and magnesium (Mg) contents. To achieve the goal, sandy loam surface was incubated with BSC having two different size fractions (e.g., <125 μm and 250–500 μm) at the rates of 1% and 2% (w/w) on the dry weight basis. The MWD of soil aggregates was measured by wet sieving method. The results of the experiment revealed that the MWD potentially improved with the application of BSC, especially at higher application rates and with finer particle sizes. When compared to the control, the soil OM content was found significantly ($p < 0.05$) higher in all BSC treatments, with finer fraction (<125 μm) showing the maximum increases. The contents of exchangeable Ca and Mg were also found to be higher in BSC treated soils with better response at higher rates of incorporation and fine manure fraction. Multiple linear regression revealed that the MWD was positively associated with OM, Ca and Mg, though the effect was significant as for Ca and Mg ($p < 0.05$). Besides, soil OM was positively related with the concentrations of exchangeable Ca and Mg with significant ($p < 0.05$) effect as for exchangeable Ca only. Overall, this research highlights the potential of BSC as an amendment to improve stability of soil aggregates as well as the availability of nutrients for sustainable crop production.

Key words: aggregate stability, di-valent cations, mean weight diameter, organic matter.

INTRODUCTION

The incorporation of organic manures in agricultural land is encouraged because of the relatively low organic matter (OM) content and several benefits in soils over the inorganic fertilization alone. While organic fertilizers offer slow nutrient release reducing nutrient loss, inorganic fertilizers are heavily associated with significant environmental and ecological costs (Rostaei et al., 2024; Zhao et al., 2024; Phiri et al., 2025). Organic manures are derived from a variety of sources such as animal–cow manure (CM), sheep manure (SM) and poultry manure (PM); crop residues– rice husk (RH), wheat straw (WH) and rice straw (RS), and specific biologically processed– vermicompost (VC), trico compost

(TC) and black soldier fly derived compost (BSC) (Karami et al., 2012; Wang et al., 2013; Rahman et al., 2022; Qiang et al., 2024). Moreover, the BSC generates compost quickly while keeping high quality and improved soil nutrient status, it might take weeks or months for conventional compost to become useful. The BSC is derived from various organic wastes, such as food scraps, agricultural residues, and livestock manure by black soldier (*Hermetia illucens*) fly larvae, which efficiently bioconverts wastes into valuable co-products in a remarkably short time frame (5 weeks) (Terrell et al., 2025; Unagwu et al., 2025; Zaato et al., 2025). The BSC is a nutrient-dense organic fertilizer which contains a higher amount

of organic carbon (OC) and acts as the key source of macro and micronutrients even compared to widely used composted CM (Karami et al., 2012; Phiri et al., 2025; Unagwu et al., 2025). Compost enhances the quality of soil by augmenting its physical, chemical, and biological characteristics. Organic manures improve soil structure, water retention, and aeration physically; enriches nutrients and stabilizes pH chemically; and fosters beneficial organisms biologically (Mokolobate et al., 2002; Begum et al., 2025; Iraj et al., 2025). Some investigations demonstrated the importance of particle size of organic fertilizers in modifying soil characteristics (Liang et al. 2016; Głąb et al., 2025). The size of manure particles affects essential physical characteristics of soil, including bulk density and total porosity. In a study, Trifunovic et al. (2018) observed an increase in saturated water content in sandy soil following the application of biochar particles smaller than 2 mm. Similarly, Roy et al. (2025) found that the saturated hydraulic conductivity of loam and sandy loam soils decreased with the decrease of vermicast sizes. Although the effects of manure particle sizes on soil properties is governed by such common mechanisms as surface area, microbial accessibility, and pore arrangement, the degree and extent of the effects depends on the properties of manures. Therefore, we designed an experiment to evaluate the effects of different sizes and application rates of BSC on soil aggregate size and stability, as soil aggregates are the critical component of soil structural integrity.

Soil structure, which play a significant role in sustaining soil health and quality, is fundamentally regulated by the quantity and arrangement of stable aggregates. Soil aggregation is the process by which particles of individual sizes are bound together by organic and inorganic materials (Zhang et al., 2016; Garba et al., 2020). Besides, the structure and behavior of aggregates formed by organic materials are crucial for understanding their fate and transport in soil and aquatic environment (Khodir et al., 2020). The mean weight diameter (MWD) of soil aggregates is a critical measure of the strength of soil structure and a crucial factor

in soil fertility and environmental aspect. The MWD of soil aggregates is influenced by multiple factors, including soil OC, polyvalent ions, soil microbes, and such anthropogenic factors as tillage operation and fertilization (Li et al., 2007; Karami et al., 2012; Park et al., 2021; Qiang et al., 2024). Organic fertilizer acts as a binding agent, which helps to enhance the soil aggregation (Abiven et al. 2009; Wang et al. 2019). Application of organic fertilizer not only increases the aggregation of soil but also increases the content of essential elements in soils required for plants. Previous studies have shown that among the driving forces, soil OC and polysaccharides are the principal factors influencing the stability of soil aggregates (Wang et al. 2019; Ren et al., 2025). Macro-aggregates (larger than 250 μm) are bound largely by plant roots and fungal hyphae, while micro-aggregates (20–250 μm) are linked together by persistent OM, oxides of silicates (Nichols & Halvorson, 2013).

The effects of organic amendments originating from plant and animal sources as the key component to improve soil physico-chemical properties, microbial functions and soil restoration have long been researched (Csitári et al., 2021; Roy & Chowdhury, 2021; Wang et al., 2013; Qiang et al., 2024; Begum et al., 2025). However, the changes in soil behavior as a result of BSC addition is rarely investigated in the recent years (Phiri et al., 2025; Terrell et al., 2025; Zaato et al., 2025). Moreover, the influence of manure particle sizes of BSC on the stability of aggregates has not yet been investigated to the best of our knowledge. Therefore, the present research was done to study the effects of BSC with two different rates and sizes on the MWD, soil OM levels, exchangeable Ca and Mg. This research also focused how OM, Ca and Mg levels regulate the MWD of soil. The hypothesis was that the addition of BSC will have a positive effect on MWD, OM, Ca and Mg levels in soils. The results of the present research would provide a basis for understanding the aggregate distribution as result of BSC application and ultimately the resistance of soils against erosion in future research.

MATERIAL AND METHODS

Soil sampling and preparation

To set up the experiment, bulk soil samples were collected besides the research field of Soil Science department of the University of Chittagong. Before collection of soil samples, the thin layer of the surface was removed by a spade. After collection, the roots and unwanted plant materials were sorted from the bulk soil samples. Soil samples were then allowed to dry by spreading on a polythene sheet followed by

sieving through 2 mm stainless steel sieve. A portion of the sieved soil samples were used for the routine analysis while another portion was used for setting up of the incubation experiment with BSC. The initial properties of the soil samples are given in Table 1. The soil was sandy loam in texture with 68% sand, 15% silt and 17% clay. The OM content was 1.23%. The concentrations of exchangeable Ca and Mg were 2.86 and 1.46 Cmol/Kg, respectively.

Table 1. Physio-chemical properties of the soil samples.

Parameters	Properties
Sand (%)	68
Silt (%)	15
Clay (%)	17
Texture	Sandy loam
OM (%)	1.23
Ca (Cmol/Kg)	2.86
Mg (Cmol/Kg)	1.46

BSC sampling and preparation

The BSC was collected from a farm located in Raozan Upazila of Chattogram district, Bangladesh where the compost was prepared from municipal food scraps by the help of black

soldier fly larvae. After collection of manures from the farm, the samples were air dried for a few days followed by sieving through different mesh sizes to get <125 µm and 250–500 µm sized fractions (Figure 1).



Figure 1. Different size fractions of BSC.

The sieved manures were analyzed for analysis of different properties (Table 2) before setting-up of the experiment. Fine sized (<125 µm) manures had relatively lower content of

OM compared to coarse sized (250–500 µm) manures. In contrast, both the total contents of Ca and Mg were found to be higher in fine sized manures.

Table 2. Important chemical properties of BSC.

Manure type	Manure sizes	OM (%)	Ca (%)	Mg (%)
BSC	<125 µm	21.80	1.45	1.04
	250–500 µm	29.85	1.42	0.50

Experimental design and incubation

The experiment was performed in laboratory condition in the Soil Science department of University of Chittagong. An amount of 100 g soil was incorporated with <125 µm and 250–500 µm sized manures at the rates of 1% and 2% (w/w) on dry weight basis. Required amount of manures was weighted and mixed homogeneously with soil. The incorporation of <125 µm and 250–500 µm sized BSC at 1% and 2% rates resulted five treatments along with control (Control; BSC- 1%, <125 µm; BSC- 1%, 250–500 µm; BSC- 2%, <125 µm; BSC- 2%, 250–500 µm). All the treatments (control and spiked soils) were put in plastic pots with replication and arranged in completely randomized way. The incubated soils were moistened with distilled water in order to keep moisture level

approximately at 60% of field capacity. The soils were incubated for a period of 60 days.

Analytical methods

The percentage of soil particles was determined by hydrometer method as described by Huq & Alam (2005) followed by textural class determination by using Marshall's triangular coordinates. The MWD of soil aggregates was measured by wet sieving method following the procedure as described in Emadi et al. (2008). To do this, soil samples were placed on the topmost sieve of a nest of sieves (2.0, 1.0, 0.5, 0.25 mm) and immersed in water followed by vertically moving the sieves for 50 times during a span of 2 minutes. Then, the soil samples remaining in each sieve were dried in an oven at 105°C and weighted for the determination of MWD by using the following equation:

$$MWD = \sum_{i=1}^n X_i W_i$$

Where, X_i = Mean diameter of a particular size range of aggregates (mm)

W_i = Dry weight of aggregates in a particular size range (g)

Methodology The OC contents of soils and manures were assessed by Walkley and Black's dichromate oxidation technique and multiplied the value by 1.72 to convert it into OM (Nelson & Sommers, 1982). For the determination of total Ca and Mg in the manures, the samples were digested with HNO_3 - $HClO_3$ acid mixture, while for the determination of exchangeable Ca and Mg in soils, the soil samples were extracted with 1N NH_4OAc followed by determination in the digests and extracts by ethylenediaminetetraacetic acid (EDTA) method (Gupta, 2001).

The two-way analysis of variance (ANOVA) followed by presentation of the figures was done through R software (version 4.5.1). In each figure, mean separation indicated by distinct lowercase letters confirmed significant differences among treatment means, while bars sharing the same letter were not significantly different according to post hoc multiple comparison tests ($p < 0.05$). Error bars represented the standard error of the mean reflecting the variability among replicates. Multiple linear regression among different parameters followed by visualization was also performed using R software (version 4.5.1).

Statistical analysis

RESULTS AND DISCUSSION

Effects of BSC on MWD of soil

Figure 2 shows the effects of different size fractions and rates of BSC on the MWD of soil aggregates. The changes in MWD with different sizes and rates indicated a dose-dependent response highlighting a potential stabilizing effect of BSC at higher application rates with finer sizes. Across manure sizes, the MWD decreased progressively from finer particles (<125 µm) to coarser ones (250–500 µm) and was lowest

in the absence of manure. Although, the MWD increased by the addition of BSC, particularly at higher application rates and finer manure sizes, the difference among the treatments was not significant ($p > 0.05$). The addition of BSC with size fraction of <125 µm at 2% rate increased the MWD more effectively over the control. For manure size <125 µm, the MWD values were 0.46 mm and 0.48 mm at 1% and 2% rates of incorporation, respectively, indicating a 25.92%

and 33.44% increase compared to the control. On the other hand, the addition of BSC at the rates of 1 and 2% resulted in 10.75% (0.40 mm)

and 20.21% (0.44 mm) increase over the control for the 250–500 μm size fraction.

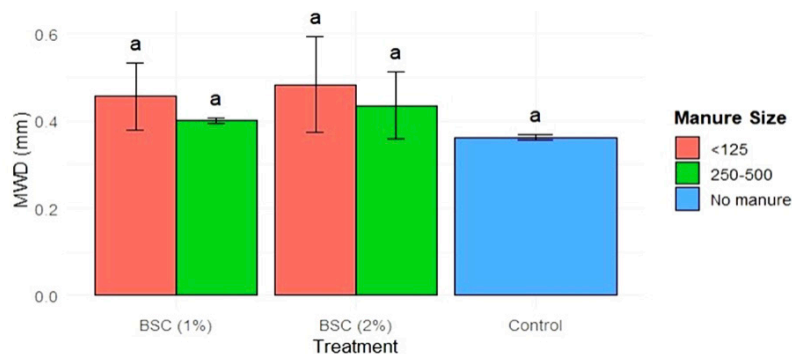


Figure 2. Effects of BSC rates and sizes on MWD.

The increase in MWD by the addition BSC, particularly at higher application rates and finer manure sizes suggested a beneficial role of BSC in improving soil aggregation. The increase in MWD particularly at finer organic fraction (<125 μm) under both rates of application could be due to greater surface area, greater cation exchange capacity and higher mineralization (Zhang et al., 2021). The results also indicated that larger manures particle or control reduced the stability of soil aggregates. Several authors reported greater MWD following the application of different sources of organic manures (Karami et al., 2012; Rahman et al., 2022). In a 3-year field experiment on greenhouse soil, Ren et al. (2025) reported that increase in OC was associated with the increase of soil aggregates, highlighting OC as the main reason for improving soil aggregate stability. In a study, Unagwu et al. (2025) found that the addition of BSC resulted in 20.4–49.5% higher aggregate stability compared to non-treated soils, and is comparable with our findings of this investigation for manure size <125 μm . In another study, Głąb et al. (2025) observed that larger compost particles (1.0–2.0 mm) were associated with higher impact on soil physical behavior than smaller particles (<1.0 mm), although finer manure particles (0.5–1.0 mm) were responsible for with greater water repellency. However, non-significant difference in MWD in our study could be due to little response of soils to the applied dose of BSC and studied incubation period. Dunjana (2012) also did not find significant improvement in soil aggregation due to application of CM even at higher doses in sandy soils indicating the importance of substantial quantity of organic manures for

significant improvement in soil aggregation. Aggregate stability of soils vary over time due to climatic conditions, agricultural practices (tillage or no tillage) and the decomposition of fresh organic input. Depending on stage of decomposition and inputs of organic manures, soil aggregation varies differently over weeks to years. Green manure shows intense effects within a month on aggregate stability, while decomposed manure has small initial effects but lasting impacts. The short-term effects of OM on aggregate stability are linked to microbial products and the long-term effects come from humified compounds (Abiven et al., 2009).

Effects of BSC on OM content

Figure 3 shows the effects of different rates and sizes of BSC on soil OM content. The results showed that OM content significantly increased ($p < 0.05$) with the application of BSC compared to the control. The highest OM was observed under the BSC (2%) treatment followed by BSC (1%) treatment, regardless of the manure size, while the control exhibited the lowest OM in soil. Moreover, manure size had a comparatively minor effect on OM for the same rate of BSC application pointing statistically non-significant ($p > 0.05$) effect. The control, which received no manure, had the lowest OM, indicating minimal improvement in soil OC status under untreated condition. In contrast, both BSC (1%) and BSC (2%) treatments exhibited markedly higher OM contents, suggesting that BSC application effectively promoted OM accumulation in soil. Besides, the highest OM under BSC (2%) treatment was found in soils treated with larger sized manure (250–500 μm).

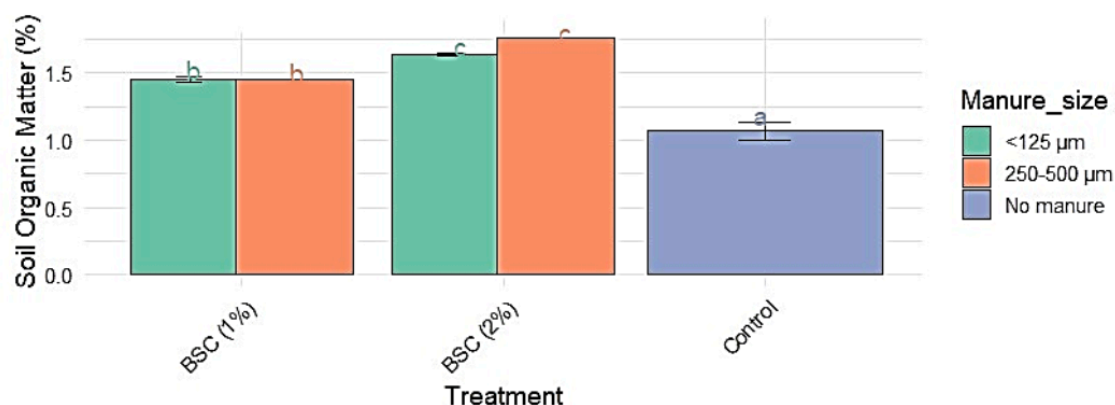


Figure 3. Effects of BSC rates and sizes on OM (%) content of soil.

The increase in OM with the increase of application rates of organic manures is extensively documented. Several authors reported increase in OM content in soils with the increase of application rate (Csitári et al., 2021; Semenov et al., 2023; Ren et al., 2025). Organic materials such as compost, biochar, manure, and crop residues contribute substantial addition of decomposable and stable organic compounds, resulting in enhanced microbial activity. This ultimately causes the formation of stable humic substances thereby increasing accumulation of OM in soil (Lehmann & Joseph, 2015; Agegnehu et al., 2016). This could be ascribed to both direct input of OC as well as improvements in soil structure that reduce carbon loss through erosion. Powlson et al. (2011) also reported that application of amendment with higher rates significantly increased OC due to higher rate of accumulation compared to decomposition losses due to greater inputs of organic materials. However, the amount of OC in manures varies with nature of manures either raw or composted, source of manures, size of manure particles and rate of application of manures (Li et al., 2007; Sodhi et al., 2009). Semenov et al. (2023) stated that small sized manures had little contribution to OC content in soils in comparison to larger sized manures, which could be due to higher decomposition of comparatively finer manure particles. Liang et al. (2014) also observed that the distribution and storage of OC are mainly concentrated in macro-aggregates. In another experiment, Li et al. (2015) found that organic

fertilizer application did not significantly affect the OC content in soils, especially in aggregates greater than 2 mm and less than 0.053 mm.

Effects of BSC on exchangeable Ca and Mg

The influence of application rate and manure size on soil exchangeable Ca concentration is illustrated in Figure 4. The results indicated that application of the BSC significantly ($p < 0.05$) increased Ca concentration over the control. The control exhibited the lowest Ca concentration ($2.89 \text{ Cmol kg}^{-1}$), whereas both BSC (1%) and BSC (2%) treatments enhanced Ca levels by 9.70-20.32% and 20.09-21.94%, respectively. Although the treatment BSC (2%) maintained slightly higher average Ca values than BSC (1%), the increase was more pronounced under BSC (1%) with fine manure particles ($<125 \mu\text{m}$), where Ca concentration increased by 9.46%. On the other hand, the increase in Ca content under BSC (2%) with fine manure particles ($<125 \mu\text{m}$) was 1.44%.

Although the concentration of Ca enhanced with the increase of application rate, the difference between two rates was not statistically significant ($p > 0.05$) for fine manure particles ($<125 \mu\text{m}$). This indicated that increasing the BSC rate beyond 1% did not further enhance Ca concentration for fine manure particles during the planned incubation period. Similarly, the difference between the size of BSC was insignificant ($p > 0.05$) at higher at of application (2%).

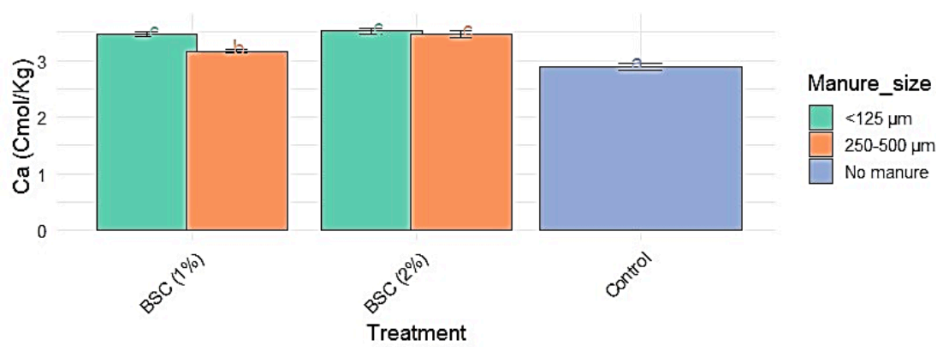


Figure 4. Effects of BSC rates and sizes on Ca (Cmol/Kg) concentration in soil.

Figure 5 shows the effects of BSC rate and manure size on soil exchangeable Mg concentration in soils. The application of the BSC at both 1% and 2% significantly enhanced the concentration of Mg in soil over the control. At higher rate of application (2%), the difference in Mg concentration between two manure sizes was higher. Besides, soils treated with finer manures (<125 µm) consistently displayed higher Mg values than those treated with coarser manures

(250–500 µm) for the same rate of application. The control had the lowest Mg concentration (1.38 Cmol/ Kg). At the 1% application rate, Mg concentrations increased by 45.54% relative to the control in the fine fraction (<125 µm) and 23.13% in the coarse fraction (250–500 µm). On the other hand, BSC (2%) with fine fraction (<125 µm) exhibited the highest Mg concentration, reaching 2.98 Cmol/Kg, corresponding to 115.66% increase compared to the control.

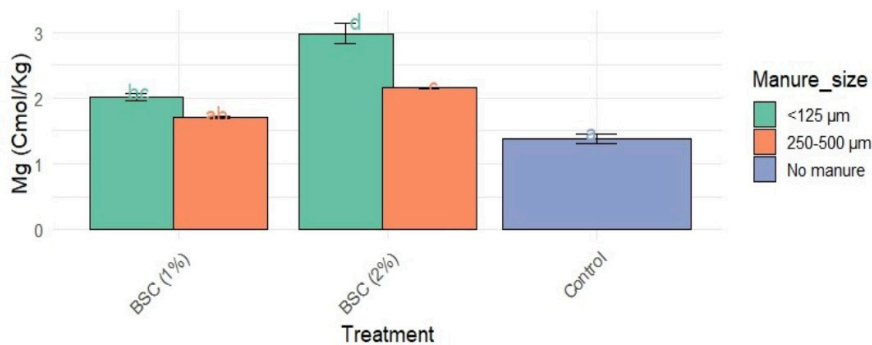


Figure 5. Effects of BSC rates and sizes on Mg (Cmol/Kg) concentration in soil.

In our present study, both increased rates and finer manure sizes of BSC contributed significantly to the concentration of Ca and Mg in amended soils compared to non-treated soils. In general, organic manures contain substantial quantities of Ca and Mg that are released in soil during the decomposition with time and their release is higher as higher rates of manure are applied. The present findings also suggested that increasing BSC rate substantially improved Ca and Mg concentrations, with finer manure particles contributing markedly to this effect by enhancing their availability in soil. Similar results were also observed in previous research

(Roy & Chowdhury, 2021; Zhang et al., 2021; Park et al., 2021; Nikolaou et al., 2023). The increase in Ca and Mg concentrations due to BSC application, especially with the increase of rate and decrease of manure size, could be due to greater mineralization of fine manures. Several researchers also observed that fine sized manure particles contributed to greater availability of base cations due to their greater surface area and enhanced microbial breakdown, resulting in quicker release of Ca and Mg compared to coarse manure particles (Calbrix et al., 2006; Roy & Chowdhury, 2024; Cong et al., 2025).

Relation of MWD with the amounts of OM, Ca, and Mg

The multiple regression shows that the MWD changed with the changes of OM, Ca, and Mg concentrations with positive associations (Figure 6). However, the association was more prominent with significant ($p < 0.05$) effect as for Ca and Mg showing the stronger co-efficient. As an independent variable, soil OM also had the positive association with the concentrations of exchangeable Ca and Mg indicating indirect synergistic effect in flocculating soil particles

(Figure 7). When compared across parameters, the positive relations of MWD with that of the OM, Ca and Mg indicated an integrative influence of OM, Ca and Mg rather than any single-variable on the stability of aggregates. Several researchers reported that soil OM and polyvalent (e.g., Ca and Mg) ions play a predominant role in stabilizing soil structure, likely by improving soil aggregation through organic-clay or mineral-clay interactions (Osman, 2012; Zhang et al., 2021; Ren et al., 2025).

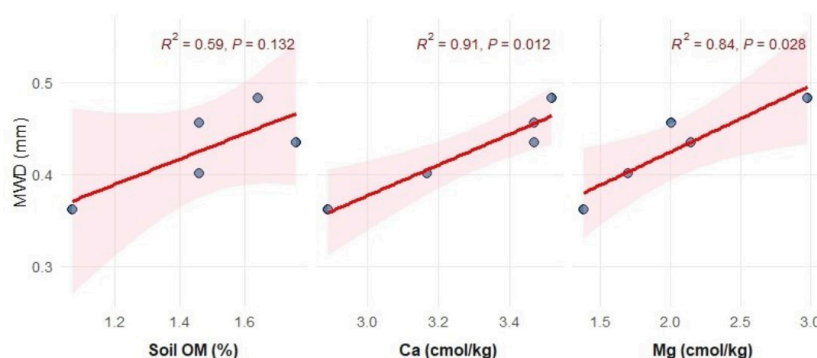


Figure 6. Relation of MWD (mm) with OM (%), Ca (Cmol/Kg) and Mg (Cmol/Kg) levels.

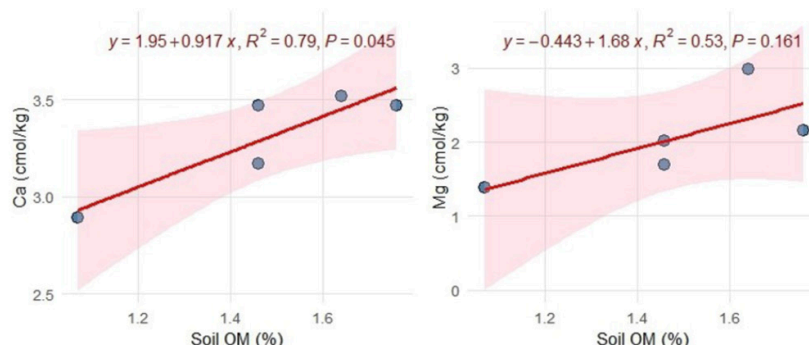


Figure 7. Relation of Ca (Cmol/Kg) and Mg (Cmol/Kg) with soil OM (%) level.

CONCLUDING REMARKS

This research revealed that BSC application improved soil physical and chemical qualities validating the proposed hypothesis. The application of BSC, especially at higher doses and finer fractions, potentially enhanced aggregate stability. The study also found that BSC addition increased exchangeable Ca and Mg concentrations- two essential nutrients that play an indirect but important role in binding soil particles and promoting aggregate stability. This study indicates that BSC can improve soil condition naturally when utilised properly with

small size fractions and the right proportions. It is expected that the results would contribute to the growing body of knowledge supporting BSC as a versatile soil amendment capable of improving both soil fertility and structure. Therefore, based on the findings of this study, it is recommended that BSC be integrated into soil fertility and land management practices, particularly in areas where soil structure and nutrient levels are declining. To get the best results, this compost needs to be used in the right amount depending on the type of soil and

requirement of plant. However, long-term field study under varied soil and climatic conditions is necessary to prove BSC's adaptability as a soil additive for safe and effective land management.

The production of BSC can provide an environmentally friendly route for converting biodegradable municipal waste into valuable soil conditioners. Municipalities and waste management authorities should come forward

to convert decomposable municipal wastes into this helpful compost. In addition, extension services should also provide training and awareness programs for farmers how to use BSC in the right way, so that they get the most benefit. Collectively, all these actions can enhance soil health, support sustainable agriculture, and contribute to environmentally responsible waste management.

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СТАБИЛНОСТ НА ПОЧВЕНИТЕ АГРЕГАТИ И ХЕМИСКИ СВОЈСТВА: ЕФЕКТИ ОД РАЗЛИЧНИ ФРАКЦИИ ПО ГОЛЕМИНА НА КОМПОСТ ДОБИЕН ОД ЛАРВИ НА ЦРНА ВОЈНИЧКА МУВА

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Резиме

Спроведен е инкубациски експеримент со цел да се испита влијанието на компост добиен од ларви на црна војничка мува (ЦВМ) врз стабилноста на почвените агрегати, изразена преку средниот тежински дијаметар (СТД), како и промените во содржината на органската материја (ОМ), изменливиот калциум (Са) и магнезиум (Мг) во почвата. За таа цел, површински слој на песоливо-глинеста почва беше инкубиран со ЦВМ во две различни големински фракции (на пр. <125 µm и 250–500 µm) во количини од 1 % и 2 % (w/w) врз основа на сува маса. СТД на почвените агрегати беше определен со методот на влажно просејување. Резултатите покажаа дека СТД значително се подобрува со примената на ЦВМ, особено при повисоки дози и кај фракциите со поситни честички. Во споредба со контролата, содржината на ОМ во почвата беше значително повисока ($p < 0,05$) кај сите третмани со ЦВМ, при што најситната фракција (<125 µm) покажа максимални зголемувања. Содржината на изменлив Са и Мг исто така беше повисока во почвите третирани со ЦВМ, со подобар ефект при повисоки дози на внесување и кај поситната фракција на органското ѓубриво. Повеќекратната линеарна регресија покажа дека СТД е позитивно поврзан со ОМ, Са и Мг, при што влијанието беше статистички значајно за Са и Мг ($p < 0,05$). Дополнително, ОМ во почвата беше позитивно поврзана со концентрациите на изменлив Са и Мг, при што статистички значаен ефект ($p < 0,05$) беше утврден само за изменливиот калциум. Општо земено, ова истражување го истакнува потенцијалот на ЦВМ како подобрувач на почвата за зголемување на стабилноста на почвените агрегати, како и за подобрување на достапноста на хранливите материи, што придонесува кон одржливо растително производство.

Клучни зборови: стабилност на агрегати, двоваленни катијони, среден тежински дијаметар, органска материја.