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The effects of adding Vertisol conditioners and emulsified Lubricating oil on soil respiration and biological soil crust thickness in sandy soil under different rainfall and moisture treatments

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Abstract

Objective

The aim of this study was to investigate the effect of adding natural and industrial soil conditioners on the effectiveness of microorganisms and the thickness of the biological crust.

Materials and methods

In the field experiment, a section of the soil surface was cut to a depth of 15 cm Measurements were taken in the middle and end of the experiment. The experiment included two factors. The first factor was conditioner factor in seven treatments. The second factor was the rainfall moisture treatment, included four treatments.

Results

Soil conditioner treatments significantly increased soil respiration compared to the control. Lubricating oil treatment (O3) and vertisol soil treatment (C3) showed the highest CO_2 release. The release rates for them were 29.13 and 27.03 mg CO_2/kg soil, respectively. Among the rainfall moisture treatments, R1 showed the highest respiration rate (26.24 mg CO_2/kg soil). While the lowest value was observed in R3 (19.79 mg CO_2/kg soil). Soil amendments also significantly increased the biological crust thickness compared to the control group (C0). Among them, the O3 treatment showed the highest crust thickness in the middle and end of the experiment (4.66 and

4.81 cm, respectively). After that, the C3 treatment recorded the highest thickness (3.15 and 3.24 cm). It should be noted that the control treatment (C0) recorded the lowest values (1.36 and 1.40 cm). The highest recorded value for crust thickness, in terms of rainfall moisture, was related to treatment R1 and showed a significant difference with treatments R2, R3 and R4.

Conclusion

Using soil conditioners, particularly lubricating oil and Vertisol, significantly increased microbial activity and biological crust development. In addition, higher moisture levels improved soil respiration and crust formation. The results of this study showed that soil amendments and moisture management are of great importance in improving the biological properties of soil and should be considered.

Keywords: biological soil crust, CO_2 emission, moisture treatments, soil conditioners, soil respiration

Paper Type: Research Paper.

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Introduction

Ecosystems in dry regions are among the most vulnerable and greatly affected by climate change (Carbone et al., 2011). Because, global climate change is causing a significant change in the characteristics and vital productive capacity of dry lands. This requires for measures to restore their functions and productive capacity and prevent soils from reaching advanced states of desertification. The most important manifestations of them are various types of erosion and the loss of soil and damage they cause. The Biological Crust is the interface between the soil and the atmosphere. It plays a crucial role in environmental hydrological processes and thus influences the dynamics of dry land ecosystem recovery. Numerous studies have demonstrated the effects of the biological Crust on hydrological processes in ecosystems (Büdel et al., 2016; Rosentreter et al., 2016). As a part of the vital components of all ecosystems, and the growth of biological crusts it enhances the growth of microorganisms. Thus, it improves the restoration of environmental balance in dry lands. The biological soil crust are communities of photosynthetic microorganisms, such as green and blue bacteria, actinomyces, and lichens, as well as microscopic animals such as nematodes and arthropods (Büdel et al., 2016; Rosentreter et al., 2016; Darby and Neher, 2016). The thickness of the soil biocrust depends on the activity of soil organisms. It works to stabilize the surface layer, which affects the stability of the soil surface, resistance to erosion, and the sustainability of desert systems (Bowker et al. 2008; Ravi et al., 2011). Bio crust fixes carbon and nitrogen, thus providing nutrients to degraded soils. It also affects moisture content, plant growth, and improves the physical and chemical properties of soil in arid areas. It increases the mean weight diameter, improves soil structure, forms more stable aggregates, reduces water conductivity, increases the moisture content of sandy soil, and other properties (Zhang et al., 2015; Coleine et al., 2026). Soil respiration and the release of carbon dioxide from the soil to the atmosphere are the result of microbial activity and root respiration. They are evidence of the physiological responses of microbial communities to changes in environmental factors **(**Franco et al., 2004; Wu et al., 2014**).** Many factors affect soil respiration, including temperature, moisture and agricultural processes such as tillage. Some studies have shown that natural and industrial soil conditioners have the ability to improve some properties of sandy soils. In arid and semi-arid regions, soil moisture is considered a determining factor in the effectiveness of organisms and their role in increasing biomass which forming biological crusts. Due to the importance of this topic, since most of the lands depend on the precipitation factor, many studies have turned to the use of soil conditioners. These conditioners increase the soil’s ability to retain moisture for a long period for the purposes of soil management. Alghamdi et al. (2024) pointed that adding clay to sandy soil may change the response of microbes, especially during periods of drought and re - moisturize. Szatanik-Kloc et al. (2021) explained that bentonite clay increases the rate of CO_2 released from the soil, especially at low levels of additions. This is attributed to the role of bentonite in increasing the soil's ability to retain moisture, and enhancing biological activity. Roychand & Marschner (2013) found increased respiration rate in sandy soil treated with clay mixed with wheat residues and sawdust compared to untreated sandy soil. Abioye et al. (2009) concluded that adding the lubricating oil with organic residues increased the rate CO_2 during different incubation periods compared to the control treatment. Wolińska et al. (2016) found that adding petroleum derivatives, increases the rate CO_2 equivalent to three times more than control treatment. This study aimed to investigate the effect of adding some natural conditioner represented by adding expanded vertisol clays and industrial conditioner represented by emulsified lubricating oil on the effectiveness of microorganisms and the thickness of the biological crust resulting from the microbiological activity under different rain and humidity conditions.

Material and methods

The study was carried out at the Al-Barjisiya Research Station affiliated with the General Authority for Agricultural Research - Ministry of Agriculture, located in the Al-Zubair area, Basrah province during the agricultural season 2023-2024. The site is located in a desert area with a dry climate. The soil is loamy sand and is classified as sandy calcareous, hyperthermic Typic Quartzipsamments. The field experiment area was divided into three blocks and each block was divided into experimental units (slabs with dimensions of 1 × 1 m). The randomized complete block design (RCBD) was used with three replicates. The first factor contained natural and artificial amendments treatments. The natural amendment was represented by Vertisol soil, which is a swelling-shrinking black clay soil taken from sugarcane fields/Maysan Governorate. It is characterized by its high content of expensive clay (Table 1). These treatments were applied at rates of 10% (C1), 20% (C2), and 30% (C3) (w/w) of sandy soil. They were applied to a depth of 1 cm as a suspension (1 soil: 6 water) sprayed on the soil surface. The artificial conditioner consisted of spent lubricating oil. The oil was emulsified with water using an anionic surfactant, following the method described by Oliveira et al. (2017) and Dheyab (2017). The levels were 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 using the volume of the emulsion (oil/water) equal to bring the soil to field capacity at a depth of 15 cm. The second factor was rainfall moisture factor with four treatments. These treatments were the irrigation treatment to the field capacity limits R1, in which Irrigation was applied to field capacity (R1), and repeated when the soil lost 50% of its field capacity moisture at a depth of 15 cm. The highest annual rainfall treatment (R_2), the rainfall rate treatment (R_3), as the treatments (R_2 and R_3) are recorded from a time series of 41 previous years and the actual rainfall recorded during the study year (R4) (Table 2). Irrigation dates and equivalent quantities were determined for the two rainfall treatments: R2 (highest rainfall) and R3 (average rainfall) as follows:

1- Identify the year that recorded the highest rainfall during the past 41 years.
2- Calculate the overall precipitation rate during the past 41 years.
3- Determine the dates of rain showers distributed over the days in each month of the year. Then, calculate the cumulative frequency (i.e., the number of showers on each day of each month, Yi).

4- The arithmetic mean of the number of showers occurring in each month was estimated separately. The arithmetic mean was calculated as follows:

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

Where, arithmetic mean=, $(\overline{y})$ for a period of 41 years, total=$\sum yi$, number of days in each month (28, 29, 30, 31) =n.

5- The days in each month with frequencies higher than the arithmetic mean were selected, while those with lower frequencies were excluded to reduce the number of rainfall events.

6- The total rainfall over the 41-year period was distributed for the two treatments (R2: highest rainfall and R3: average rainfall) according to the most frequent rainfall events. The proportion of each representative value was then calculated relative to the total frequency of these events.

The treatments were initiated before the onset of rainfall in early November. The addition of (R0) water equivalent to rainfall treatments continued until May 3 (end of the rainy season). During rainfall events, all experimental units were covered with plastic sheets, except for treatment R4, which was left uncovered to receive natural rainfall during the study year.

The thickness of the biological crust was measured in the field experimental units for two periods, the first at the middle of the experimental period (March), the second at the end of the study period (August). A soil section was dug to a depth of 15 cm, and the thickness of the biological crust was measured. Soil samples were also collected for further analyses. Soil respiration was estimated by measuring CO_2 release. Glass containers (5 cm in diameter) containing 1 N NaOH solution were placed on the soil surface and tightly covered with plastic cylinders (10 cm in diameter) to trap the CO_2 released from microbial respiration throughout the experimental period. The released CO_2 gas was determined by back titration of NaOH solution (1 N) with HCl (hydrochloric acid) (1 N) in the presence of phenolphthalein indicator as in the method described in Ciardi & Nannipieri (1990) according to the following reaction:

$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

The amount of CO_2 in milliequivalents (meq) was calculated as follows

meq CO_2 = meq (NaOH) − meq (HCl)

mg CO_2 = meq CO_2 × equivalent weight

Results and discussion

Biology activity (Soil Respiration): Results in Figure 1 show a highly significant effect of conditioner factor on CO_2 release from the soil (mg CO_2 kg^{-1} soil). The O_3 and C_3 treatment recorded the highest respiration rate (29.133 and 27.026 mg CO_2 kg^{-1} soil, respectively), followed by O_2, C_2, O_1, and C_1 treatments. The variation increases with the increase in the addition level compared to the control treatment that achieved the lowest values of (15.776 mg CO_2 kg^{-1} soil), with increases of 2.813%, 2.602%, 2.401%, 2.228%, 2.209%, and 1.773% for O_3, C_3, O_2, C_2, O_1, and C_1, respectively, compared with the control (C_0).

Table 1. Some physical and chemical properties of soil at depths of 0-5 and 5-10 cm and Vertisol soil conditioner

Soil property	Unit	0-5 cm	5-10 cm	Vertisol soil conditioner
pH (1:1)	—	7.8	7.9	8.1
EC	dS m^{-1}	4.2	4.4	6.12
Saturated moisture content	%	31.55	31.88	65.8
Field capacity	%	20.12	20.22	45.4
Sand	g kg^{-1}	887	885	58
Silt	g kg^{-1}	64.81	65.83	348
Clay	g kg^{-1}	48.19	49.17	592
Texture	—	Loamy sand	Loamy sand	Clay
Particle density	Mg m^{-3}	2.64	2.66	2.65
Bulk density	Mg m^{-3}	1.65	1.66	1.30
Porosity	%	37.50	37.59	50.94
MWD	mm	1.545	1.540	0.47
Saturated hydraulic conductivity	cm h^{-1}	14.87	14.22	0.70
CEC	cmol(+) kg^{-1}	6.22	5.88	40.90
Organic matter	g kg^{-1}	2.18	2.00	6.80
Soluble ions				
Ion	**Unit**	**0-5 cm**	**5-10 cm**	**Vertisol soil conditioner**
$CaCO_3$	g kg^{-1}	138	135	266.12
Ca^{2+}	mmol L^{-1}	8.20	7.00	17.00
Mg^{2+}	mmol L^{-1}	18.00	8.90	16.40
Na^{+}	mmol L^{-1}	6.22	6.30	22.50
K^{+}	mmol L^{-1}	3.18	3.20	6.44
HCO_3^{-}	mmol L^{-1}	6.90	6.55	3.40
CO_3^{2-}	mmol L^{-1}	0.00	0.00	0.00
Cl^{-}	mmol L^{-1}	25.00	24.00	35.00
SO_4^{2-}	mmol L^{-1}	9.30	8.90	8.44

This may be attributed to the indirect effect of lubricating oil in increasing soil moisture content by reducing upward capillary movement and surface evaporation, thereby enhancing soil respiration. This is also associated with increased microbial activity and growth, as well as enhanced plant growth, density, and root biomass. These results are consistent with the results of Wolińska et al. (2016) and Kim et al. (2023).

Table 2. Timing and amount of rainfall and moisture treatments during the study period (mm)

Treatment	Month	Date	Amount (mm)	Treatment	Month	Date	Amount (mm)
R1	Nov	24	21	R2	Nov	2	11.18
R1	Nov	29	21	R2	Nov	11	21.01
R1	Dec	4	21	R2	Nov	24	16.13
R1	Dec	10	21	R2	Nov	29	18.05
R1	Dec	18	21	R2	Dec	1	2.91
R1	Dec	22	21	R2	Dec	2	5.27
R1	Dec	28	21	R2	Dec	5	7.65
R1	Jan	4	21	R2	Dec	18	3.98
R1	Jan	11	21	R2	Dec	30	7.30
R1	Jan	18	21	R2	Jan	2	5.18
R1	Jan	25	21	R2	Jan	14	2.74
R1	Feb	1	21	R2	Jan	15	3.41
R1	Feb	8	21	R2	Jan	27	2.96
R1	Feb	15	21	R2	Jan	31	4.33
R1	Feb	22	21	R2	Feb	10	3.76
R1	Mar	1	21	R2	Feb	19	3.76
R1	Mar	7	21	R2	Feb	24	5.26
R1	Mar	13	21	R2	Feb	27	9.76
R1	Mar	19	21	R2	Mar	18	8.27
R1	Mar	25	21	R2	Mar	20	18.18
R1	Mar	31	21	R2	Mar	24	27.10
R1	Apr	5	21	R2	Mar	28	11.00
R1	Apr	10	21	R2	Apr	2	12.52
R1	Apr	15	21	R2	Apr	4	18.41
R1	Apr	20	21	R2	Apr	6	4.88
R1	Apr	25	21	R2	Apr	14	26.35
R1	Apr	30	21				

As for the role of Vertisol conditioner in increasing soil respiration, this is due to its direct effect in increasing the soil's water retention. This is because of its high water-holding capacity, resulting from the high clay content and cation exchange capacity (CEC). The application of this conditioner in suspension form allows clay particles to penetrate into the sandy soil and coat its particles.

Table 2. Continued

Treatment	Month	Date	Amount (mm)	Treatment	Month	Date	Amount (mm)
R3	Nov	2	3.32	R4	Nov	26	1.40
R3	Nov	11	6.23	R4	Nov	27	0.40
R3	Nov	24	4.78	R4	Jan	1	1.00
R3	Nov	29	5.35	R4	Jan	26	6.70
R3	Dec	1	1.97	R4	Feb	1	0.30
R3	Dec	2	3.57	R4	Feb	11	11.20
R3	Dec	5	2.12	R4	Feb	12	0.10
R3	Dec	18	2.69	R4	Feb	14	0.50
R3	Dec	30	4.94	R4	Feb	15	2.00
R3	Jan	2	6.69	R4	Feb	16	0.30
R3	Jan	14	3.53	R4	Feb	24	10.70
R3	Jan	15	4.40	R4	Feb	25	1.00
R3	Jan	27	3.83	R4	Mar	11	1.40
R3	Jan	31	5.60	R4	Mar	19	21.30
R3	Feb	10	2.60	R4	Mar	22	5.40
R3	Feb	19	2.59	R4	Mar	23	0.10
R3	Feb	24	3.62	R4	Mar	24	0.20
R3	Feb	27	6.73	R4	Mar	25	9.50
R3	Mar	18	2.45	R4	Apr	8	3.30
R3	Mar	20	5.40	R4	Apr	10	1.10
R3	Mar	24	8.03	R4	Apr	15	0.10
R3	Mar	28	3.26	R4	Apr	30	2.40
R3	Apr	2	1.85	R4	May	1	19.80
R3	Apr	4	2.73	R4	May	2	0.40
R3	Apr	6	2.15	R4	May	3	0.20
R3	Apr	14	3.90	R4	May	10	0.10
Total water depth (mm)	R_1=609		R_2=249.82		R_3=93.88		R_4=100.9

R1: Irrigation applied when soil moisture reached 50% of available water, R2: Moisture treatment equivalent to the highest rainfall recorded over a 41-year period, R3: Moisture treatment equivalent to the average rainfall over a 41-year period, and R4: Actual rainfall data for the study year (2023-2024), obtained from the Agricultural Meteorology Station, Al-Zubair, Ministry of Agriculture.

Thus, increasing the soil's ability to retain moisture and restricting the movement of water upward to the top by capillary rise as a result of forming a mulch layer that reduces capillary rise of water due to the lack of homogeneity between the pores of sandy and clayey soils. It increases soil moisture retention, which is positively reflected in increasing the effectiveness of microorganisms and enhancing plant growth (shoot and root biomass) by increasing the level of addition of Vertisol conditioner. These results are consistent with the findings of Roychand & Marschner (2013).

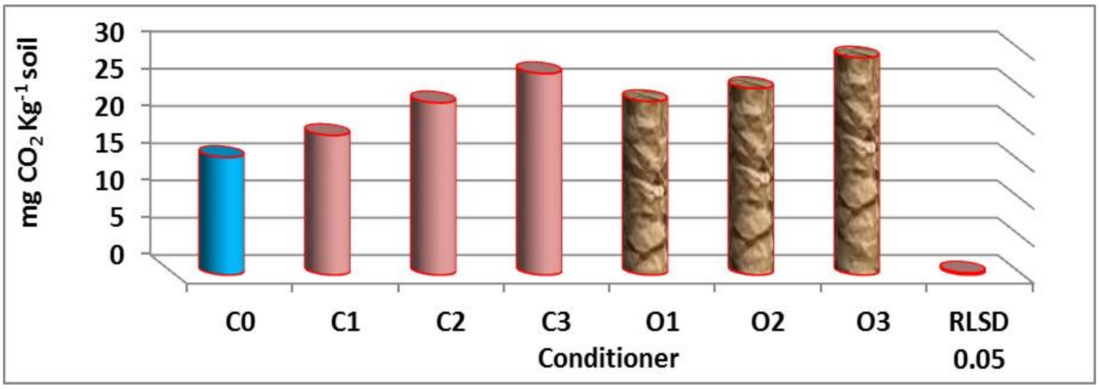


Figure 1. Effect of soil conditioner treatments on CO_2 release from soil (mg CO_2 kg^{-1} soil).

The results in Figure 2 show a highly significant effect of the rainfall moisture factor on the rate of CO_2 release (mg CO_2 kg^{-1} soil). It shows that field capacity treatment R1 recorded the highest respiratory rate (26.240 mg CO_2 kg^{-1} soil) with a significant difference from other treatments, followed by R2, and then R4 and R3 treatment. The R_3 treatment recorded the lowest value (19.785 mg CO_2 kg^{-1} soil). It was accompanied by decreases of 2.530%, 2.539%, and 2.548% were observed for R2, R4, and R3, respectively, compared with R1. This is attributed to the effect of the moisture content in the soil in increasing the activity of microorganisms in converting them from the lag phase to the exponential (log) phase. In addition, most enzyme-catalyzed reactions take place in an aqueous medium. The decreasing of moisture content in the soil led to decrease the activity of microorganisms and decline the respiration process (Schimel et al., 2007; Belnap et al., 2016). Although the R1 treatment outperformed the other treatments (R2, R3, and R4) due to its optimal moisture conditions for microorganisms and plants, the differences in CO_2 release among R2, R3, and R4 were relatively small compared with the total moisture added in R1. This suggests that microorganisms have a certain tolerance to moisture deficiency, often greater than that of plants. Results in Table 3 show a highly significant effect of the interaction between the soil conditioner factor and rainfall moisture factor on the CO_2 values. They show significant differences in CO_2 values between treatment rain and moisture It varies depending on the type and level of the applied conditioner. The results indicate that soil conditioners enhanced CO_2 release under all rainfall moisture treatments (R1, R2, R3, and R4), with the effect increasing as the application level increased.

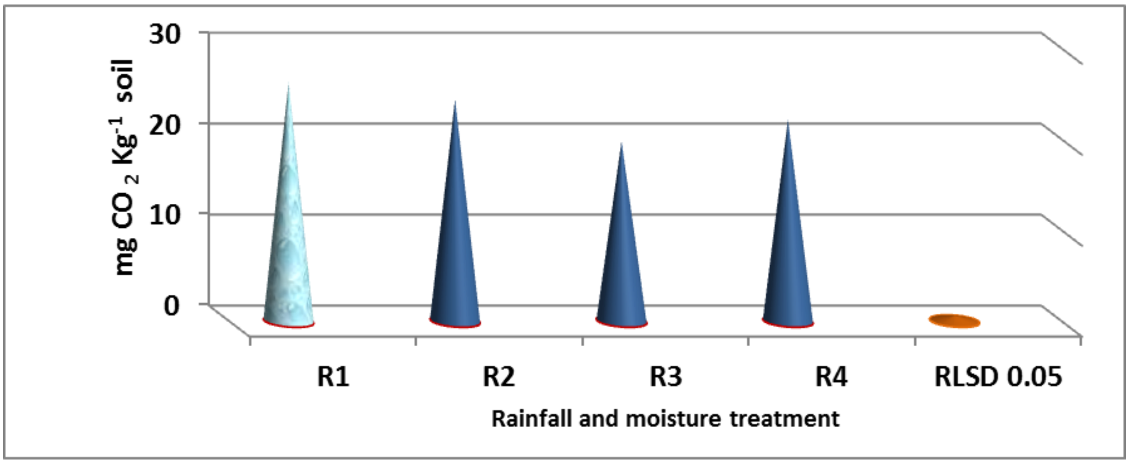


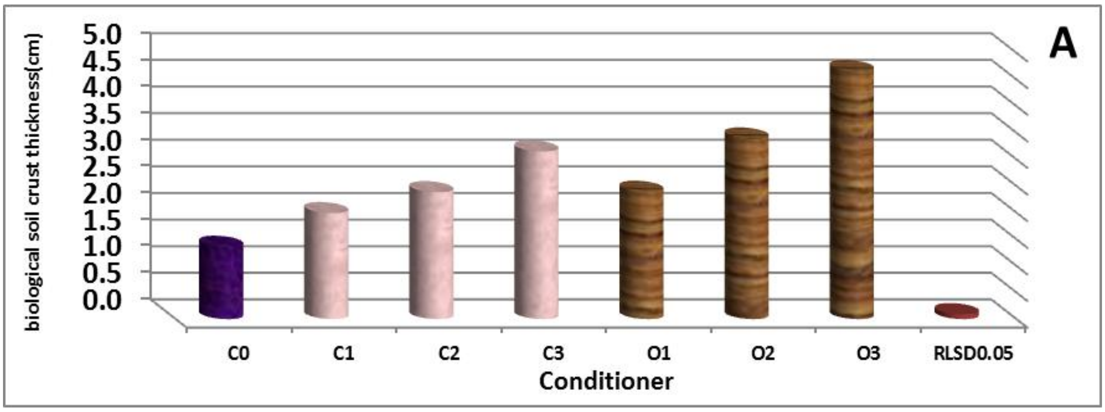
Figure 2. Effect of rainfall-moisture treatments on CO_2 release (mg CO_2 kg^{-1} soil)

They are interleaved with the conditioner levels when the level is increased addition the conditioner, whether it is a clay conditioner or an oil conditioner. It is due to the conditioner role in increasing moisture retention to a level suitable for the growth and activity of microorganisms under different moisture levels. This effect was more pronounced at higher levels (O_3 and C_3), which reduced the differences among rainfall treatments (R1, R2, R3, and R4), which overlapped with it. Table 3 also shows that the highest CO_2 values were recorded for O_3 and C_3 combined with R1 (30.850 and 30.645 mg CO_2 kg^{-1} soil, respectively), while the lowest value was observed in the control treatment (C0) combined with R3 (14.397 mg CO_2 kg^{-1} soil).

Table 3. Interaction effect of conditioner treatments and rainfall-moisture regimes on CO_2 release (mg CO_2 kg^{-1} soil)

Conditioner	R1	R2	R3	R4
C0	18.22	16.04	14.40	14.44
C1	22.80	19.09	14.84	18.20
C2	27.53	25.03	17.03	22.80
C3	30.65	29.45	23.76	24.25
O1	25.38	25.38	20.11	22.27
O2	28.25	25.86	21.07	24.90
O3	30.85	30.14	27.29	28.25
LSD (0.05) = 1.98	Values are means of replicates. Differences were compared using LSD at $P \leq 0.05$.			

Biological soil crust thickness: The results in Figure 3 show a highly significant effect of the conditioner factor on biological soil crust thickness formed in the soil at the middle and end of the experimental period. These findings show there are significant differences between all the treatments of the conditioner, with significant superiority compared to the control treatment. The thickness of the biological crust of the treatments of the added conditioners increases with the increase in the level of adding the conditioners. Increases of 3.658%, 2.391%, 2.500%, 1.391%, 1.383%, and 0.991% were observed for O_3, O_2, C_3, O_1, C_2, and C_1, respectively, compared with the control (C0). The significant superiority of the emulsified oil treatments is due to the multiple effects of the added this conditioner through the role of direct oil as a highly viscous material in binding soil particles together.(Dheyab, 2017) and indirect effects represented by increase moisture retention by improving soil structure (Dowdeswell-Downey et al., 2023) and by reducing the movement of capillary water due to the formation of Hydrophobic surfaces soil particles (Dheyab, 2017). It led to increased activity of microorganisms such as fungi, algae, bacteria and plant roots in binding soil particles together to form a biological crust. The increase in biological crust thickness with Vertisol application (from C1 to C3) is also attributed to multiple factors. These include the direct role of fine clay particles in binding sandy soil particles and forming bridges between them. In addition, Vertisol enhances water retention due to its high content of expansive clay minerals. Indirectly, it improves microbial activity by increasing soil moisture and reducing surface water loss through limiting capillary movement, resulting from differences in pore size distribution between sandy and clay soils (Dheyab, 2017). Results in Figure 3 also show the effect of soil conditioner at the end of experiment followed a similar trend at the middle of the experiment. In continuing superiority of treatment O_3 is followed by treatment C_3 and then the other treatments in sequence O_2, C_2, O_1 and C_1 and the least in control treatment 0 with an increasing (3.808, 2.483, 2.242, 1.7, 1.508, 1.15) % for treatments O_3, O_2, C_3, C_2, O_1, C_1, noting an increase in the biological soil crust thickness for all the added conditioner at the end of the experiment Compared to their values at the middle of the experiment. This indicates the continued effect of soil conditioners in enhancing microbial activity and the production of binding agents, which increased soil particle cohesion and crust stability. This effect persisted despite the soil being exposed to harsh drought conditions after the end of the rainy season (June-July). The results in Figure 4 show a highly significant effect of the rainfall moisture factor on the biological soil crust thickness at the middle and end of the experiment period. These findings show at the mid-experiment (Figure 4A) appearance there are significant differences between all the rain moisture treatments, with the superiority of treatment R_1 over the other treatments, followed by treatment R_2, then R_4, and the least treatment R_3, with decreases of 2.33%, 2.40%, and 2.19% for treatments R_2, R_4, and R_3, respectively, compared to treatment R_1. This is due to the variation in the effectiveness of organisms that are affected by the moisture content of each treatment, which shows the effect of rain treatments on the effectiveness of organisms. Cruz-Paredes et al. (2021) found an increase in effectiveness of microorganisms in soil at different moisture coefficients and decreased effectiveness when moisture content decreased. Figure 4-B shows the results in the end of experiment period take similar trend with the results of the middle of the experiment with an increase in the thickness of the biological crust for all rain treatments.



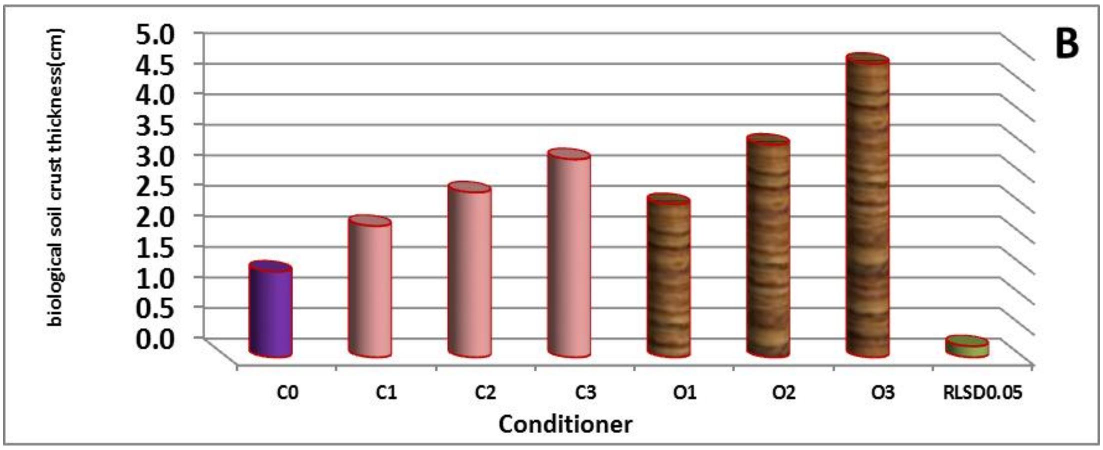


Figure 3. Effect of treatments on biological soil crust thickness at mid-experiment (A) and end of experiment (B).

This is due to the continued effect of the effectiveness of microorganisms and their secretions for the remainder of the rainy season. It made the soil particles more cohesion and the crust highly stable due to the addition of conditioner in spite of the soil was exposed through harsh drought conditions after the end of the rainy season. Overall, biological soil crust thickness increased at the end of the experiment compared with mid-experiment. Increases of 5.12%, 6.85%, 4.75%, and 3.29% were recorded for R1, R2, R3, and R4, respectively. The variation in the increase rates according to the treatments is due to the regularity of the moisture content of treatments R1, R2 compared to R3, R4 for the last months of wet season (April and May) **(**Table 4). The results in Table 5 show that there is no significant effect of the interaction between the conditioner and rainfall factor on the soil biocrust thickness. The results in Table 4 show biological soil crust thickness, which enhances with the increase in the level of adding Vertisol soil conditioner and emulsified lubricating oil conditioner, is varied according to the difference in rainfall and moisture treatments.

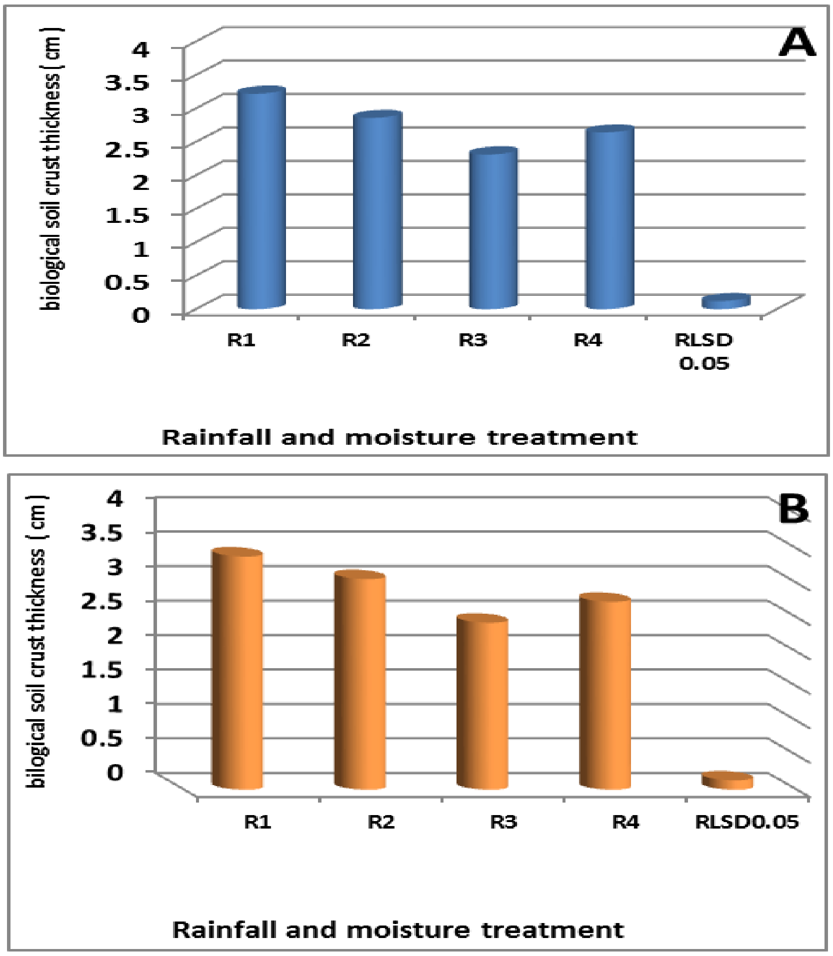


Figure 4. Effect of rainfall-moisture treatments on biological soil crust thickness at mid-experiment (A) and end of experiment (B).

Table 4. Interaction effect of conditioner treatments and rainfall-moisture regimes on biological soil crust thickness (mm)

Conditioner	Mid-experiment				End of experiment			
	R1	R2	R3	R4	R1	R2	R3	R4
C0	1.57	1.47	1.07	1.33	1.58	1.47	1.23	1.33
C1	2.27	1.93	1.83	1.93	2.40	2.33	1.87	2.00
C2	2.63	2.57	2.00	2.33	3.13	3.07	2.23	2.37
C3	4.03	3.07	2.50	3.00	4.17	3.13	2.53	3.13
O1	2.57	2.50	2.17	2.33	2.73	2.63	2.20	2.47
O2	4.00	3.50	2.83	3.23	4.07	3.53	3.07	3.27
O3	5.50	5.00	3.80	4.33	5.63	5.23	3.83	4.53
LSD (0.05): Not significant (n.s.) for both measurement times								

The highest values were shown in the factorial treatment O_3R_1, followed by treatment C_3R_1 and then O_2R_1. The lowest values appeared in treatment C_0R_3 at both the middle and end of the experiment period, consistent with the previously discussed trends. Despite this, all treatments showed higher values at the end of the season compared with the middle of the season.

Table 5. Analysis of variance (ANOVA) for CO_2 release and biological soil crust thickness

Source	df	CO_2 release (mg CO_2 kg^{-1} soil)	Crust thickness (mid) (mm)	Crust thickness (end) (mm)
C (Conditioner)	6	201.625**	79.033**	35.944**
R (Rainfall-moisture)	3	129.237**	17.335**	9.185**
C × R	18	3.917**	1.078 n.s.	5.430 n.s.

C: Conditioner treatments, R: Rainfall-moisture treatments, df: Degrees of freedom, ** Significant at $P \leq 0.01$, n.s.: Not significant

Conclusion: The results of this study showed that the use of Vertisol clay and emulsified oil as soil amendments can improve microbial activity and soil respiration in sandy soils under different rainfall moisture regimes. This improvement is achieved through such factors as reduced evaporation losses, better soil moisture retention, creation of more favorable conditions for microbial growth and activity, and the formation and stability of biological soil crusts. Overall, the results showed that both natural (Vertisol) and synthetic (oil-based) amendments, especially when used under water-limited conditions, have the ability to effectively improve the physical and biological properties of sandy soils. Therefore, it can be concluded that the use of these amendments can improve soil quality, support soil ecosystem functions, and increase soil resilience in arid and semi-arid environments.

Author contributions

D. S. J. contributed to conducting the soil respiration experiment through the estimation of carbon dioxide (CO_2) as well as performing all laboratory analyses of the studied soil properties and performing statistical and graphical representation of the data; A. H. D. contributed to collecting rainfall data for a 41-year time series, calculating modal peaks for the highest probabilities of monthly rainfall events; and D. R. N. contributed to select the representative study site and designing the field experiment for measuring the thickness of the biological soil crust. All authors contributed to the preparation, writing, discussion, review and final approval of the manuscript

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Data availability

The data contributing to the findings of this study are available from the investigating researcher upon request.

Ethical considerations

No human or animal participants were used in this study. All laboratory procedures were performed in accordance with standard procedures.

Conflict of Interest

The researchers declare no conflict of interest regarding the publication of this paper.

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اثرات افزودن اصلاح‌کننده‌های خاک ورتیسول و روغن روان کننده امولسیون شده بر تنفس خاک و ضخامت پوسته زیستی خاک در خاک شنی تحت تیمارهای مختلف بارندگی و رطوبت

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چکیده

هدف: هدف از این مطالعه بررسی اثر افزودن اصلاح‌کننده‌های طبیعی و صنعتی خاک بر فعالیت میکروارگانیسم‌ها و ضخامت پوسته زیستی خاک بود.

مواد و روش‌ها: در آزمایش مزرعه‌ای، بخشی از سطح خاک تا عمق ۱۵ سانتی‌متر برش داده شد. اندازه‌گیری‌ها در میانه و پایان آزمایش انجام شد. این آزمایش شامل دو عامل بود. عامل اول، نوع اصلاح‌کننده در هفت تیمار مختلف و عامل دوم، رطوبت ناشی از بارندگی در چهار تیمار بود.

نتایج: تیمارهای اصلاح‌کننده خاک به طور معنی‌داری موجب افزایش تنفس خاک نسبت به شاهد شدند. تیمار روغن روان‌کننده (O3) و تیمار خاک ورتیسول (C3) بیشترین میزان آزادسازی CO_2 را نشان دادند که به ترتیب برابر با ۲۹/۱۳ و ۲۷/۰۳ میلی‌گرم CO_2 به ازای هر کیلوگرم خاک بود. در میان تیمارهای رطوبتی، تیمار R1 بیشترین میزان تنفس (۲۶/۲۴ میلی‌گرم CO_2 به ازای هر کیلوگرم خاک) را نشان داد، در حالی که کمترین مقدار در ۱۹/۷۹ میلی‌گرم CO_2 به ازای هر کیلوگرم خاک مشاهده شد. اصلاح‌کننده‌های خاک همچنین موجب افزایش معنی‌دار ضخامت پوسته زیستی نسبت به گروه شاهد (C0) شدند. در میان آن‌ها، تیمار O3 بیشترین ضخامت پوسته را در میانه و پایان آزمایش به ترتیب ۴/۶۶ و ۴/۸۱ سانتی‌متر نشان داد. پس از آن، تیمار C3

بیشترین ضخامت (۳/۱۵ و ۳/۲۴ سانتی‌متر) را ثبت کرد. همچنین کمترین مقادیر مربوط به تیمار شاهد (C0) بود که به ترتیب ۱/۳۶ و ۱/۴۰ سانتی‌متر ثبت شد. بیشترین مقدار ضخامت پوسته زیستی در میان تیمارهای رطوبتی مربوط به R1 بود که تفاوت معنی‌داری با تیمارهای R2 ، R3 و R4 داشت.

نتیجه‌گیری: استفاده از اصلاح‌کننده‌های خاک، به‌ویژه روغن روان‌کننده و ورتیسول، موجب افزایش قابل توجه فعالیت میکروبی و توسعه پوسته زیستی خاک شد. علاوه بر این، افزایش رطوبت موجب بهبود تنفس خاک و تشکیل پوسته گردید. نتایج این مطالعه نشان داد که اصلاح خاک و مدیریت رطوبت نقش مهمی در بهبود ویژگی‌های زیستی خاک دارند و باید مورد توجه قرار گیرند.

کلمات کلیدی: اصلاح‌کننده‌های خاک، انتشار CO_2، پوسته زیستی خاک، تنفس خاک، تیمارهای رطوبتی

نوع مقاله: پژوهشی

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