Short Research Article

Humic acid as an organic biosurfactant in amelioration of physical constraints of sandy soils

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 biosurfactantproperty 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 poorlystructured sandy soils. Such organic biomolecules capable enough to bring about consistent improvements to soil quality within a short periodwill be beneficial for alleviating major obstacles in sustainable agriculture.

Keywords: Humic acid, biosurfactant, water stable aggregates, sandy soil

1. Introduction

Sandy soils are identified by over sixty-eight percent sand and less than eighteen percent clay contents at a depth of the first one hundred centimetres of the solum(Osman, 2018). Low clay content results in poor water retention capacity and reduced nutrient availability, thereby hindering crop productivity (Murphy, 2015).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 (Unkovich, 2014).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 (Mindari and Kusuma, 2013). 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 (Nasiroleslami et al., 2021). 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 (Klavins and Purmalis, 2010).

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 (Singh et al., 2018).HA can modify soil properties and improve the bioavailability of plant nutrients, thereby stimulating photosynthetic activity (Ding et al. 2021) and enhancing productivity in sandy loam soil (Khan et al. 2018).

Surfactants like HA can promote the absorption and retention of nutrients and moisture in soil (Liu *et al.,* 2014).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 (Szczerski et al., 2013). Owing to the diverse reactive functional groups on the surface of HA such as –COOH, -OH and $–NH_2$, 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 (Wang et al., 2019). With this background, the present study is focussed on providing clear insights on the effect of HAas a biosurfactanton various soil physical propertiessuch aswater 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. Material and methods

2.1. Materials

Humic acid used in the present study was procured from the Department of Agriculture of Keralaaccredited 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 (KAU, 2016), geographically located between 9^{o} 30' 29" North (latitude) and 76^{o} 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, soilcollected from Onattukara sandy plains was shade dried, sieved, and filled in the pots. Two kilograms of soil sample filled in each potwere 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 HAwere 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 ratioon the 30^{th} day of incubation. The experiment was designed in a completely randomized design.

Water stable aggregates were determined bythe wet sieving method using Yoder's apparatus (Yoder, 1936). The core method was used to determine WHC as well as BD (Gupta and Dakshinamoorthi, 1980). The methodology used for particle density was the Pycnometer method as described by Blake and Hartge (1986). Porosity was determined through equation;

Soil Porosity = [1 - (Bulk Density/Particle Density)] x 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 (Bouyoucos, 1936). The calculation method (Rasheed, 2016)for the clay-dispersion indices is as follows:

Dispersion ratio=[(% (silt+clay) in water / (%(silt+clay) in 0.5 N Calgon)] x 100

Clay dispersionratio = [(% clay in water / (% clay in 0.5 N Calgon)] x 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 T_5 (HA @ 15 kg ha^{-1}), followed by T_4 (HA @ 10 kg ha^{-1}), which was on par with T_3(HA @ 5 kg ha^{-1}).The treatment T_2 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 WSAcould 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 (Gumus and Seker, 2015). 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(Piccolo et al., 1997;Mamedov et al.,2014; Tahoun et al., 2022). Humic acid helps in the maintenance of microaggregate stability, followed by coactive binding of microaggregatesthrough organic clay compounds, resulting in the formation of stable macro-aggregates in the soil (Regelink et al., 2015; Zhou et al., 2019). Moreover, the functional groups present in HA hasten the organomineral complex formation in the soil which could result in the improvement of various physical properties of the soil (Glaser et al., 2002).

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%) WHCwas recorded in T_4 (HA @ 15 kg ha^{-1}) and T_1 (HA @ 0 kg ha^{-1}) respectively. Compared to the control, $T_{2,}$ $T_{3,}$ T_4 and

T_5showed 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 (Zhou et al., 2019). Similar results of the effect of HAs in increasing soil WHChave been reported by Billingham, 2012 and Yang et al., 2021. 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 (Billingham, 2012). Similarly, Kandra et al. (2024) reported that the addition of HA enhanced the available water capacity and improved the water retention capacity of sandy and clayey soils.

3.2. 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 1.54to 1.41 Mg m^{-3}. T_1 (control- HA @ 0 kg ha^{-1}) recorded the highest value of 1.54 Mg m^{-3}, followed by T_2 (HA @ 5 kg ha^{-1}) with a value of 1.51 Mg m^{-3} which was on par with T_3 (1.48 Mg m^{-3}) and T_4 (1.45 Mg m^{-3}). The application of15 kg ha^{-1}-ofHA (T_5)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 increasedfrom 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 (Ahmad *et al.*, 2015; Zhou *et al.*, 2019).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 (Zhou *et al.*, 2019). The influence of HA on BD and porosity was more pronounced in higher application doses were reported in sandy (Kandra et al., 2024), loamy sand (Ahmad et al., 2015) as well ascalcareous soils (Mahmoud et al.,2011)

3.3. 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 increasingthe 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 T_1 (control- HA @ 0 kg ha^{-1}) which was followed by T_2 (HA @ 2.5 kg ha^{-1}) having 44.27percent and the lowest value was recorded in T_5 (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 T_1 (control- HA @ 0 kg ha^{-1}) and T_5 (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 (1994), who foundthat an increased rate of HA significantly reduced the amount of dispersible clay (enhanced stability) in entisol soils. Similarly,Ozdemir (2023) reported that HAhas 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 (Gumuş& Şeker, 2015).

Figure 1is the correlogram showing therelationship 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 (2015), Li et al (2007), and Shao et al (2023).

The regression model and coefficient of determination of the relationship between WSA (as a dependent variable) with other physical parameters are shown in figure 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.

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, WHCand 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 conversations and managing soil sustainability.

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 (Reynolds, 1970)
pH	8.1	Potentiometry (Rajkovich et al., 2012)
EC (dS m^{-1})	1.04	Conductometry (Rajkovich et al., 2012)
C (%)	36.18	CHNS analyser (Hervas et al., 1989)
H (%)	2.56	
N (%)	0.76	

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

Particulars	**Value**	**Methods**
Sand (%)Silt (%) Clay (%)	 69.92 18.03 12.05	Hydrometer meter (Bouyoucos, 1936)
Bulk density, (Mg m^{-3})	1.55	Core Sampler (Gupta and Dakshinamoorthi, 1980)
pH (1 : 2.5:: Soil : Water)	5.18	Glass Electrode pH Meter (Jackson, 1973)
EC (dS m^{-1} at 25^{o}c)	0.14	Glass Electrode pH Meter (Jackson, 1973)
Organic carbon (g kg^{-1})	0.20	Walkley and Black method (Walkley and Black, 1934)

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

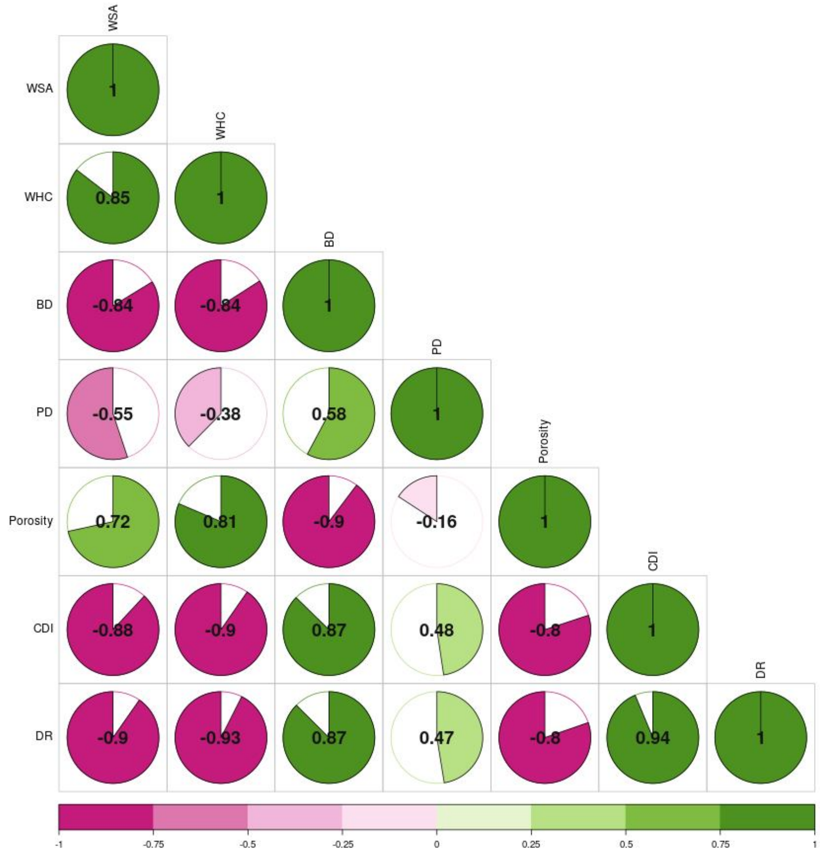
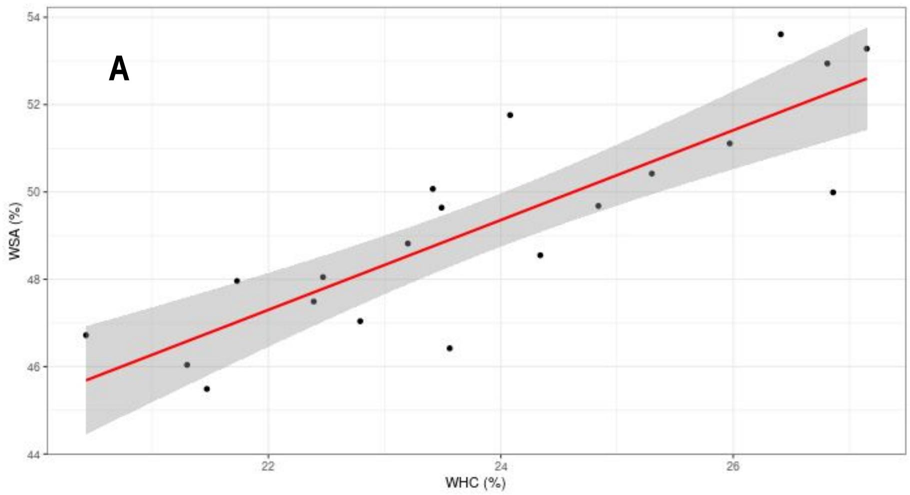


Figure 1. Correlogram of simple Pearson's correlation coefficients matrix of the soil parameters such as water stable aggregates (WSA), water holding capacity (WHC), bulk density (BD), particle density (PD), porosity, dispersion ratio (DR) and clay dispersion ratio (CDR) of sandy soilas affected by soil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


A
WSA (%)
WHC (%)
54
52
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48
46
44
22
24
26

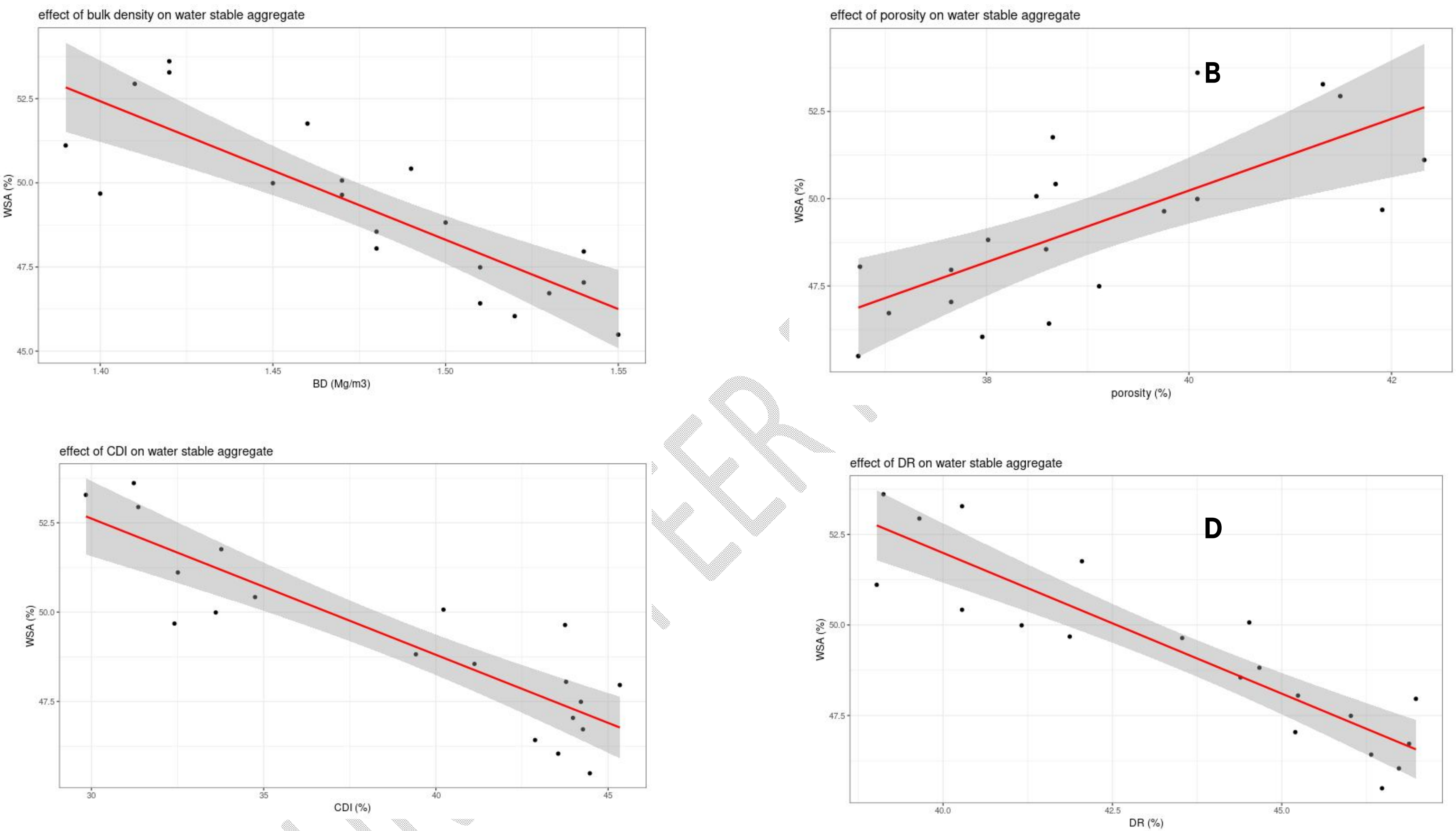
effect of bulk density on water stable aggregate
WSA (%)
BD (Mg/m3)
effect of porosity on water stable aggregate
B
WSA (%)
porosity (%)
effect of CDI on water stable aggregate
WSA (%)
CDI (%)
effect of DR on water stable aggregate
D
WSA (%)
DR (%)

Figure 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).

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