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Effect of adding Versol soil conditioner and emulsified lubricating oil on mean weight diameter and erosion of sandy soils using different moisture and rainfall conditions

Dhuha Salim Jameel[1], Ali Hamdhi Dheyab[2] and Dakhil Radhi Ndewi[3]

[1,2,3]Soil Sciences and Water Resource Department, Agriculture College, Basrah University, Iraq.

Email: pgsduhasalim@uobasrah.edu.iq, Ali.dheyab@uobasarah.equ.iq, Dakhil.nedawi@uobasrah.edu.iq

I. Abstract :

This study comprised two experiments: A field experiment and a pot experiment ,the field experiment was conducted at the Al-Burjasiya Research Station, Al-Zubair District, during the 2023-2024 winter season, on a sandy loam soil, to demonstrate the effect of the soil conditioners Vertisol and emulsified lubricating oil on the weighted diameter and soil erosion. The experiment included the use of soil conditioners: Two soil conditioners, Vertisol, at levels of 10, 20 and 30% were symbol C1, C2 and C3 respectively, calculated as the weight of the soil at a depth of 1 cm of sandy soil, as a suspension at a ratio of 1 part soil to 6 parts water, added directly to the surface of the experimental units. The second conditioner is used lubricating oil mixed with water, it was emulsified by adding a synthetic emulsifying agent (an anionic surfactant), it was added at levels of 0.1, 0.3 and 0.5%, were symbol O1, O2, and O3 respetively, of the soil weight, to a depth of 15 cm, in addition to the control treatment C0. The moisture and rainfall treatment factor included four treatments: irrigation and re-irrigation after 50% of the available water has been lost to the soil's field capacity (R1), irrigation equal to the highest rainfall (R2), and the average rainfall treatment (R3). R2 and R3 were derived from 41 years' rainfall data for previous years. They were added as standard irrigation treatments equivalent to rainfall. In addition, a direct rainfall treatment for the study year (R4) was applied. R.O. water was used as a substitute for rainwater. Irrigation and re-irrigation were carried out in treatments R2 and R3, based on the highest frequency of rainfall in a given month. The results showed that the addition of soil conditioners generally led to an increase in the weighted mean diameter (MWD) with significant differences between the addition levels. The Vertisol C3 soil treatment and the emulsified lubricating oil O3 treatment recorded the highest MWD values, respectively, with significant differences compared to the control treatment. Regarding the moisture treatments, treatment (R1) recorded the highest MWD value, with significant differences compared to the other treatments, reaching 4.553 mm. Conversely, the lowest MWD value was recorded in treatment (R3), at 3.878 mm. The results also showed a significant advantage of soil conditioners in reducing soil loss through erosion compared to the control treatment. Furthermore, the results demonstrated that the moisture treatment (R3) recorded the highest values for soil loss through erosion. While the lowest values for soil loss through erosion were observed in treatment (R1).

Keywords : *Soil conditioners, emulsified lubricating oil, Verticillium soil, weighted diameter modifier, soil erosion.*

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II. Introduction:

Sandy soils suffer from several limitations, most notably the deterioration of their properties; they are loose and susceptible to loss and wind erosion due to their high erosive potential. Wind erosion is a widespread environmental problem in arid and semi-arid regions worldwide (Jarrah *et al*., 2020).

It represents a serious environmental challenge with far-reaching effects on ecosystems. This challenge is particularly evident in areas experiencing accelerated human-induced erosion, leading to significant losses of soil resources such as organic matter and nutrients. In addition to the associated social and economic damages, it also has a significant impact on global biochemical cycles and human health. Furthermore, it damages public infrastructure, main roads, and agricultural lands, and releases dust from the soil into the atmosphere. Erosion is a major global concern (Katra, 2020).

Wind erosion is the process by which surface soil particles are detached from their original location by wind (Zuo et al., 2015). It is influenced by many factors, including wind, soil, weather, vegetation, topography, and soil type. Vegetation limits the Wind erosion results from the direct obstruction of soil particle movement by wind. The biological crust that forms on the surface of sandy soils reduces wind erosion. This crust binds soil particles together, forming a cohesive structure. This reduces the amount of scattered particles that can be transported by the wind and limits wind speed (Pi *et al*., 2021).

MWD is an indicator of soil aggregate stability. It is closely related to soil structure and its ability to remain stable under climatic changes such as rainfall, wind, and agricultural practices. Higher MWD values indicate greater soil particle cohesion, a higher concentration of larger particles, and stronger soil structure, resulting in greater resistance to wind erosion. This also indicates increased soil moisture retention and reduced water loss through evaporation. Lower values indicate loose soil structure and increased susceptibility to wind erosion. Therefore, studying soil aggregate stability through MWD measurement, a key factor and one of the most important indicators for determining soil susceptibility to wind erosion. Increasing the weighted diameter (MWD) and maintaining soil aggregate stability are important factors and indicators for reducing soil sensitivity to erosion and for assessing soil structure stability (Li *et al*., 2023).

For these reasons, effective strategies or techniques must be followed, to increase the stability of soil aggregates and thus control wind erosion. One such solution is the addition of natural and petroleum-based conditioners, which contribute to promoting the growth of native plants and the formation of a biological crust on the surface of sandy soils. This is achieved by increasing the activity of organisms and their secretions, which improve the properties and stability of sandy soil aggregates. This technique is internationally recognized as a promising method, to reduce the effects of wind erosion, protect ecosystems from degradation, and restore their productivity. Adding clay to sandy soils is a natural strategy used in reclaiming these soils. Clay has been used to control wind erosion in desert regions, due to its ability to retain water and preserve nutrients in these soils. Increasing the clay and organic matter content is one of the

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important factors that increases the binding strength between soil particles, and increases the stability of soil aggregates, thus reducing wind erosion (Pi *et al*., 2021).

Pi *et al.* (2021) found that adding bentonite mixed at ratios of 0, 2, 4, 8 and 16% (W/W) to different locations in the United States of America, with soil surface moistening using 0.5 cm nozzles, reduced the amount of soil lost by wind erosion by 36, 37, 47 and 71% for the above addition levels, due to increased stability of soil aggregates.

The use of petroleum products, when combined with natural conditioners such as bentonite, enhances the stability of soil aggregates, reduces erosion, and helps stabilize the soil against wind erosion (Katra, 2021).

Abulimiti *et al*. (2023) in China found that adding bentonite at levels of 0, 0.2, and 0.4% mixed with sandy soil, along with an equivalent moisture treatment of 50% of the annual rainfall, reduced soil loss from wind erosion by 99% at wind speeds as high as 12 m/s. This was achieved without any soil loss from wind compared to the control treatment. This effect is attributed to the role of bentonite colloids in binding sand particles through penetration and filling of soil pores, thus increasing soil stability.

This study aims to evaluate the effect of adding both Vertisol soil conditioner and emulsified motor oil on improving soil structure, represented by MWD, and reducing the amount of soil lost by erosion, using different moisture and rainfall parameters for sandy soils.

III. Materials and Methods:

The study included two experiments. The first was a field experiment conducted at the Al-Burjasiya Research Station, General Authority for Agricultural Research, Ministry of Agriculture, located in the Al-Zubair, West Kritat area, during the 2023-2024 growing season. The area's physiography is within a desert region with an arid climate, at latitude and longitude 30°22'47"N and 47°36'09"E. It has a sandy texture and its soil is classified as a type of quartzite (Table 1).

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Table (1) Some physical and chemical properties soil for a depth (0-5)(5-10) cm and Vertisol soil conditioner.

Soil properties		Unit	Depth 0-5	Depth 5-10	Vertisol s conditioner
pH 1:1			7.80	8.10	7.80
E.C		d.sm $^{-1}$	4.20	4.40	6.12
Moisture content saturated		%	31.55	31.88	65.80
Field capacity		%	20.12	20.22	45.40
Sand		gm.kg $^{-1}$	887.000	885.000	58.000
Silt		gm.kg $^{-1}$	64.808	65.830	348.000
Clay		gm.kg $^{-1}$	48.192	49.170	592.000
Texture			sand	sand	Clay
Particle density		mg. m $^{-3}$	2.26	2.30	2.65
Bulk density		mg. m $^{-3}$	1.65	1.66	1.30
Porosity		mg. m $^{-3}$	36.96	38.55	50.94
MWD		mm	1.545	1,540	0.47
Saturated hydraulic conductivity		cm.hour $^{-1}$	14.87	14.22	0.70
Organic matter		gm. Kg $^{-1}$	0.16	0.13	6.80
Soluble ions	$CaCo_3$	gm.kg $^{-1}$	138	135	266.12
Soluble ions	Ca^{+2}	mmole L $^{-1}$	16.40	14.00	17.00
Soluble ions	Mg^{+1}	mmole L $^{-1}$	18.00	17.80	16.40
Soluble ions	Na^{+2}	mmole L $^{-1}$	6.22	6:30	22.50
Soluble ions	k	mmole L $^{-1}$	3.18	3.20	6.44
Soluble ions	HCO_3^{-3}	mmole L $^{-1}$	6.90	6.55	3.40
Soluble ions	CO_3^{-2}	mmole L $^{-1}$	0.00	0.00	0.00
Soluble ions	Cl^{-1}	mmole L $^{-1}$	50.00	48.00	70.00
Soluble ions	So^{--2}	mmole L $^{-1}$	9:30	8.90	8.44

The field experiment area was divided into three blocks. Each block was further divided into 28 experimental units, each measuring 1×1 m. A randomized complete block design (RCBD) with three replicates was used.

The study factors included the first factor: the treatment of the conditioners, represented by Vertisol soil, which is a black cracked clay soil taken from sugarcane fields, Maysan Governorate and is characterized by its high content of expanded clay, its characteristics are shown in Table 2. These treatments were added at levels of 10, 20 and 30%, were symbol C1, C2 and C3, of the weight of the sandy soil to a depth of 1 cm for the area of the experimental unit in the form of a suspension (1) soil: 6 water) sprayed on the surface of the soil.

The treatment of the artificial soil conditioner involves using used lubricating oil emulsified with water and an anionic surfactant (Dheyab, 2017) at levels of 0.1% (O1), 0.3% (O2), and 0.5% (O3) w/w of the weight of the sandy soil to a depth of 15 cm. The volume of the emulsion (oil/water) is equal to the required volume to bring the sandy soil to its field capacity limits at a depth of 15 cm.

The second factor is the moisture and rainfall treatment, consisting of four treatments: the irrigation treatment to the field capacity limit (R1), in which irrigation is repeated to the field capacity limit after 50% of the moisture content at the field capacity has been depleted to a depth of 15 cm in the sandy soil; the highest annual rainfall treatment (R2); and the average rainfall treatment (R3). Treatments (R2 and R3) are recorded from a time series of 41 years of rainfall in Basra Governorate. Additionally, there is a treatment directly based on the rainfall of the current study year (R4). As shown in Table 3, these treatments were implemented in both the field and laboratory experiments. The irrigation dates

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and equivalent amounts for the highest rainfall treatment (R2) and the average rainfall treatment (R3) were determined as follows:

Identify the year with the highest rainfall over the past 41 years.

Calculate the average rainfall over the past 41 years.

Determine the dates of rainfall events distributed across the days of each month. Then calculate the cumulative frequency (the number of showers per day of each month, Yi).

Estimate the arithmetic mean of the number of showers in each month.

$$\overline{Y} = \frac{\sum yi}{n}$$

Where: y: - Arithmetic mean

yi: Total number of showers per month over a period of 41 years.

n: Number of days in each month (28, 29, 30, 31).

1. Days in each month with a higher frequency of showers than the monthly mean (mode peaks above the mean) were selected, while those with lower frequency were ignored.

2. The total rainfall over the past 41 years for both treatments (R2, highest rainfall) and (R3, average rainfall) was divided proportionally by the most frequent modes. The ratio of each mode value to the total number of frequencies calculated from the most frequent modes was then determined.

The total rainfall for each of the two treatments (R2, highest rainfall) was divided proportionally by the number of modes (those with the highest frequency). The study treatments were started before the rainy season, beginning in November, and the process of adding R.O. water equivalent to the rainy treatments continued until 5/3 (May) (end of the rainy season). The experimental units for all the working treatments were covered with plastic covers during the rainy season, except for treatment (R4), which was left uncovered to receive the rain. In the study year, seeds were taken from desert plants that had previously grown at the study site and were planted in the experimental units.

The second experiment: The pot experiment was conducted at the Agricultural Research Station, University of Basra/Karma Ali, under conditions similar to those in the field. Plastic pots measuring (20 x 20) cm and 15 cm deep were filled with 8.5 kg of soil taken from the Zubair Research Station to a depth of (0-10) cm. The same experimental parameters and procedures as in the field experiment were applied using a completely randomized design (CRD) with 28 factorial treatments resulting from the factorial compatibility between the treatment parameters for the soil conditioners (C0, C1, C2, C3, O1, O2, and O3) and the moisture and rainfall parameters (R1, R2, R3, and R4). The experiment was replicated with three copies on November 22, 2024. Wild cress seeds were sown in the pot soil, and the experiment continued until the end of the rainy season on May 3.

Undisturbed samples were taken from the experimental units of the field experiment using a soil core cylinder to depths of 0-5 and 5-10 cm at the middle and end of the experiment, in which the weighted diameter rate was estimated. The dry sieving method was used to estimate the weighted diameter rate for the depths of the studied soils according to the method of (Van Bavel, 1949; Youker and McGuinness, 1956) according to the equation mentioned in Black *et al.* (1965).

The amount of soil lost after the pot experiment was estimated by passing the pots through a wind tunnel for 5 minutes at different speeds of soil particle movement, according to the classification of the Russian scientist Skalov (1960) (Table 2). The class centers for the speeds listed in the aforementioned table were used, and the weight difference at each speed was estimated according to the method described by Abulimiti *et al.* (2023). The average speed was then used to calculate the amount of soil lost for the purposes of analysis of variance.

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Table (2) Required wind speed (m/s) Soil particle movement according to the classification of the Russian scientist Skalov (1960).

Sand type	Sand grain dimensions (mm)	Wind speed (m/s)
Fine granules	0.10-0.25	4.50-6.70
Medium granules	0.25-0.50	6.70-8.40
Large granules	0.50-1.00	8.40-11.40
Coarse granules	1.00-2.00	11.40-13.00

Table (3) Equivalent moisture coefficients for rainfall.

Moisture and Rainfall treatment	Nov		December		Jan		Feb		Mar		Apr		MAY	
	date	Quant	date	Quant	Date	Quant	date	Quant	date	Quant	Date	Quant	Date	Quant
R1	24	21	4	21	4	21	1	21	1	21	5	21	-	-
	29	21	10	21	11	21	8	21	7	21	10	21	-	-
	-	-	18	21	18	21	15	21	13	21	15	21	-	-
	-	-	22	21	25	21	22	21	19	21	20	21	-	-
	-	-	28	21	-	21	-	-	25	21	25	21	-	-
	-	-	-	-	-	21	-	-	31	21	30	21	-	-
R2	2	11.18	1	2.91	2	5.18	10	3.76	18	8.27	2	12.52	-	-
	11	21.01	2	5.27	14	2.74	19	3.76	20	18.18	4	18.41	-	-
	24	16.13	5	7.65	15	3.41	24	5.26	24	27.1	6	4.88	-	-
	29	18.05	18	3.98	27	2.96	27	9.76	28	11	14	26.35	-	-
	-	-	30	7.3	31	4.33	-	-	-	-	-	-	-	-
R3	2	3.32	1	1.97	2	6.69	10	2.6	18	2.45	2	1.85	-	-
	11	6.23	2	3.57	14	3.53	19	2.59	20	5.4	4	2.73	-	-
	24	4.78	5	2.12	15	4.4	24	3.62	24	8.03	6	2.15	-	-
	29	5.35	18	2.69	27	3.83	27	6.73	28	3.26	14	3.9	-	-
	-	-	30	4.94	31	5.6	-	-	-	-	-	-	-	-
R4	26	1.4	-	-	1	1.0	1	0.3	11	1.4	8	3.3	1	19.8
	27	0.4	-	-	26	6.7	11	11.2	19	21.3	10	1.1	2	0.4
	-	-	-	-	-	-	12	0.1	22	5.4	15	0.1	3	0.2
	-	-	-	-	-	-	14	0.5	23	0.1	30	2.4	10	0.1
	-	-	-	-	-	-	15	2.0	24	0.2	-	-	-	-
	-	-	-	-	-	-	16	0.3	25	9.5	-	-	-	-
	-	-	-	-	-	-	24	10.7	-	-	-	-	-	-
	-	-	-	-	-	-	25	1.0	-	-	-	-	-	-

Total Water Depth Added from Irrigation Treatment and Rainfall (mm)			
100.9 = R4	93.88 = R3	249.82= R2	609= R1

- R1: Irrigation after the water reaches 50% of the available water.
- R2: Equivalent humidity treatment represents the highest rainfall for a 41-year time series.
- R3: Equivalent humidity treatment represents the rainfall rate for a 41-year time series.
- R4: Represents rainfall data for the study year 2023.-2024 according to Agricultural meteorology/ station Research Bourgeois/Al-Zubair, affiliated with the Ministry of Agriculture.

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IV. Results and Discussion:

Mean Weight Diameter (MWD):

The results of the F-test (Table 4) show a highly significant effect of soil conditioners on the mean weighted diameter (MWD). When comparing the experimental treatments, significant differences were observed among all conditioner treatments on the MWD values (Figure 1). The differences between treatments with added conditioners increased with increasing levels of addition. These differences were significant compared to the control treatment (C0). The lubricating oil (O3) treatment achieved the highest values at 5.605 mm, followed by treatment C3, which yielded values of 5.356 mm, compared to treatment, which achieved the lowest values at 1.691 mm. The overall mean MWD values for the treatments followed the following sequence:

O3 > C3 > O2 > C2 > O1 > C1 > C0

Table (4) Statistical Analysis of the F-test for the mean weight diameter

Factor	d.f	F- Value
Conditioner C	6	851.343 **
Humidity and Rainfall Treatments R	3	73.006 **
Depth D	1	341.311 **
C * R	18	3.394 **
C * D	6	18.004 **
D * R	3	1.455 N.S
C * R *D	18	1.247 N.S
** Highly significant N.S Non- significant		

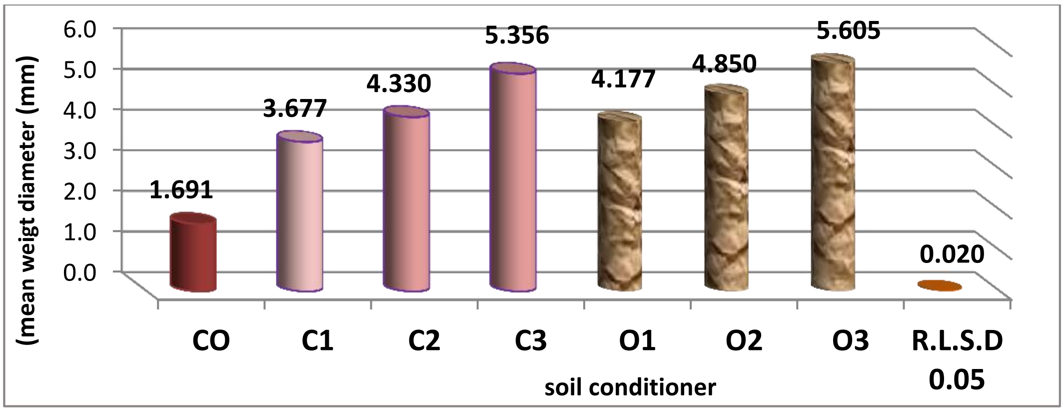

Figure (1) Effect of soil conditioner factor on mean weight diameter (mm).

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The reason for the increased MWD values when using emulsified lubricating oil conditioner is due to its direct effect. It contains viscous substances composed of long hydrocarbon chains that bind soil particles together. In addition, it has an indirect effect by increasing soil moisture content. This promotes the growth of microorganisms (fungi, cyanobacteria, green algae, actinomycetes, and lichens). Their secretions bind soil particles, thus improving soil structure and increasing plant density and root mass (Benlap, 2016). These results are consistent with Al-Bayati and Al-Zubaidi (2008), who showed that petroleum derivatives coat soil particles and aggregates. They increase the contact angles between soil particles and water. Consequently, they affect water movement in different directions and reduce water absorption. This, in turn, reduces soil aggregate degradation due to wetting. Katra (2021) The use of hydrocarbon petroleum products stabilizes the soil. It reduces soil erosion and wind erosion, and maintains the fertility of the topsoil. These materials can be combined with natural conditioners such as bentonite or clay to enhance soil structure stability. Regarding the effect of the soil conditioner Vertisol on soil aggregate formation and increasing MWD values. It works by binding small and large sand particles and creating bridges and bonds between them. This increases the MWD values of sandy soils due to the clay particles and organic matter. The formation of clay bridges between sand particles during wetting and drying cycles increases the stability of soil aggregates, as soil structure stability increases under these conditions (Djajadi *et al*., 2011). This effect is most pronounced in the topsoil layer, forming the biological crust, which is characterized by highly stable soil aggregates (Rodriguez-Caballero *et al*., 2018). These results are consistent with Al-Madi (2018) which showed an increase in the weighted diameter of sandy loam soils when treated with Vertisol clays.

The results of the F-test (Table 4) show a highly significant effect of the moisture and rainfall treatment factor (R) on MWD values. Figure (2) clearly shows significant differences between all moisture and rainfall treatments. The variability in MWD values increases with the variation in the total added water values across the moisture and rainfall treatments. The field capacity treatment (R1) achieved the highest MWD value at 4.553 mm, followed by treatment (R2) at 4.362 mm, and then treatment (R4) at 4.129 mm. The lowest value was observed in treatment (R3), which achieved 3.878 mm. This variability in MWD values is attributed to the variation in soil moisture regime between the treatments, in terms of soil moisture content, its regularity, and the depth of total added water in each moisture and rainfall treatment over time. This regularity also affects the effectiveness of microbial activity. Natural vegetation contributes to increased biomass, increased biotic secretions and root secretions in the soil, and higher organic content. This leads to the formation of strong bonds between sandy soil particles and the creation of more stable aggregates (Zhai *et al*., 2025). Furthermore, the moisture and rainfall treatments, especially those with high water depth (R1 and R2), recorded the highest moisture content. Consequently, the amount of water was suitable and balanced for the growth and increased effectiveness of soil organisms. Soil moisture significantly affects soil aggregate formation by enhancing microbial activity and the decomposition of organic matter, which in turn improves soil structure. Adding water to the soil creates surface tension within the thin water layer surrounding the soil particles, thus enhancing adhesion between adjacent particles (Vijay *et al*., 2018). Liu *et al.* (2025) demonstrated an increase in the weighted diameter and stability of soil aggregates, upon the addition of different moisture levels. 10, 20, 40 and 60% of the soil's field capacity.

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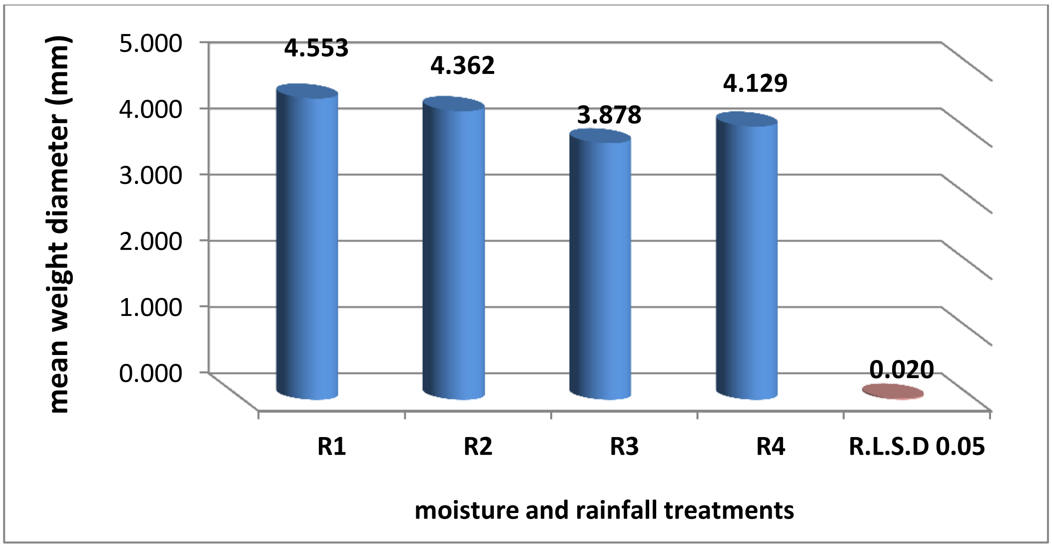

Figure (2) The effect of moisture and rainfall coefficients on the mean weight diameter (mm).

The results of the F-test (Table 4) showed a highly significant effect of soil depth on the variation of MWD values. Figure (3) shows a significant increase in MWD values at depth D1 compared to depth D2. Depth D1 achieved the highest MWD value of 4.562 mm, compared to depth D2. The values at D2 were 3.921 mm. This increase in MWD values at the surface depth (D1) compared to the subsurface depth (D2) is attributed to the density of the root system of natural plants at this depth. This density is a result of root secretions and decomposition, which produce organic matter. This organic matter acts as a binding agent, holding soil particles together and forming stable aggregates. Cerdà *et al*. (2018) demonstrated that the growth of crops and natural plants increases the organic matter content of the soil, with organic matter increasing at the surface depth. These results are consistent with those of Shbeib (2016), who found an increase in MWD at surface depths compared to subsurface depths. Furthermore, the formation of the biocrust is driven by the activity of microorganisms, whose activity is highest in the surface layer exposed to light. The autotrophic organisms in the biocrust can perform photosynthesis and generate organic carbon, which in turn binds soil particles together. In addition, the products of microbial decomposition form soil aggregates, thus improving soil structure stability and increasing its ability to retain moisture and nutrients (Belnab and Lange, 2013).

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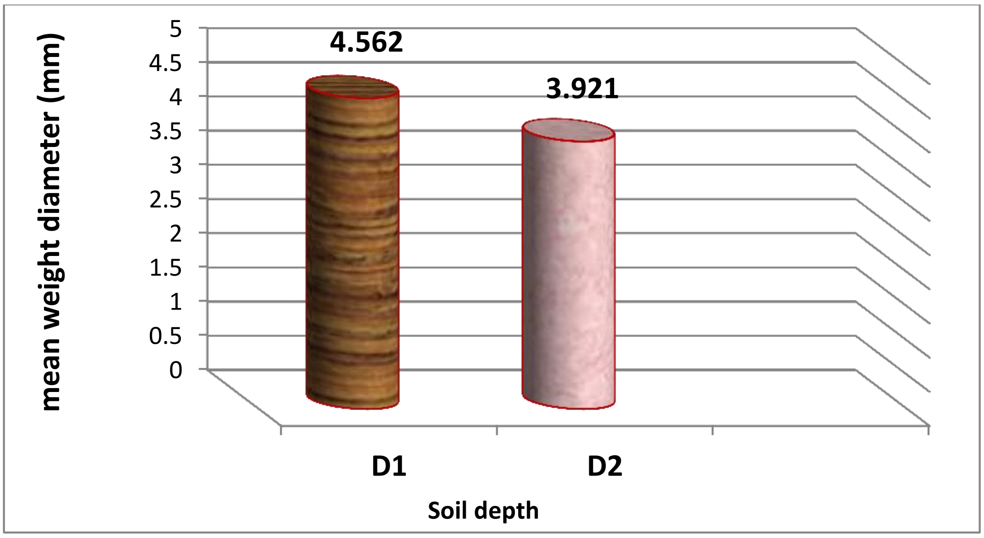

Figure (3) The effect of soil depth on the mean weight diameter (mm).

Regarding the effect of the twofold interaction between soil conditioners and moisture and rainfall treatments on MWD values, The results of the F-test (Table 4) show a highly significant effect of the twofold interaction on MWD values. Table (5) indicates that the effect of the conditioner treatment on MWD values varies according to the moisture and rainfall treatment. The highest differences between the conditioner treatments were observed when they interacted with treatment R1, followed by treatment R2, then treatment R4, and the lowest differences with treatment R3. This is attributed to the effect of the added conditioners at different levels, which is enhanced by increasing moisture levels according to the moisture and rainfall treatments. The highest values were observed with the moisture treatment R1 and the level of lubricating oil used (O3), reaching 6.04 mm. This was followed by the Vertisol C3 conditioner treatment at the same moisture treatment (R1), reaching 5.75 mm. The lowest MWD values were observed with the treatment The comparison (C0) for the moisture treatment R3 showed a value of 1.59 mm. As is evident from the results, MWD generally increased with the addition of conditioners and their levels, depending on the type of moisture and rainfall treatment, especially in treatments R1 and R2. This is because this interaction enhanced the effect of each conditioner individually on MWD values, resulting in higher values for the treatments compared to the control treatment. Furthermore, the growth of some desert plants and the increase in their root secretions, as well as the activity of microorganisms, were enhanced by the addition of soil conditioners. This led to the binding of soil particles and increased aggregate stability. The conditioners also played a role in strengthening soil structure and making it more cohesive during wetting and drying cycles when moisture and rainfall treatments were applied. This, in turn, led to an increase in total added water, especially in the moisture and rainfall treatments with a high water depth, R1 and R2.

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Table (5) Effect of the dual interaction between the conditioner factor and the moisture and rainfall treatments on the mean weight diameter of the soil (mm) at the end of the experiment.

Conditioner	moisture **and rainfall treatment**			
	R1	**R2**	**R3**	**R4**
C0	1.78	1.7	1.59	1.6
C1	3.92	3.7	3.44	3.6
C2	4.72	4.2	4.05	4.1
C3	5.75	5.5	4.93	5.1
O1	4.54	4.2	3.84	4.0
O2	5.22	4.9	4.50	4.6
O3	6.04	5.9	4.86	5.5
R.L.S.D$_{0.05}$	0.69			

The F-test for statistical analysis (Table 4) demonstrates a highly significant interaction effect between the two factors of soil conditioner use and soil depth variation on MWD values, when comparing MWD values for the different treatment factors. Table (6) shows that the values increased significantly with the addition of soil conditioners and their levels, particularly at shallow depth D1. This interaction with soil depth variation resulted in increased MWD values, especially at depth D1 compared to depth D2. The highest variations were observed with treatments C2, C3, O2, and O3 when interacting with soil depth. The highest values were recorded with treatment O3 at shallow depth D1, at 6.236 mm. This was followed by treatment C3 with Vertisol conditioner at 5.728 mm. The control treatment (C0) at depth D2 recorded the lowest values, at 1.619 mm. The increase in MWD values after adding soil conditioners, especially at depth D1, is attributed to the effect of these conditioners. Their concentration increases in the surface layer of the soil, thus improving soil structure. Furthermore, they increase plant root density and enhance the activity of microorganisms and their secretions. These microorganisms act as binding agents, linking particles together and forming stable soil aggregates, thereby increasing MWD values compared to depth D2. These results are consistent with those of Dheyab (2017), who found a decrease in MWD values with increasing depth due to the interaction between soil conditioner additions and variations in soil depth. This is attributed to the role of conditioners in improving soil structure and root system growth. Through root secretions, organic matter is produced, forming binding agents. These agents bind soil particles together and form stable aggregates at shallow depths compared to subsurface depths.

The results in Table (4) show no significant differences between the factors of moisture and rainfall treatments and soil depth. Similarly, there are no significant differences in the three-way interaction between the factors of the amendments, moisture and rainfall treatments, and soil depth.

Table (6) Effect of the dual interaction between the soil conditioner factor and soil depth on the mean weight diameter of the soil (mm).

Conditioner	**Soil depth (cm)**	
	0-5	**5-10**
C0	1.763	1.619
C1	3.827	3.527
C2	4.675	3.944
C3	5.728	4.985
O1	4.417	3.939
O2	5.244	4.456
O3	6.236	4.976
R.L.S.D$_{0.05}$	0.51	

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Amount of soil loss due to wind erosion :

The results of the F-test (Table 7) show a highly significant effect of soil amendments on the amount of soil lost due to erosion at the end of the experiment. Figure (4) shows that the control treatment C0 significantly outperformed the other treatments by 0.008 tons ha^{-1} (during the 5-minute measurement period).

Table (7) Statistical Analysis of the F-test for the rate of soil loss due to wind erosion.

Factor	d.f	F-Value
Conditioners C	6	140.450 *
moisture **and rainfall treatment R**	3	16.891 **
A*R	18	2.723 *
** Highly significant	* Significant	

This was followed by treatment C1, which recorded a soil loss of 0.004 tons ha^{-1}, also significantly higher than the other treatments. Then came treatment O1, which recorded a value of 0.003 tons ha^{-1}, also significantly higher than the other treatments. Following this was treatment O2, which recorded a value of 0.002 tons ha^{-1}. The lowest values were recorded in treatments O3, C3, and C2, at 0.001 tons ha^{-1}. This is attributed to the role of oil and clay amendments in increasing the moisture retention capacity of sandy soils and increasing water content. Plant availability, increased plant growth, root secretions, and microbial activity and secretions, which enhance the physical properties of the soil, improve soil structure, and increase MWD (Figure 1), in addition to the role of these improvers in promoting the formation of a biological crust, which leads to increased cohesion between soil particles, improved soil structure, and an increase in the size of soil aggregates resistant to wind erosion (Rodriguez-Caballero *et al*., 2018; Katra, 2021).

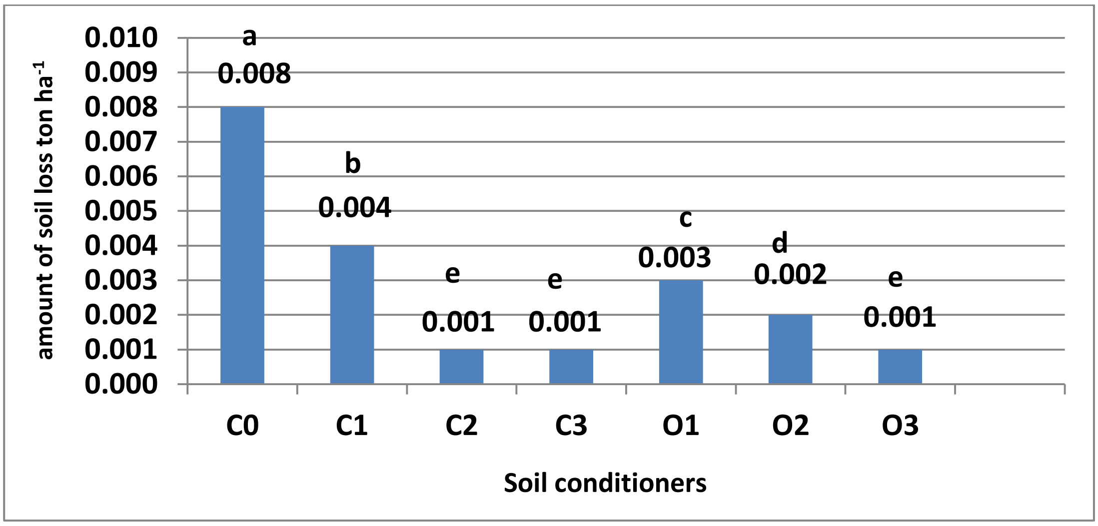

Figure (4) Effect of soil conditioner on the amount of soil lost by erosion (ton ha^{-1}).

The results of the statistical analysis in the F-test (Table 7) show a highly significant effect of the moisture and rainfall treatments on the average amount of soil lost. Figure (5) shows a significant advantage for treatment R3 in recording the highest average amount of soil lost, reaching 0.004 tons ha^{-1}. This is compared to treatments R1, R2, and R4, which recorded values of 0.002, 0.003, and 0.003 tons ha^{-1}, respectively.

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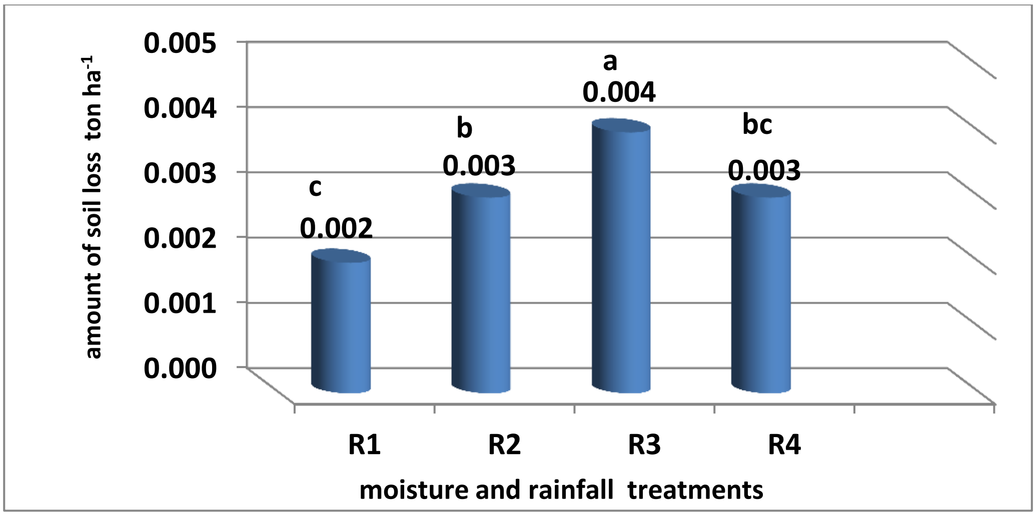

Figure (5) The effect of moisture and rainfall treatments on the amount of soil lost (tons ha^{-1}).

This is attributed to the variation in the depth of water added in the moisture and rainfall treatments. The increase in moisture content in R1 and R2, followed by R4 and then R3, was reflected in the activity of microorganisms and an increase in their biomass. Furthermore, the root systems of the growing natural plants, which were enhanced by the increased moisture content and the duration of irrigation or rainfall, played a role in improving soil structure and increasing MWD (Figure 1). In addition to the role of living organisms in the formation of the biological crust, it reduces the amount of soil lost through wind erosion (Chen *et al*., 2014). Li *et al.* (2025) demonstrated that rainfall can reduce wind erosion by up to 40–80%. This is attributed to increased moisture content, increased cohesion between particles, and reduced soil susceptibility to erosion.

The results of the statistical analysis of the F-test (Table 7) show a highly significant interaction effect between soil conditioner and rainfall and moisture treatments on the average soil loss due to erosion. Table (8) shows a decrease in the values for all levels of Vertisol and emulsified lubricating oil compared to the control treatment. This decrease increases with the level of application and varies according to the rainfall and moisture treatments (Table 3). The smallest differences in the average soil loss were observed between the moisture and rainfall treatments R1, R2, R3, and R4 when they interacted with the higher levels of conditioner O3, O2, and C3, followed by the O1 and C2 treatments. This is attributed to the mechanism of action of the amendments in reducing soil loss due to erosion. When Vertisol is used, clay, which has a high surface area, increases the soil's ability to retain moisture. This leads to increased binding strength between clay and sand particles, resulting in more stable soil aggregates during wet and dry periods, and increased soil moisture retention. The cohesion between particles makes them resistant to separation and transport by wind (Weil and Brady, 2016). In the treatments under study, the periodic addition of moisture and rainfall treatments (Table 3) contributed to strengthening the bonding forces between soil particles and increasing MWD (Figure 2), thus making the soil particles resistant to separation and transport by wind. As for the emulsified lubricating oil enhancer, its role is attributed to its improvement of the soil's physical properties by coating soil particles with a hydrophobic hydrocarbon layer. This layer reduces the disintegration of soil particles and increases cohesion between particles during periods of drought and when a suitable moisture level is available due to water addition or rainfall. The petroleum-based materials increase the soil's moisture content, thus enhancing its resistance to wind erosion (Rostami *et al*., 2023). Furthermore, the biological crust formed on the soil surface plays a role. Its formation, thickness, and stability depend on the activity of microorganisms and their biomass, which is enhanced by the moisture content and their ability to retain a suitable moisture level between irrigation and shower periods. Rainfall (Chamizo *et al*., 2013), which depends on the role of the amendment, its level of addition, and its interaction with the moisture content of the wet and rainfall treatments. The C0R3 factor treatment recorded the highest amount of soil loss due to erosion at 0.010 tons ha^{-1}. The lowest values appeared with the C2R1, C2R2, C3R1, C3R2, C3R4, O2R1, O3R1, O3R2, and O3R4 factor treatments, which were 0.001 tons ha^{-1}.

Table (8) Effect of the soil conditioner factor and the rainfall moisture factor on the amount of soil lost (tons ha^{-1}).

Conditioners	Rainfall moisture factor			
	R1	R2	R3	R4
C_0	0.006 d	0.007 c	0.010 a	0.008 b
C_1	0.002 h	0.004 f	0.005 e	0.005 e
C_2	0.001 i	0.001 i	0.002 h	0.002 h
C_3	0.001 i	0.001 i	0.002 h	0.001 i
O_1	0.003 g	0.003 g	0.004 f	0.004 f
O_2	0.001 i	0.002 h	0.002 h	0.002 h
O_3	0.001 i	0.001 i	0.002 h	0.001 i

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