



Humic Acid as an Organic Biosurfactant in Amelioration of Physical Constraints of Sandy Soils

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil productivity is often attributed to soil structure, as fertile soil with ideal soil structure and adequate moisture level is considered productive. Soil structure is a key factor that influences the movement and retention of water in the soil, the pattern of soil erosion, the formation of crusts, nutrient recycling, root penetration, and the productivity of crops. The present study aims to assess the biosurfactant property of humic acid (HA) in weakly structured sandy soil. An incubation study was carried out by soil application of different doses of HA viz; 0, 2.5, 5, 10 and 15 kg ha⁻¹ for 30 days at field capacity. Soil supplemented with 15 kg ha⁻¹ HA was observed to have the highest percentage of water stable aggregates (WSA), water holding capacity (WHC), and porosity, and the lowest value for bulk density (BD), dispersion ratio (DR) and clay dispersion ratio (CDR). The study proves that applying HA at the aforementioned dosage can bring about a notable enhancement in the stability in poorly structured sandy soils. Such organic biomolecules capable enough to bring about consistent improvements to soil quality within a short period will be beneficial for alleviating major obstacles in sustainable agriculture.

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Keywords: Humic acid; biosurfactant; water stable aggregates; sandy soil.

1. INTRODUCTION

Sandy soils are primarily characterized by their texture, which greatly influences their physical properties. These soils typically lack strong aggregation, resulting in weak soil structure [1]. Low clay content results in poor water retention capacity and reduced nutrient availability, thereby hindering crop productivity [2]. Low water retention capacity of sandy soils also retards the biological activity of the soil. Furthermore, elevated levels of organic matter breakdown rates retard organic matter preservation in sandy soils [3]. Improvement of structural properties of sandy soil can be achieved through the addition of complex and resistant polymeric biomolecules such as humic substances.

Humic acid, a major constituent of humic substances has immense potential to improve soil fertility, soil structure, water holding capacity, and soil cation exchange capacity [4]. Soil application of HAs can be a sustainable alternative for improving many physical and chemical properties of sandy soil, resulting in increased yield and quality in crop plants [5]. The heterogeneous nature of HA due to hydrophilic acidic groups, hydrophobic aliphatic and aromatic groups, imparts biosurfactant property that improves water stable aggregates in soil. As HA has high soil aggregate formation efficiency that provides potential binding sites for chelating macro- and micro-nutrients and consequently improve soil fertility [6].

Sandy soils are water repellent, which causes reduced and uneven infiltration of water into soils and results in yield reduction in crops. Surfactants reduce the surface tension of water, allowing its easy penetration resulting in even wetting of soils. Biosurfactants can reduce the surface and interfacial repulsive forces between the two dissimilar phases and allow these two phases to become miscible. The application of biosurfactants in agricultural soils is anticipated to improve nutrient status, increase wettability, and achieve a more even dissemination of complex nutrients [7]. HA can modify soil properties and improve the bioavailability of plant nutrients, thereby stimulating photosynthetic activity [8] and enhancing productivity in sandy loam soil [9].

Surfactants like HA can promote the absorption and retention of nutrients and moisture in soil

[10]. Humic acid gets adsorbed on to the clay particle surfaces through bridging with polyvalent cations, forming humus-clay complexes. Humic acid improves the productivity and quality of the soil by increasing macroaggregate formation, carbon pool, soil fertility, soil cation exchange capacity, mineral nutrition and microbial activity [11]. Owing to the diverse reactive functional groups on the surface of HA such as $-\text{COOH}$, $-\text{OH}$ and $-\text{NH}_2$, there is a high tendency in the molecule to form stable colloidal aggregates. These stable aggregates provide potential binding sites for macro and micronutrients and consequently improve soil fertility [12]. With this background, the present study is focussed on providing clear insights on the effect of HA as a biosurfactant on various soil physical properties such as water stable aggregates (WSA), water holding capacity (WHC), bulk density (BD), particle density (PD), porosity, dispersion ratio (DR) and clay dispersion ratio (CDR) of sandy soil.

2. MATERIALS AND METHODS

2.1 Materials

Humic acid used in the present study was procured from the Department of Agriculture of Kerala accredited company, Rohini Agro Science, which is available in the trade name 'humic super shine'. Initially, the product was subjected to chemical characterization and the details are shown in Table 1. The soil used in the experiment was collected from Onattukara sandy plain, designated as AEU 3, a special agro-ecological unit in Kerala [13], geographically located between $9^{\circ} 30' 29''$ North (latitude) and $76^{\circ} 20' 75''$ East (longitude).

2.2 Methods

The incubation study was carried out under field capacity to analyze the biosurfactant property of HA. For the present study, soil collected from Onattukara sandy plains was shade dried, sieved, and filled in the pots. Two kilograms of soil sample filled in each pot were added with HA at four different doses viz; 2.5, 5.0, 10 and 15 kg ha^{-1} and were incubated for 4 weeks. Soil samples without HA were maintained as the control for the experiment. Biosurfactant properties were assessed from the incubation study by taking observations on water stable aggregates and clay dispersion ratio on the 30th

day of incubation. The experiment was designed in a completely randomized design.

Water stable aggregates were determined by the wet sieving method using Yoder's apparatus [14]. The core method was used to determine WHC as well as BD [15]. The methodology used for particle density was the Pycnometer method as described by Blake and Hartge [16]. Porosity was determined through equation;

$$\text{Soil Porosity} = [1 - (\text{Bulk Density}/\text{Particle Density})] \times 100.$$

The soil particle was analyzed using the Bouyoucos hydrometer method. Then, the micro-aggregate stability was calculated by measuring the quantity of silt and clay in both calgon-dispersed and water-dispersed soil samples [17]. The calculation method [18] for the clay-dispersion indices is as follows:

$$\text{Dispersion ratio} = [(\% \text{ (silt+clay) in water} / \% \text{ (silt+clay) in 0.5 N Calgon})] \times 100$$

$$\text{Clay dispersion ratio} = [(\% \text{ clay in water} / \% \text{ clay in 0.5 N Calgon})] \times 100$$

3. RESULTS AND DISCUSSION

Tables 1 and 2 provide information on the various physical and chemical properties of both the soil and HA used for the present study. The soil was classified as sandy loam in texture with an acidic reaction and normal electrical conductivity.

3.1 Influence of Different Doses of Humic Acid (HA) Applications on Water Stable Aggregates (WSA)

Water stable aggregates are an important measure of soil aggregation, which showed significant variation due to the addition of HA at different levels. The effects of different doses of HA on WSA are shown in Table 3. The highest value of WSA (52.735%) was recorded in T₅ (HA @ 15 kg ha⁻¹), followed by T₄ (HA @ 10 kg ha⁻¹), which was on par with T₃ (HA @ 5 kg ha⁻¹). The treatment T₂ applied with 2.5 kg ha⁻¹ was on par with the control, proving that at least 5 kg ha⁻¹ of HA application is required to bring about significant improvement in WSA levels within one month. A further increase of HA levels to 5, 10 and 15 kg ha⁻¹ could subsequently improve the WSA by 2.95%, 4.14% and 6.41% compared to that of the control. The steady improvement in WSA could be explained by the biological and physicochemical role of HA in enhancing the initial aggregate formation in the soil brought about by increased level of humic or fulvic acids, carbohydrates and metal ions [23]. Similar findings showing the positive impact of HA application on the improvement of soil aggregate stability were also reported in diverse soil textures such as loam, silt loam, silty clay loam, loamy sand, and sandy soils [24,25,26]. Humic acid helps in the maintenance of microaggregate stability, followed by coactive binding of microaggregates through organic clay compounds, resulting in the formation of stable macro-aggregates in the soil [27,28]. Moreover, the functional groups present in HA hasten

Table 1. Physical and chemical properties of humic acid used for the experiment

Particulars	Value	Methods
Physical appearance	Coarse Crystals	Visual observation
Moisture content (%)	5.20	gravimetric method [19]
C (%)	36.18	CHNS analyser [20]
H (%)	2.56	
N (%)	0.76	

Table 2. Physical and chemical properties of soil used for the experiment

Particulars	Value	Methods
Soil Texture:		Bouyoucos hydrometer method [17]
Sand (%)	69.92	
Silt (%)	18.03	
Clay (%)	12.05	
Bulk density, (Mg m ⁻³)	1.55	Core Sampler [15]
pH (1: 2.5:: Soil : Water)	5.18	Glass Electrode pH Meter [21]
EC (dS m ⁻¹ at 25°C)	0.14	Glass Electrode pH Meter [21]
Organic carbon (g kg ⁻¹)	0.20	Walkley and Black method [22]

Table 3. Effect of Humic acid on soil physical properties

Treatment/ doses of HA	Water stable aggregates (%)	Water holding capacity (%)	Bulk density (Mg m⁻³)	Particle density (Mg m⁻³)	Porosity (%)	Clay dispersion ratio (%)	Dispersion ratio (%)
T ₁ (control- 0 kg ha ⁻¹)	46.32 ^c	21.50 ^d	1.54 ^a	2.45	37.35 ^c	44.07 ^a	46.32 ^a
T ₂ (2.5 kg ha ⁻¹)	47.48 ^c	22.54 ^{cd}	1.51 ^{ab}	2.44	38.03 ^c	44.05 ^a	46.14 ^a
T ₃ (5 kg ha ⁻¹)	49.27 ^b	23.61 ^c	1.48 ^{bc}	2.42	38.71 ^{bc}	41.13 ^b	44.28 ^b
T ₄ (10 kg ha ⁻¹)	50.46 ^b	25.27 ^b	1.45 ^c	2.41	39.83 ^{ab}	33.64 ^c	41.34 ^c
T ₅ (15 kg ha ⁻¹)	52.74 ^a	26.59 ^a	1.41 ^d	2.40	41.31 ^a	31.24 ^d	39.52 ^d
SE(m)	0.444	0.731	0.012	0.027	0.551	0.613	0.332
CD (5%)	1.284	1.245	0.034	NS	1.698	1.765	1.034

the organomineral complex formation in the soil which could result in the improvement of various physical properties of the soil [29].

3.2 Influence of Different Doses of Humic Acid (HA) Applications on Water Holding Capacity (WHC)

The data presented in Table 3 revealed that there was a significant impact of different doses of HA on WHC. The WHC ranged between 26.59% and 21.50% during 30 days incubation study. The highest (26.59%) and lowest (21.50%) WHC was recorded in T₄ (HA @ 15 kg ha⁻¹) and T₁ (HA @ 0 kg ha⁻¹) respectively. Compared to the control, T₂, T₃, T₄ and T₅ showed an increment of 1.04%, 2.11%, 3.77%, and 5.09% WHC respectively. These results may be attributed to the gradual formation of soil aggregate stability during the incubation periods. Humic acid could decrease soil BD and increase the soil water retention in the top 100 cm of the soil, which intern results in improvement of soil structure and soil health [28]. Similar results of the effect of HAs in increasing soil WHC have been reported by Billingham, [30] and Yang et al., [31]. This positive influence is due to the soil WHC being enhanced by the hydrophilic component of HA (which attracts water) and the improved soil structure. Furthermore, studies have reported that the combined application of HA and FA has a high tendency to form colloids or humic-clay complexes, thereby leading to a significant increase in WHC [30]. Similarly, Kandra et al. [32] reported that the addition of HA enhanced the available water capacity and improved the water retention capacity of sandy and clayey soils.

3.3 Influence of Different Doses of Humic Acid (HA) Applications on Bulk Density (BD), Particle Density (PD), and Porosity

Bulk density was significantly decreased with an increase in the rate of application of HA (Table 3) ranging from 1.54 to 1.41 Mg m⁻³. T₁ (control- HA @ 0 kg ha⁻¹) recorded the highest value of 1.54 Mg m⁻³, followed by T₂ (HA @ 5 kg ha⁻¹) with a value of 1.51 Mg m⁻³ which was on par with T₃ (1.48 Mg m⁻³) and T₄ (1.45 Mg m⁻³). The application of 15 kg ha⁻¹ of HA (T₅) significantly decreased the BD by 8.4% compared to the control. In the case of PD, there was no significant difference was observed in case of PD. However, as the level of HA dose increased from 2.5 to 15 kg ha⁻¹, the porosity of the

experimental soil gradually increased from 1.02% to 3.96% respectively, compared to control. The decrease in BD and increase in porosity with HA application can be explained by due to the improvement in macro-aggregate formation, organic carbon and soil aggregate stability [33,28]. The use of HA in soil as an organic source improved the physical condition of soil by improving the aggregate stability of soil and reducing the compactness of soil which eventually resulted in decrease in BD of soil and thereby improved the water infiltration [28]. The influence of HA on BD and porosity was more pronounced in higher application doses were reported in sandy [32], loamy sand [33] as well as calcareous soils [34].

3.4 Influence of Different Doses of Humic Acid (HA) Applications on Micro Aggregate Stability

The application of HA significantly affected the micro aggregate stability of soil. Data presented in Table 3 showed that increasing the rate of application of HA dose resulted in a decreased rate of dispersion ratio (DR) and clay dispersion ratio (CDR). The highest value of DR (46.32%) was recorded in T₁ (control- HA @ 0 kg ha⁻¹) which was followed by T₂ (HA @ 2.5 kg ha⁻¹) having 44.27 percent and the lowest value was recorded in T₅ (HA @ 15 kg ha⁻¹) with 31.24% of DR. Similar trend was also followed in case of CDR with highest (44.07%) and lowest value (31.24) were recorded in T₁ (control- HA @ 0 kg ha⁻¹) and T₅ (HA @ 15 kg ha⁻¹) respectively. Compared to the control, HA level at 15 kg ha⁻¹ caused decrement in DR and CDR by 6.8% and 12.83% respectively. This indicates that the application of HA has a significant role in reducing the dispersion of soil may be due to the strong binding of soil particles as a result of stable micro aggregates. These findings are consistent with Piccolo and Mbagwu [35], who found that an increased rate of HA significantly reduced the amount of dispersible clay (enhanced stability) in entisol soils. Similarly, Ozdemir [36] reported that HA has a role in the improvement of resistance to dispersion and mechanical forces. These results attributed to the fact that both macro- and micro aggregates showed increased stability when HA was added to the weakly aggregated soils [23].

Fig. 1 is the correlogram showing the relationship between WSA and selected soil physical properties at a 0.05% level of significance. There is a positive correlation of WSA with WHC

(0.85^{***}) and porosity (0.72^{***}), and a negative correlation also estimates between WSA with BD (-0.84^{***}), CDR (-0.881^{***}) and DR (-0.903^{***}). The results are in agreement with Gumuş & Şeker [23], Li et al. [37], and Shao et al. [38].

The regression model and coefficient of determination of the relationship between WSA

(as a dependent variable) with other physical parameters are shown in Fig. 2. There is a positive regression between WSA with WHC and porosity, and the coefficient of determination value is 0.73 and 0.51 respectively. In the case of BD, CDR and DR, WSA showed negative regression with coefficient of determination values of 0.70, 0.78, and 0.82 respectively.

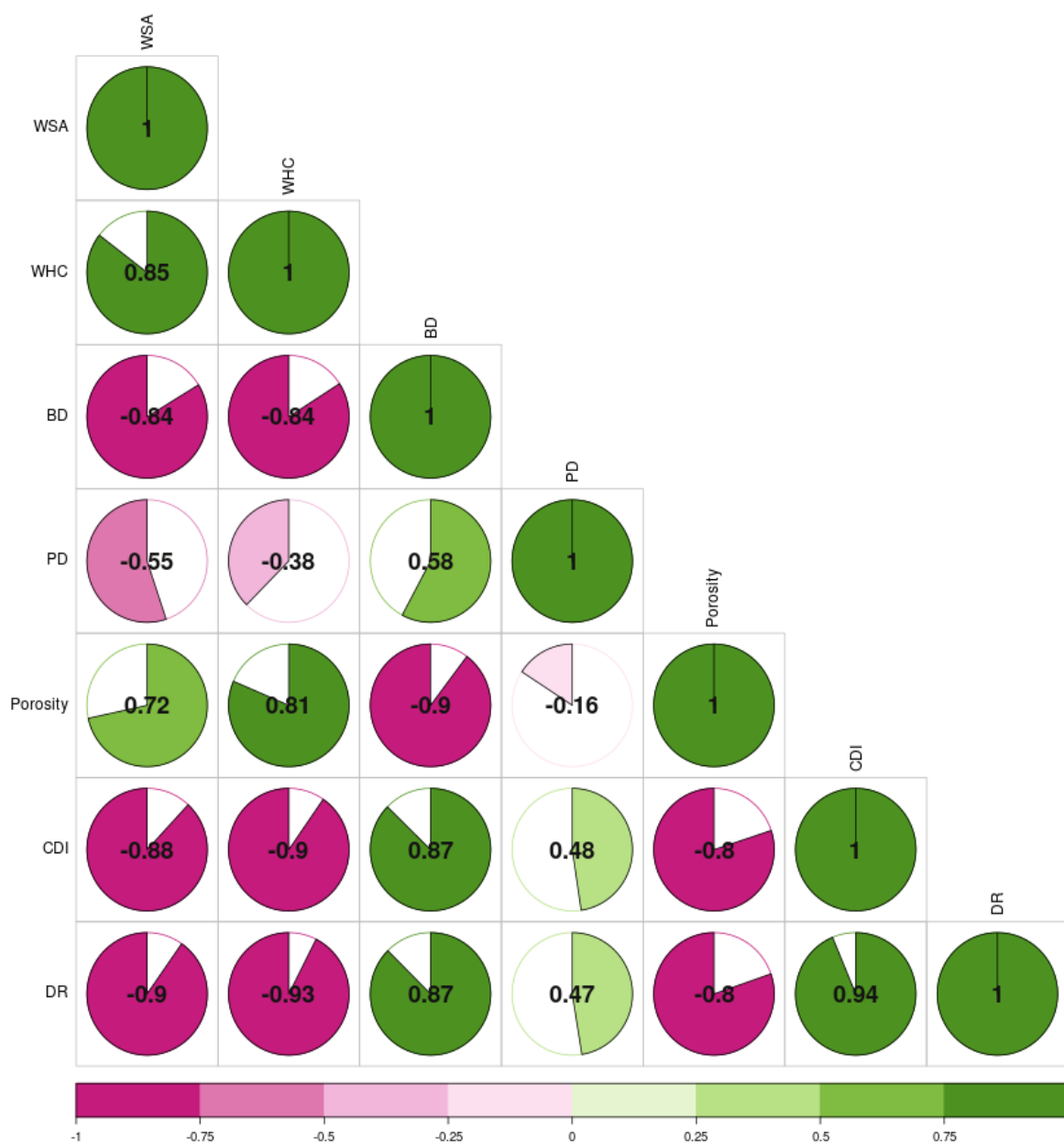
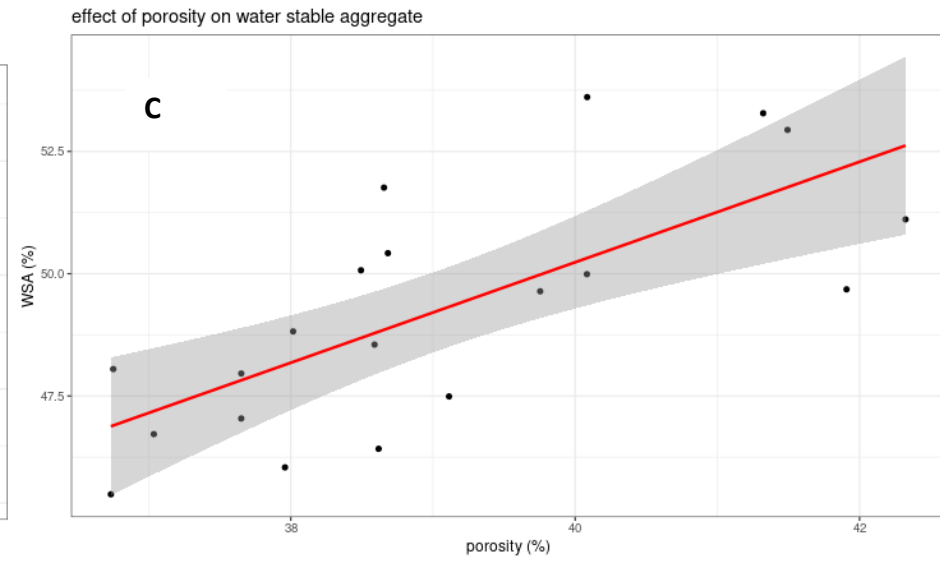
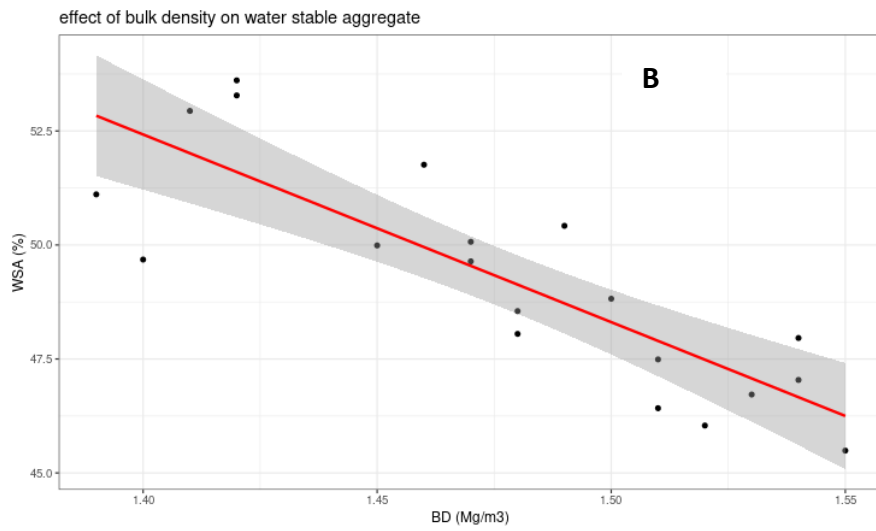
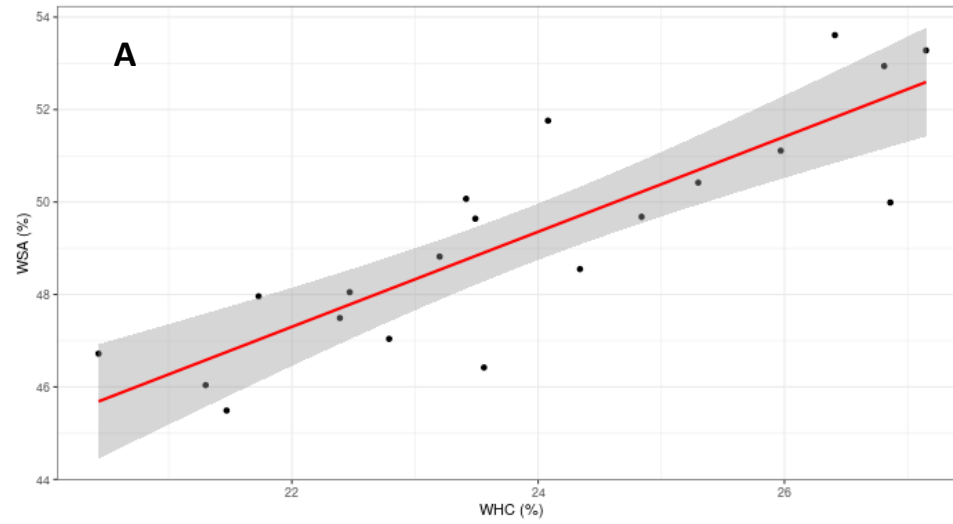


Fig. 1. Correlogram of simple Pearson's correlation coefficients matrix of the soil parameters such as water stable aggregates (WSA), water holding capacity (WHC), bulk density (BD), particle density (PD), porosity, dispersion ratio (DR) and clay dispersion ratio (CDR) of sandy soils affected by soil addition of three humic acid (HA) rates (0 , 2.5, 5, 10, 15 kg ha⁻¹ soil)



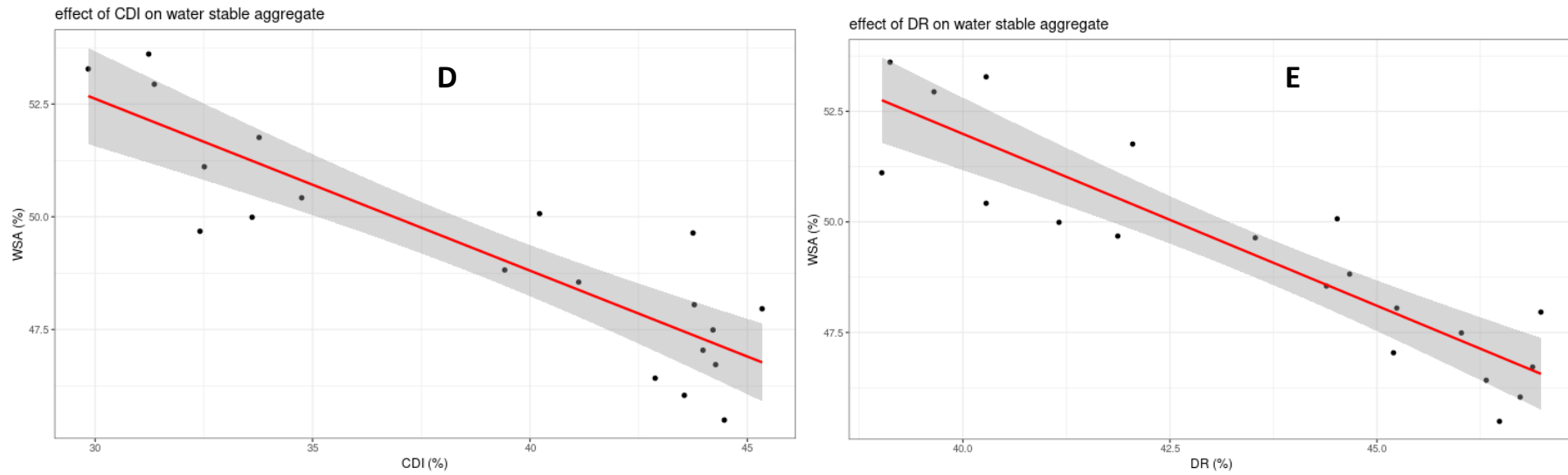


Fig. 2. Regression analysis of WSA (as dependent variable) water stable aggregates (WSA) (as dependent variable) with water holding capacity (WHC) (A), bulk density (BD) (B), porosity (C), clay dispersion ratio (CDR) (D) and dispersion ratio (DR) (E)

4. CONCLUSION

The findings of this laboratory investigation suggest that the application of HA as a biosurfactant has a significant positive effect on soil aggregate stability, WHC and porosity. The addition of HA at the rate of 15 kg ha⁻¹ was found to be best for WSA, WHC and porosity in sandy soils. The lowest BD, CDR and DR was also recorded from the treatment applied with HA at the rate of 15 kg ha⁻¹. The use of HA may contribute to enhancing soil health through better soil micro and macro aggregation. According to the study, HA can be utilized as an effective tool for facilitating soil conservation and managing soil sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Osman kt, Osman kt. Sandy soils. Management of Soil Problems. 2018;37-65.
2. Murphy BW. Impact of soil organic matter on soil properties—a review with emphasis on Australian soils. Soil Research. 2015;53(6):605-635.
3. Unkovich MJ. A review of the potential constraints to crop production on sandy soils in low rainfall south-eastern Australia and priorities for research. Report for GRDC Low Rainfall Zone Regional Cropping Solutions Network (Grains Research and Development Corporation); 2014. Available:www. grdc. com. au/research/reports/report
4. Mindari W, Kusuma ZS. Isolation and characterization of humic acid of various waste materials on saline soil and their effects to paddy. Proceeding of International Conference on Green –Agro Industry, Ina Garuda Hotel, Yogyakarta. 2013;255-233.
5. Nasiroleslami E, Mozafari H, Sadeghi Shoaie M, Habibi D, Sani B. Changes in yield, protein, minerals, and fatty acid profile of wheat (*Triticum aestivum* L.) under fertilizer management involving application of nitrogen, humic acid, and seaweed extract. J. Soil Sci. Plant Nutr. 2021;21(4):2642-2651.
6. Klavins M, Purmalis O. Humic substances as surfactants. Environ. Chem. Lett. 2010;8(4):349-354.
7. Singh R, Glick BR, Rathore D. Biosurfactants as a biological tool to increase micronutrient availability in soil: A Review. Pedosphere. 2018;28(2):170-189.
8. Ding Z, Ali EF, Almaroai YA, Eissa MA, Abeed AH. Effect of potassium solubilizing bacteria and humic acid on faba bean (*Vicia faba* L.) plants grown on sandy loam soils. J Soil Sci Plant Nutr. 2021;21:791–800.
9. Khan RU, Khan MZ, Khan A, Saba S, Hussain F, Jan IU. Effect of humic acid on growth and crop nutrient status of wheat on two different soils. J Plant Nutr. 2018;41:453–460.
10. Liu G, Ozores-Hampton M, McAvoy G, Hogue B, Snodgrass CA. Application of surfactants in commercial crop production for water and nutrient management in sandy soil. Academia, [e-journal]. 2014;7(1). Available:https://www.researchgate.net/publication/272165929_Applicati_on_of_Surfactants_in_Commercial_rop_Production_for_Water_and_Nutri ent_Management_in_Sandy_Soil Retrieved on [21 may 2022].
11. Szczerski C, Naguit C, Markham J, Goh TB, Renault S. Short-and long-term effects of modified humic substances on soil evolution and plant growth in gold mine tailings. Water Air Soil Pollut. 2013;224(3):1-14.
12. Wang L, Li Y, Weng L, Sun Y, Ma J, Chen Y. Using chromatographic and spectroscopic parameters to characterize preference and kinetics in the adsorption of humic and fulvic acid to goethite. Sci. Total Environ. 2019;666:766-777.
13. KAU [Kerala Agricultural University]. Package of practices recommendations: Crops (14th Ed.). Kerala Agricultural University, Thrissur. 2016;360.
14. Yoder RE. A direct method of aggregate analysis of soils and a study of the physical

- nature of erosion losses 1. *Agronomy Journal*. 1936;28(5):337-351.
15. Gupta RP, Dakshinamoorthy C. Procedures for physical analysis of soil and collection of agrometeorological data. India Agricultural Research Institute, New Delhi. 1980;293.
 16. Blake GR, Hartge KH. Bulk density. *Methods of soil analysis: Part 1 Physical and mineralogical methods*. Soil Sci. Soc. Am. 1986;5:363-375.
 17. Bouyoucos GJ. Directions for making mechanical analyses of soils by the hydrometer method. *Soil Sci.* 1936;42(3):225-230.
 18. Rasheed SM. The effect of clay content and land use on dispersion ratio at different locations in Sulaimani governorate—Kurdistan region—Iraq. *Open Journal of Soil Science*. 2016;6(1):1-8.
 19. Reynolds SG. The gravimetric method of soil moisture determination Part III An examination of factors influencing soil moisture variability. *Journal of Hydrology*. 1970;11(3):288-300.
 20. Hervas L, Mazuelos C, Senesi N, Sáiz-Jiménez C. Chemical and physico-chemical characterization of vermicomposts and their humic acid fractions. *Science of the Total Environment*. 1989;81:543-550.
 21. Jackson ML. *Soil Chemical Analysis* (2nd Ed.). Prentice Hall of India, New Delhi. 1973;498.
 22. Walkley AJ, Black IA. Estimation of soil organic carbon by chromic acid titration method. *Soil Sci.* 1934;31:29-38.
 23. Gumuş İ, Şeker C. Influence of humic acid applications on soil physicochemical properties. *Solid Earth*. 2015;7:2481-500.
 24. Piccolo A, Pietramellara G, Mbagwu JSC. Use of humic substances as soil conditioners to increase aggregate stability. *Geoderma*. 1997;75(3-4):267-277.
 25. Mamedov AI, Bar-Yosef B, Levkovich I, Rosenberg R, Silber A, Fine P, Levy GJ. Amending soil with sludge, manure, humic acid, orthophosphate and phytic acid: Effects on aggregate stability. *Soil Research*. 2014;52(4):317-326.
 26. Tahoun AMA, El-Enin MMA, Mancy AG, Sheta MH, Shaaban A. Integrative soil application of humic acid and foliar plant growth stimulants improves soil properties and wheat yield and quality in nutrient-poor sandy soil of a semiarid region. *Journal of Soil Science and Plant Nutrition*. 2022;22(3):2857-2871.
 27. Regelink IC, Stoof CR, Rousseva S, Weng L, Lair GJ, Kram P, et al. Linkages between aggregate formation, porosity and soil chemical properties. *Geoderma*. 2015;247:24–37. Available:<https://doi.org/10.1016/j.geoderma.2015.01.022>
 28. Zhou L, Monreal CM, Xu S, McLaughlin NB, Zhang H, Hao G, Liu J. Effect of bentonite-humic acid application on the improvement of soil structure and maize yield in a sandy soil of a semi-arid region. *Geoderma*. 2019;338:269-280.
 29. Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—a review. *Biology and Fertility of Soils*. 2002;35:219-230.
 30. Billingham K. Humic products: Potential or presumption for agriculture. NSW Agriculture; 2015.
 31. Yang F, Tang C, Antonietti M. Natural and artificial humic substances to manage minerals, ions, water, and soil microorganisms. *Chemical Society Reviews*. 2021;50(10):6221-6239.
 32. Kandra B, Tall A, Vitková J, Procházka M, Šurda P. Effect of humic amendment on selected hydrophysical properties of sandy and clayey soils. *Water*. 2024;16(10):1338.
 33. Ahmad I, Ali S, Hassan F, Ijaz S, Abbas Z, Ahmad M, et al. Use of coal derived humic acid as soil conditioner for soil physical properties and its impact on wheat crop yield. *Int. J. Biosci.* 2015;5:81–89.
 34. Mahmoud MM, Hassanein AHA, Mansour SF, Khalefa AM. Effect of soil and foliar application of humic acid on growth and productivity of soybean plants grown on a calcareous soil under different levels of mineral fertilizers. *Journal of Soil Sciences and Agricultural Engineering*. 2011;2(8): 881-890.
 35. Piccolo A, Mbagwu JSC. Humic substances and surfactants effects on the stability of two tropical soils. *Soil Sci. Soc. Am. J.* 1994;58(3):950-955.
 36. Ozdemir N. Effects of applications of synthetic polymer and humic acid on resistance to dispersion and mechanical forces. *Soil Studies*. 2023;12(1):54-61.
 37. Li XG, Li FM, Zed R, Zhan ZY. Soil physical properties and their relations to

- organic carbon pools as affected by land use in an alpine pastureland. *Geoderma*. 2007;139(1-2):98-105.
38. Shao F, Zeng S, Wang Q, Tao W, Wu J, Su L, et al. Synergistic effects of biochar and carboxymethyl cellulose sodium (CMC) applications on improving water retention and aggregate stability in desert soils. *Journal of Environmental Management*. 2023;331:117305.

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