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The effect of riser height in a fixed sprinkler irrigation system, irrigation interval, and addition of emulsified spent engine oil conditioner on soil moisture content and salt distribution in clay soil

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Abstract
A field experiment was conducted to study the effect of sprinkle riser height in a fixed sprinkler irrigation system at three height treatments 1m (h_1), 1.25m (h_2), and 1.5m (h_3) and two irrigation intervals 5 days (I_5) and 9 days (I_9) calculated from a US pan Class- A-, using an emulsified Spent engine oil conditioner at 0.3% w/w (O_1), in addition to a control treatment (Oc), on some properties of clay soil represented by moisture content and salt distribution in the soil profile. The results showed a significant superiority of sprinkler riser height h_1 in achieving the highest values of moisture content (PW%) and the lowest values of electrical conductivity (EC) (dS m^{-1}) compared to the two heights h_2 and h_3. Irrigation interval I_5 was achieved the highest PW% values and the lowest EC values compared to irrigation interval I_9, with a significant difference. While, the addition of emulsified Oil conditioner treatment (O_1) achieved the highest PW% values and the lowest EC values compared to the control treatment.

Keywords: Sprinkler riser height, fixed sprinkler irrigation system, emulsified spent engine oil conditioner, irrigation interval, soil moisture content, electrical conductivity, clay soil

Introduction

Appropriate irrigation is considered the fundamental pillar for the sustainability and management of soil and water resources. This process is not limited to merely supplying water to the soil but also aims to preserve the physical, chemical, and fertility properties of the soil, preventing its degradation. It further seeks to enhance the soil's ability to perform its functions optimally, in addition to providing a suitable environment to support plant growth by reducing the effort required for water and nutrient uptake. The primary goal of efficient irrigation management is to achieve the highest levels of productivity and crop quality. Conventional irrigation wastes enormous quantities of water due to losses from evaporation and surface runoff, which in turn leads to soil property degradation (Qureshi, 2020) [24]. Furthermore, water scarcity and the resulting increasing soil salinity are among the most prominent challenges threatening global food security sustainability, especially in arid and semi-arid regions (FAO, 2021) [13]. Therefore, sprinkler irrigation is considered a highly efficient system for the use and conservation of irrigation water, and one of the most effective techniques for addressing water scarcity in agricultural production (Chen *et al*., 2023) [9]. Sprinkler irrigation systems also offer greater control over irrigation water compared to traditional surface irrigation methods. This control aims to achieve good and uniform distribution of irrigation water, thereby providing a balanced environment between soil moisture and nutrients. This is accomplished by preventing water loss due to over-irrigation in some field areas and under-irrigation in others, which could lead to soil degradation and crop stress from water deficit. Several factors affect the uniformity of water distribution in sprinkler irrigation systems, including the type of sprinkler, nozzle diameter, spray angle, operating pressure, sprinkler spacing and arrangement, sprinkler riser height, and tilt angle (Noory *et al*., 2025) [20]. Sprinkler riser height has emerged as a crucial factor, which depends on the crop type and height. It affects the homogeneity and uniformity of water distribution over the irrigated area and reduces water loss through evaporation and wind drift. The chance of water droplets being exposed to wind effects and evaporation before reaching the soil surface increases with higher sprinkler riser height (Mohamed *et al*., 2019) [19]. Therefore, the appropriate selection of sprinkler nozzle sizes, operating pressure, sprinkler riser height, and spacing in sprinkler irrigation, in addition to the optimal amount of irrigation water required for the crop root zone, can be made. This selection should neither cause surface runoff nor damage the crop, while providing the best possible water distribution under prevailing wind conditions (Pawlak and Kołodziejczak, 2020; Sharma, 2022) [23, 31]. Dehkordi, (2014) [10] indicated that water distribution uniformity improves with increased sprinkler riser height under moderate wind speeds; however, under high wind speeds, increasing the riser height has a negative effect on distribution uniformity.

For the purpose of sustaining and efficiently managing soil and water environmental resources under water scarcity and the degradation of soil physical, chemical, and fertility properties, the irrigation interval has emerged as a successful technique. It maintains soil moisture within optimal limits for plant growth, prevents water stress, and reduces irrigation water evaporation from the soil surface (Bian *et al*., 2024) [7]. Using the optimal irrigation interval allows for supplying the root zone with appropriate moisture without excessively saturating the soil. This improves the soil's water retention capacity and reduces losses through deep percolation, which otherwise causes nutrient leaching. To improve soil properties and limit their degradation, some innovative solutions have appeared to enhance the soil's water-holding capacity. These include the use of petroleum derivative emulsions, which can form a thin water-repellent layer around particle surfaces and aggregates, as well as coat water-conducting capillary pores. This works to slow the rate of water loss through evaporation, thereby enhancing the soil's ability to retain water, increasing plant-available water, and improving water use efficiency (Hasan *et al*., 2019) [14]. It also reduces direct evaporation from the soil surface, which lessens the phenomenon of salt ascent and accumulation on the soil surface via capillary rise, thereby helping to mitigate the severity of topsoil salinity (Shabeeb, 2016 ; Dheyab, 2020) [30, 11].

This study aims to evaluate the effect of sprinkler riser height, irrigation interval, the addition of emulsified spent engine oil, and their interactions on soil water retention capacity and salt leaching efficiency. These are important characteristics for assessing irrigation system efficiency and their impact on plant water stress.

Materials and Methods

A field experiment was conducted at the Research Station of the College of Agriculture - University of Basrah, located at latitude 30°.53" N and longitude 74°.47" E during winter season 2023-2024, on a clay soil texture, on an area of 25000 m². The soil was classified as Typic Torrifluvent Hyperthermic, Calcareous, Clayey, Mixed (Al-Atab, 2008) [3]. Composite soil samples were collected from the field for three depths (0-30) cm, then dried and passed through a 2 mm sieve for chemical analyses, while some samples were passed through an 8 mm sieve and it received on a 4 mm sieve to estimate the physical properties of the study soil as shown in Table(1). Methods described in Black *et al*., (1965) [8], Jackson, (1958) [16], Page *et al*., (1982) [22], and Richards, (1954) [25] were used to determine the physical and chemical characteristics. The experiment included four factors ، the first factor: Sprinkler riser height at three proposed heights: 1m (h_1), 1.25m (h_2), and 1.5m (h_3) at a pressure of 3.5 bar. The second factor: Irrigation interval, irrigating every 5 days (I_5) and 9 days (I_9), calculated from a US Class- A - evaporation pan. The third factor: conditioner factor with two treatments: emulsified spent engine oil treatment at a concentration of 0.3% (O_1) and a control treatment (Oc). the fourth factor: Horizontal distance from the sprinkler center, divided into three equal distances from the sprinkler center to the end of the spray diameter depending on the wetted area according to sprinkle riser height, represented by the first third near the sprinkler center (X_1), the middle third (X_2), and the last third (X_3). The experimental soil was plowed twice orthogonal using a moldboard plow, then the land was divided into three blocks with a distance of 2 m between each two blocks. Afterwards, each block was divided into experimental units according to the wetted diameter based on sprinkle riser height and distributed randomly to match the number of factorial treatment combinations of the factors included in the experiment (3 sprinkle riser heights × 2 irrigation intervals × 2 conditioner addition levels × 3 distances). Then, the factorial treatments were randomly distributed to the experimental units in each block. The spent engine oil conditioner was added after emulsification using an anionic emulsifying agent to the soil surface and to a depth of 0-30 cm. Composite soil samples were taken at the end of the experiment from all experimental units and for the three distances from the sprinkler center before the subsequent irrigation and for the addition depth of 0-30 cm, and placed in polyethylene containers for the purpose of estimating gravimetric moisture content (PW%) by the gravimetric method and electrical conductivity (EC) determined extraction 1:1 soil to water . The results were statistically analyzed using the Genstat DE10.3 statistical program.

Table 1: Some physical and chemical properties of the study soil

Soil properties		Unite	depth 0-30
pH 1:1		-	7.25
Electric Conductivity		dS m-1	14.96
Pw at field capacity		%	31.82
sand		gm kg-1 / soil	199.222
silt			275.793
clay			524.985
texture		Clay	
particles density		μg.gm m^{-1}	2.61
Bulk density			1.31
porosity		%	49.67
Soil resistance to penetration		KN m^{-2}	2435.50
mean weight Diameter (MWD)		mm	0.205
Saturated hydraulic conductivity		M d^{-1}	0.187
O.M		gm kg^{-1}	5.156
CaCO3		gm kg^{-1}	3.19.900
Soluble ions	Ca^{+2}	mmol l^{-1}	28.601
	Mg^{+2}		20.848
	Na^{+1}		32.694
	K^{+1}		18.329
	$HCO3^{-2}$		19.717
	$CO3^{-2}$		0.00
	Cl^{-1}		83.821
	$SO4^{-2}$		26.207

Results and Discussion

1. Soil moisture content (%)

The results in table (6) showed a highly significant effect of the sprinkle riser height factor on Pw% values. Significant differences were found between all treatments (Figure1), moisture content increase with decreasing sprinkle riser height, the highest values are recorded at sprinkle riser height 1m (h_1), followed by 1.25m (h_2), then 1.5m (h_3), with values of 25.44%, 24.52%, and 23.11% respectively, this is attributed to the lower sprinkler riser height is the Uniform distribution of irrigation water at nearly constant depths over the entire irrigated field area, achieving a better wetted area compared to treatments with higher sprinklers, in addition to reducing irrigation water loss through evaporation due to its shorter time spent in the air during its release from the sprinkler nozzle until it falls onto the soil surface. These results agree with Kuti *et al*., (2019) [17], where they found that the depth of irrigation water added to the wetted area within the effective wetted radius was greater at sprinkler riser heights of 2 and 3 m compared to a height of 4 m. This is consistent with Mohamed *et al*., (2019) [19] and Sulaiman and Khalaf, (2022) [32], who found that the best values for soil moisture content and uniformity of water distribution were achieved at low sprinkle riser heights under conditions of low wind speed, high relative humidity, and low temperatures

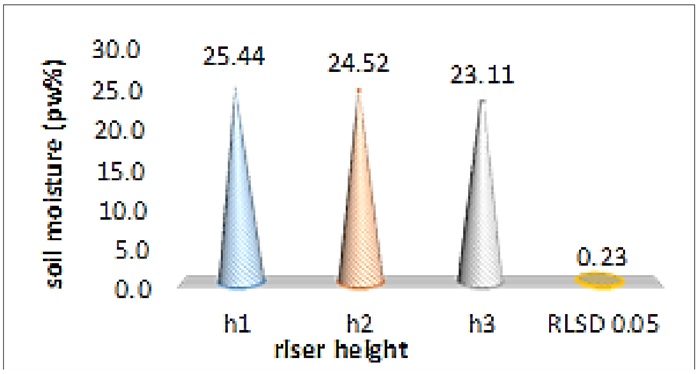


Fig 1: Effect of sprinkle riser height on soil moisture content (Pw%)

Table (6) showed a highly significant effect of the irrigation interval factor on soil Pw% values., there was significant difference between the two irrigation interval treatments (Figure 2), where the irrigation interval every 5 days (I_5) treatment excelled in achieving the highest moisture content, which reached 25.28%, compared to the irrigation interval every 9 days (I_9) which reached 23.43%, this is attributed to the closer irrigation periods may increase Pw% values in the soil and maintain a high Pw%, compared to the I_9 irrigation interval where moisture loss through evaporation increases due to the longer irrigation interval and the occurrence of cracks in the soil surface layer, this leads to increased water movement irregular through the formed cracks in the surface layer in three directions, especially downward movement due to gravity, These results consistent with reached by Abdul-Rahman and Al-Sheikhly (2009) [2] that Pw% values for treatments irrigated every three days is higher than the treatments irrigated every five days, due to greater exposure of these treatments to evaporation and moisture depletion processes, as the change in Pw% values between two consecutive irrigations was smaller in the 3-day irrigation interval compared to the 5-day interval.

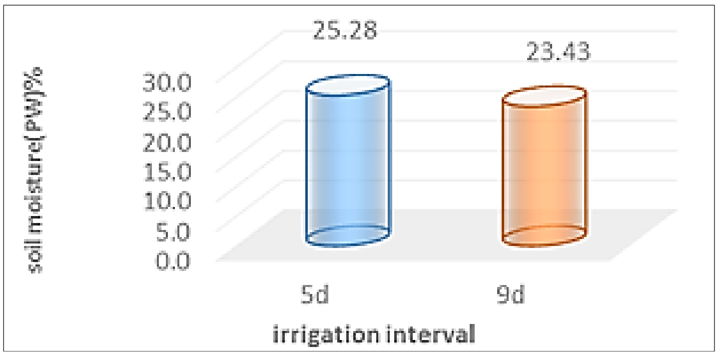


Fig 2: Effect of irrigation interval on soil moisture content values (Pw%)

The results in table (6) showed a highly significant effect of adding emulsified spent engine oil on soil moisture content values (Pw%) for the addition depth of 0-30 cm. The addition of the conditioner (O_1) led to an increase in Pw% values significantly compared to the control treatment (O_c) (Figure 3), with averages (25.49%, 23.22%) for O_1 and O_C treatments respectively, with an increase percentage of 9.80% compared to the control treatment. The effect of conditioner addition in increasing Pw% values is attributed to the ease of Infiltration of the emulsified petroleum conditioner into the soil profile, led to partially or completely coat soil particles and aggregates, making their surfaces hydrophobic, also plays a role in coating the internal surfaces of pores, limiting the capillary rise of water to the soil surface, thereby reducing the loss process through surface evaporation, which increases the soil's water-holding capacity (Shabeeb *et al*., 2019 and Dheyab, 2020) [29, 11]. Husham and Abd Al Gabar, (2013) [15] also indicated that emulsified engine oil leads to an increase in the soil's water-holding capacity through the mechanism of redistributing the pore volume between and within soil aggregates, in addition to increasing total porosity, which positively reflects on increasing water retention in the soil.

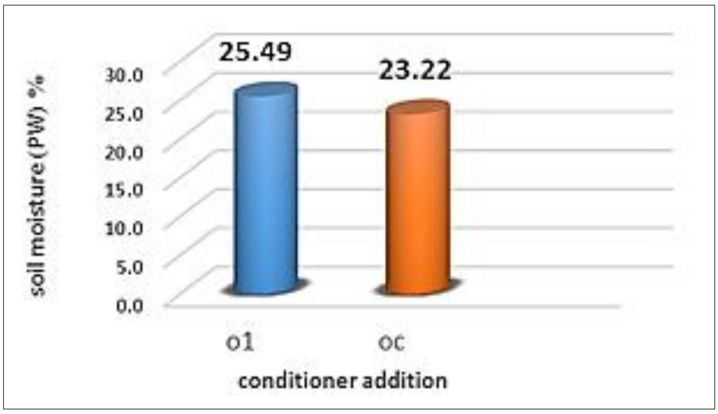


Fig 3: Effect of emulsified spent engine oil conditioner on soil moisture content (Pw%)

The results table (6) showed a highly significant effect of the horizontal distance from the sprinkler center factor on soil moisture content values (Pw%). significant differences were found in Pw% values (Figure 4), where an increase in Pw% values is observed when approaching the sprinkler center and decreasing with distance from it. The highest Pw% values appeared at the first distance close to the sprinkler center, (X_1), with an average of 25.67%, followed by the middle distance X_2 (24.24%), and the lowest at the far distance from the sprinkler center X_3 (23.16%). this is attributed to the water droplets exiting the sprinkler nozzle different in exit angle and speed, therefore, small and medium droplets tend to fall in places close to the sprinkler center due to air resistance overcoming their kinetic energy, while larger and heavier droplets travel farther from the sprinkler center, covering a longer distance in the air to the end of the wetted circle or the edges, due to it has greater momentum (Suryanarayana *et al*., 2013) [33], this makes them susceptible to drift and evaporation processes due to wind speed and high temperatures (Martinez-cob *et al*., 2008; Sanchez *et al*., 2011; Arunadevi *et al*., 2021) [18, 26, 5], in addition to the low uniformity coefficient at those distances. This agrees with what AbdulKarem and Dheyab, (2022) [1] found, a decrease in%Pw values with increasing distance from the sprinkler center, attributing it to the dispersion of irrigation water droplets exiting the sprinkler nozzle due to wind speed and high temperatures. Furthermore, the high kinetic energy (momentum) of large droplets results in high impact energy on the soil surface, negatively affecting soil structure and the formation of a soil crust that reduces water infiltration and increases the retention of free water on the soil surface for a longer period, increasing loss through direct surface evaporation.

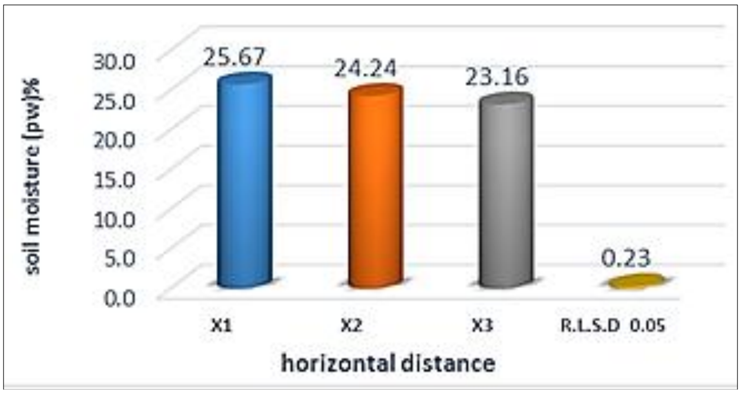


Fig 4: Effect of horizontal distance from sprinkler center on soil moisture content values (Pw%)

The results in table (6) showed a significant effect of the interaction between the irrigation interval factor and the addition of emulsified spent engine oil conditioner factor. The results in table 2 show the significant increase in Pw% between I5 and I9 treatments varies depending on the addition of conditioner, the highest variance was observed when the conditioner was added (O1) compared to the control treatment (Oc), so the highest value of Pw% recorded at I5O1(26.54%) and the lowest values recorded at I9Oc factorial treatment (22.41%), this is attributed to the treatments irrigated every 5 days with conditioner addition retain higher moisture content until the subsequent irrigation compared to treatments irrigated every 9 days without conditioner addition. the addition of emulsified spent engine oil as a conditioner had sufficient time for the process of Surrounding soil particles and aggregates, improving soil structure, and closing ends of the pore, which reduces evaporation from the soil surface by reducing the capillary rise of soil water (Dheyab, 2020) [11].these results agree with what Al-mehmdy and Al-Hashemi, (2025) [4] found regarding the decrease in%Pw for soil under treatments irrigated with longer time intervals compared to those irrigated with shorter intervals.

The results in table (6) showed a significant effect of the interaction between the factors of adding emulsified spent engine oil conditioner and the horizontal distance from the sprinkler center on Pw% values ،the table (2) shows the significant superiority of the treatment of the horizontal distance close to the center of the sprinkler (X_1) and its interaction with the addition of spent engine oil conditioner, with a significant difference compared to the other studied treatments, and this varies according to the variation in conditioner addition. Generally, the highest%Pw values were 26.96% at the horizontal distance treatment (X_1) with conditioner addition (O_1), represented by treatment X_1O_1, while the lowest values were at the horizontal distance treatment far from the sprinkler center X_3 and its interactions with control treatment (Oc), represented by treatment X_3O_c, with a value of 22.01%, this is attributed to the impact of closer

Table 2: Effect of experimental factors and their interactions on soil moisture content values (Pw%)

Irrigation interval * adding Conditioner				adding Conditioner *distance				
I		O_1	O_C	O		X_1	X_2	X_3
I_5		26.54	24.45	O_1		26.96	25.21	24.31
I_9		24.03	22.41	O_C		24.38	23.26	22.01
RLSD 0.05		0.26		RLSD 0.05		0.33		
Irrigation interval * riser height * adding Conditioner				adding Conditioner * riser height *distance				
I	h	O_1	O_C	O	h	X_1	X_2	X_3
I_5	h_1	27.71	24.79	O_1	h_1	28.50	26.32	25.18
	h_2	26.90	24.12		h_2	27.09	25.41	24.55
	h_3	25.01	23.17		h_3	25.30	23.91	23.21
I_9	h_1	25.62	23.63	O_C	h_1	25.15	24.32	23.16
	h_2	24.46	22.60		h_2	24.26	23.37	22.45
	h_3	23.26	20.99		h_3	23.74	22.09	20.42
RLSD 0.05		0.47		RLSD 0.05		0.57		

distance from the sprinkler center with conditioner addition is the increased volume of water added in this treatment and the improvement of soil physical properties, especially increased soil porosity and change in the Size distribution of soil pores, which in turn increases the soil water-holding capacity and moisture retention (Hasan *et al*.,2019) [14]. and this enhanced by the role of the conditioner in reducing evaporation-transpiration potential and water loss at that distance or irrigated area, which is the last third from the sprinkler center.

The results in table (6) showed a highly significant effect of the Triple interaction between sprinkle riser height, irrigation interval, and addition of spent engine oil conditioner on Pw% values, results in the table 2 shows that%Pw values for the Triple interactions vary significantly among themselves according to the levels and interactions of these studied factors. Generally, they increase with a decrease in each of sprinkle riser height and irrigation interval with addition conditioner (O1). The highest values were at the distance close to the sprinkler center, irrigation interval of 5 days, and conditioner addition in treatment ($h_1I_5O_1$), with a average of 27.71%, while the lowest average was at the treatment with high sprinkle riser heights (h_3), irrigation interval of 9 days, and no conditioner addition ($h_3I_9O_c$), which reached 20.99%.

The results in table (6) showed a highly significant effect of the triple interaction between the factors of sprinkle riser height, addition of emulsified spent engine oil conditioner, and distance from the sprinkler center on Pw% values. the results in table 2 show the highest values were recorded at sprinkle riser height (h_1), conditioner addition (O_1), and horizontal distance from the sprinkler center (X_1), represented by the factorial treatment $h_1O_1X_1$, with average of 28.49%, followed by the factorial treatment $h_2O_1X_2$ with a average 27.09%. The increase in%Pw values is due to the cumulative effect of the interaction of the factors: sprinkle riser height, spent engine oil conditioner, and horizontal distance from the sprinkler center, with a significant difference between treatments. While, the lowest%Pw values were at sprinkle riser height (h_3), control treatment (O_c), and the far horizontal distance from the sprinkler center (X_3) in treatment (h_3OcX_3), with average of 20.42%.

2. Salt Distribution in Soil

The results in table (6) show a high significant effect of the sprinkle riser height factor on soil electrical conductivity values (EC). There are significant differences found between all treatments (Figure 5). the EC values decrease with decreasing sprinkle riser height, so the lowest values at sprinkle riser height 1m (h_1), followed by 1.25m (h_2), then 1.5m (h_3), with average of 6.86 dS m^{-1}, 7.91 dS m^{-1}, and 9.15 dS m^{-1} respectively. This is attributed to the increase sprinkler riser height led to decrease the moisture uniformity coefficient within the wetted circle, reducing Moisture distribution efficiency, in addition to its effect on increasing the Dispersion Index and its relationship with the kinetic energy of sprinkler water droplets and their negative impact at high heights. Furthermore, increasing sprinkler riser height contributes to increased direct loss of irrigation water droplets through evaporation due to the longer time period droplets remain in the air from exiting the sprinkler nozzle until arrive to the soil surface, which led to a decrease in soil moisture content (Figure 1 in the research) and reduced water movement within the soil Profile, negatively reflecting on salt leaching efficiency. These results agree with Kuti *et al.*, (2019) [17] and Fordjour *et al.*, (2020) [12], who found an increase in electrical conductivity values with increased sprinkler riser height in a sprinkler irrigation system. Sehsah *et al.*, (2014) [28] confirmed that sprinkle riser height is the most influential factor on EC values, which decrease with a decrease in sprinkle riser height from 120 cm to 100 cm then 60 cm

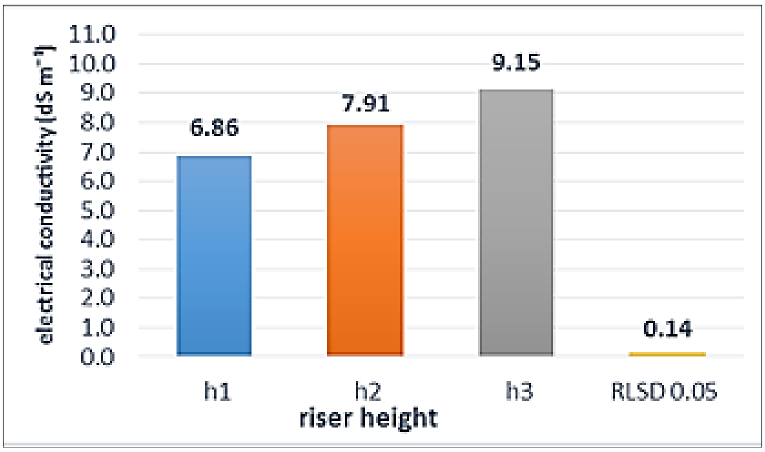
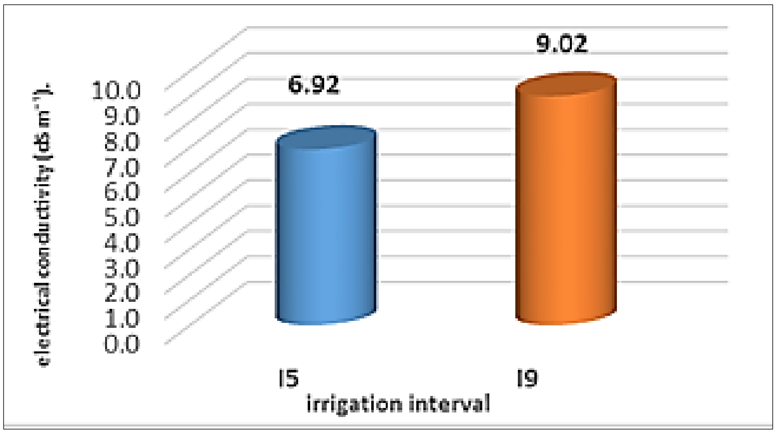


Fig 5: Effect of sprinkler riser height on electrical conductivity values (dS m^{-1})

The results in table (6) showed a highly significant effect of the irrigation interval factor on soil electrical conductivity values (EC). The result in figure 6 showed there was a significant difference between the two irrigation interval treatments, the irrigation interval every 5 days treatment (I_5) excelled in achieving the lowest EC values 6.92 dS m^{-1}, compared to the irrigation interval every 9 days (I_9) which reached 9.02 dS m^{-1}, with a decrease percentage of 23.28%. This is attributed to the shorter irrigation intervals to adding irrigation water quantities at closer intervals, with a 5-day irrigation interval, leads to maintaining optimum moisture content, contributing to filling most pores with irrigation water. This led to decrease in salt concentration and their displacement from the surface layer to sub surface layers away from the root zone, limiting capillary water movement towards the soil surface which causes salt accumulation and the dominance of upward movement in soil columns. These results agree with AbdulKarem and Dheyab (2022) [1], who found a decrease in EC values with a decrease in irrigation interval due to adding irrigation water at closer intervals, helping the soil remain moist most of the time, and that most soil pores are filled with water, increasing the process of dissolving and leaching salts and their vertical movement within the soil Profile.



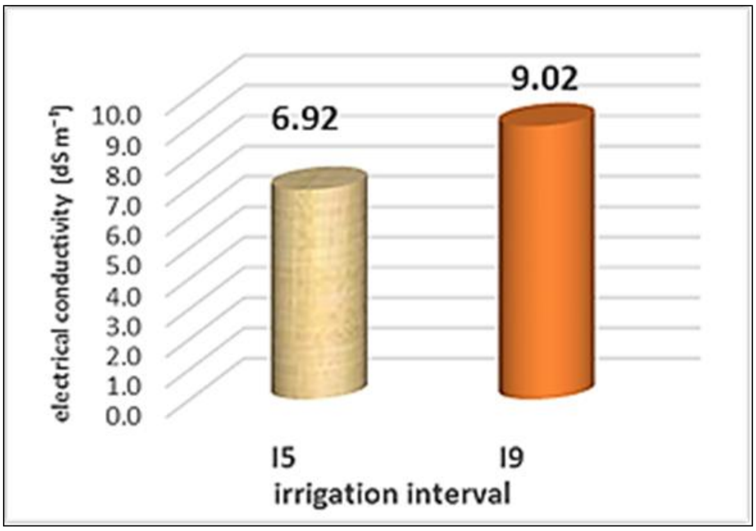


Fig 6: Effect of irrigation interval on electrical conductivity values (dS m^{-1})

The results in table (6) showed a highly significant effect of adding emulsified spent engine oil on (EC) values for the soil at the addition depth of 0-30 cm, the addition of the conditioner (O_1) led to a decrease in EC values significantly compared to the control treatment (Oc) (Figure7), where the average EC values were (6.80 dS m^{-1}) and (9.13 dS m^{-1}) respectively, With decrease percentage of 34.26% compared to the control treatment (Oc), this is attributed to role of emulsified spent engine oil in coating the soil particles and aggregates that's lead to enhancing physical properties, represented by reduced upward water movement, increasing Soil moisture retention (Moisture conservation figure), which increases water movement and salt leaching efficiency, enhanced through improved soil structure, thus decreasing EC values. These results agree with Shabeeb, (2016) [30] and Dheyab (2020) [11], who found a decrease in EC values when adding the petroleum emulsion, attributing it to coating the internal surfaces of pores, limiting capillary rise of water to the soil surface, thereby reducing water loss through surface evaporation.

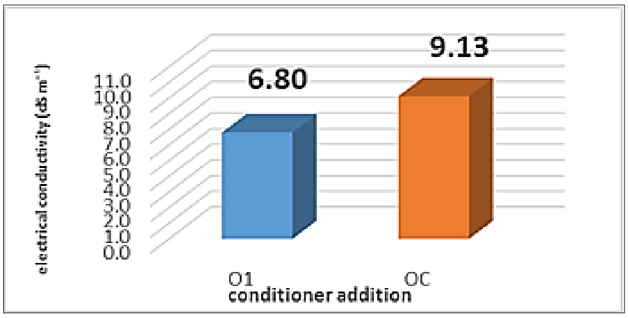


Fig 7: Effect of conditioner addition on electrical conductivity values (dS m^{-1})

The results in table (6) showed a high significant effect of the horizontal distance from the sprinkler center factor on soil electrical conductivity values (EC). A significant difference are found in EC values between all distances from the sprinkler center (Figure 8), generally, observed that EC values decrease when approaching the sprinkler center and increase with distance from it. The lowest EC values were at the first third (X_1) 6.33 dS m^{-1}, followed by the second third (X_2) 8.03 dS m^{-1}, then the far distance from the sprinkler center represented by the last third (X_3) 9.55 dS m^{-1}. This is due to the variation in irrigation water distribution over the field area with different horizontal distances from the sprinkler center, which decreases with increasing distance, in addition to the increase in kinetic energy of irrigation water droplets with increased distance from the sprinkler center and its effect on reducing moisture content and water movement through the soil Profile, reflecting on the efficiency of salt movement and leaching from the soil Profile. These results agree with AbdulKarem and Dheyab (2022) [1], who found an increase in electrical conductivity values with increasing distance from the sprinkler center in a fixed sprinkler irrigation system.

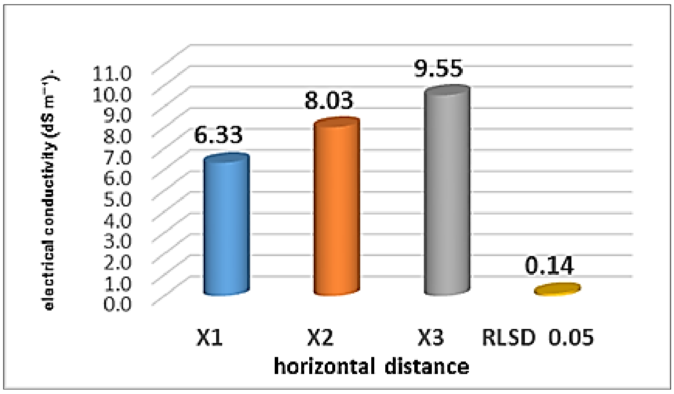


Fig 8: Effect of horizontal distance from sprinkler center on electrical conductivity values (dS m^{-1})

The results in table (6) showed a high significant effect of the interaction between sprinkle riser height and irrigation interval on electrical conductivity values (EC), table 3 shows that the differences in EC values between sprinkle riser height treatments varies depending to the difference in irrigation interval.the smallest variations between h_1, h_2, and h_3 appeared at irrigation interval I_5 compared to I_9. This variation is due to the role of irrigation interval I_5 in increasing moisture content between irrigations and its effect on improving soil structure, which enhances salt leaching efficiency despite the variation in sprinkle riser height. In the same context, irrigation interval I_9 at the low sprinkle riser height h_1 and at the factorial treatment h_1I_9 decrease the EC values to 8.18 dS m^{-1}, outperforming heights h_2 and h_3 at the same mentioned irrigation interval, which gave higher values of (8.86) dS m^{-1} and (10.01) dS m^{-1} respectively.

The results in table (6) showed a significant effect of the interaction between sprinkle riser height and addition of emulsified spent engine oil on (EC) values. Table 3 shows that the variations in EC values between treatments O_1 and Oc vary according to the variation in sprinkle riser height, the highest variations appeared at height h_1 and decrease with increasing riser height to h_2 then h_3. The reason for this variation is that the addition of the petroleum emulsion enhanced the soil's ability to retain water for the longest period depending on the level of water added to the soil, which was affected by sprinkle riser height and its role in uniform water distribution and other soil properties related to soil structure and water and salt movement. the highest EC values were recorded in treatment Oc at height h_3 in treatment $O_C h_3$, with average 10.21 dS m^{-1}, while the lowest EC values were recorded at the addition level O_1 and height h_1 in treatment $O_1 h_1$, with average 5.67 dS m^{-1}, this is due to the role of the emulsified spent engine oil conditioner in reducing soil salinity for the aforementioned reasons related to its effect on improving soil physical properties. This agrees with Ogbeide and Eriyamremu,(2023) [21] and Dheyab, (2020) [11], who found a decrease in EC values when adding the emulsified petroleum conditioner compared to the control treatment and non-emulsified petroleum additions.

The results in table (6) showed a high significant effect of the interaction between irrigation interval and distance from the sprinkler center on (EC) values. Table 3 shows that the variations in EC values between the mentioned distances from the sprinkler center X_1, X_2, and X_3 vary according to the difference in irrigation interval. The highest differences between the mentioned distances appeared at irrigation interval I_9 compared to irrigation interval I_5, this is due to a shorter irrigation interval enhances increased salt leaching efficiency despite the difference in distance from the sprinkler center. The highest values appeared at treatment I_9X_3, reaching 10.65 dS m^{-1}, and the lowest at the factorial treatment I_5X_1, recorded 5.54 dS m^{-1}.

The results in table (6) showed a high significant effect of the interaction between the addition of emulsified spent engine oil and the horizontal distance from the sprinkler center on (EC) values. Table 3 shows that the variations between distances from the sprinkler center X_1, X_2, and X_3 vary according to the treatment of adding the emulsified petroleum conditioner. The highest differences between the mentioned distances appeared at the emulsified oil conditioner addition treatment O_1 and the lowest at the control treatment Oc, this is due to salt leaching efficiency increases with increased soil moisture content, which is enhanced by adding the emulsified conditioner. The results show that the highest values appeared at the factorial treatment OcX_3 with average of 10.51 dS m^{-1} and the lowest at treatment O_1X_1 with average 5.36 dS m^{-1}.

The results in table (6) showed a high significant effect of the interaction between sprinkle riser height and horizontal distance from the sprinkler center on (EC) values. The results in table 3 show the increase in EC values with increasing distance from the sprinkler center from X_1 to X_2 then X_3 varies according to sprinkle riser height, the smallest differences appeared at sprinkle riser height h_1 and increase with increasing sprinkle riser height h_2 then h_3, this is due to the uniformity coefficient of moisture distribution is higher at low sprinkle riser height and decreases with increasing sprinkle riser height, reflecting on differences in moisture content and the effect on salt leaching efficiency through the soil Profile, so EC values increased with increasing sprinkle riser height and horizontal distance from the sprinkler center, with the highest values recorded at height h_3 and distance X_3, which recorded 11.00 dS m^{-1}, while height h_1 achieved the lowest values at distance X_1 with a value of 5.61 dS m^{-1}.

Table 3: Effect of the interactions between experimental factors on electrical conductivity (EC) values (dS m^{-1})

Riser height * Irrigation interval		
h	I	
	I_5	I_9
h_1	5.54	8.18
h_2	6.95	8.86
h_3	8.28	10.01
RLSD 0.05	0.19	

Adding Conditioner *riser height			
O	h		
	h_1	h_2	h_3
O_1	5.67	6.66	8.08
O_C	8.04	9.15	10.21
RLSD 0.05	0.19		

Distance *adding Conditioner		
X	O	
	O_1	O_C
X_1	5.36	7.30
X_2	6.46	9.59
X_3	8.59	10.51
RLSD 0.05	0.19	

Irrigation interval * distance			
I	X		
	X_1	X_2	X_3
I_5	5.54	6.77	8.45
I_9	7.12	9.28	10.65
RLSD 0.05	0.19		

riser height * distance				
h	X			RLSD 0.05
	X_1	X_2	X_3	
h_1	5.61	6.75	8.21	0.23
h_2	6.23	8.04	9.45	
h_3	7.15	9.29	11.00	

The results in table (6) showed a significant effect of the triple interaction between sprinkler riser height, irrigation interval, and addition of emulsified spent engine oil conditioner on EC values. The results in the table 4 show that irrigation interval I_5 led to convergence of EC values between heights h_1 and h_2, while the difference in EC values increases at height h_3, the height h_1 outperforming in recording the lowest EC values compared to heights h_2 and h_3 for both the addition and control levels O_1 and Oc in achieving the lowest EC values of 4.41 dS m^{-1} and 6.65 dS m^{-1} respectively. Also, increasing the irrigation interval from I_5 to I_9 led to an increase in EC values at height h_3 compared to heights h_1 and h_2, with the highest values recorded at factorial treatments under irrigation interval I_9 and at the addition level Oc and at height h_3, represented h_3I_9Oc factorial treatment, while the lowest values were at irrigation interval I_5, addition level O_1, and at height h_1 represented $h_1I_5O_1$ factorial treatment. This is attributed to the resultant effect of the factors and their interactions and their effect on salt movement and leaching within the soil and the decrease in EC values.

The results in the table (6) showed a high significant effect of the triple interaction between irrigation interval, conditioner addition, and horizontal distance from the sprinkler center on EC values. The table 4 shows an increase in EC values with increasing horizontal distance from the sprinkler center according to irrigation interval and conditioner addition. Factorial treatments that did not been add the conditioner showed an increase in EC values at distance X_3, followed by distance X_2, and a significant decrease in EC values at distance X_1 compared to the mentioned two distances. This variation increases at the non-addition treatment Oc and with an increase in irrigation interval from I_5 to I_9. Meanwhile, factorial treatments which the conditioner has been added O_1 showed a decrease in EC values at distances X_2 and X_1, with a significant difference compared to distance X_3, which gave the highest values compared to the two distances. generally, treatment $I_5O_1X_1$ recorded the lowest EC values, which reached 4.88 dS m⁻¹, while the highest EC values were at treatment I_9OcX_3, which gave values of 11.20 dS m⁻¹, this is attributed to the resultant effect of the factors represented by closer irrigation periods at irrigation interval I_5 compared to I_9 in increasing moisture content, which in turn increased water movement in different directions, increasing salt leaching efficiency. These results agree with Bahmaei *et al.*, (2020 [6].

The results in table (6) showed a high significant effect of the triple interaction between sprinkle riser height, irrigation interval, and horizontal distance from the sprinkler center on EC values. Table 4 shows that EC values vary with different horizontal distances from the sprinkler center according to sprinkle riser height and irrigation interval. Factorial treatments close to the sprinkler center showed a decrease in EC values at distance X_1, followed by distance X_2, while a significant increase in EC values occurred at distance X_3 compared to the mentioned distances, this variation increases with increasing sprinkle riser height from h_1 to h_3. The highest values were recorded at treatment $h_3I_9X_3$, which reached 11.87 dS m⁻¹, while factorial treatments close to the sprinkler center showed a evident decrease in EC values at heights h_2 and h_1, with a significant difference compared to height h_3, this effect increases with a decrease in irrigation interval from I_9 to I_5, where the lowest values were recorded at treatment $h_1I_5X_1$, which reached 4.61 dS m⁻¹. This effect is attributed to the resultant effect of the influencing factors and their interaction on increased soil salinity with increased irrigation interval due to the longer period between irrigations, increasing the amount of evaporated water leaving high salt concentrations, while increased soil salinity with increased distance from the sprinkler center is due to the non-uniform distribution of water emitted from the sprinkler within the wetted circle and the decrease in the uniformity coefficient as we move away from the sprinkler center due to the effect of temperature and wind speed on water droplets exiting the sprinkler (Santra, 2021) [27].

The results in table (6) showed a high significant effect of the triple interaction between the experimental factors represented by sprinkler riser height, addition of emulsified spent engine oil conditioner, and horizontal distance from the sprinkler center on EC values, results in table 4 show that the EC values decrease with a decrease in both of sprinkler riser height, horizontal distance from the sprinkler center, and the addition of emulsified spent engine oil. The lowest values were recorded at sprinkle riser height (h_1), conditioner addition (O_1), and horizontal distance from the sprinkler center (X_1), represented by the factorial treatment $h_1O_1X_1$, with average 4.79 dS m⁻¹, Meanwhile, the highest EC values were at sprinkler riser height h_3, control treatment Oc, and the horizontal distance far from the sprinkler center (X_3) in treatment (h_3OcX_3), with average 11.38 dS m⁻¹. The increase in EC values is attributed to the cumulative effect of the interaction of the factors: sprinkle riser height, emulsified spent engine oil conditioner, and horizontal distance from the sprinkler center for the aforementioned reasons.

Table 4: Effect of the interactions between experimental factors on electrical conductivity (EC) values (dS m⁻¹)

Irrigation interval * adding Conditioner * riser height								
I	O_1			O_C			RLSD 0.05	
	h_1	h_2	h_3	h_1	h_2	h_3		
I_5	4.41	5.56	7.20	6.66	8.33	9.36	0.27	
I_9	6.92	7.76	8.97	9.43	9.97	11.05		
Adding Conditioner * distance * Irrigation interval				**Irrigation interval * riser height* distance**				
O	X	I		I	h	X		
		I_5	I_9			X_1	X_2	X_3
O1	X_1	4.89	5.84	I5	h_1	4.62	5.04	6.95
	X_2	5.20	7.72		h_2	5.56	6.99	8.29
	X_3	7.08	10.09		h_3	6.44	8.28	10.12
OC	X_1	6.19	8.40	I9	h_1	6.60	8.46	9.47
	X_2	8.34	10.84		h_2	6.89	9.09	10.61
	X_3	9.82	11.20		h_3	7.87	10.30	11.87
RLSD 0.05		0.27		RLSD 0.05		0.33		

The results in table (6) showed a high significant effect of the four-way interaction between sprinkle riser height, irrigation interval, addition of emulsified spent engine oil conditioner, and horizontal distance on EC values. It is observed that EC values vary with increasing horizontal distance from the sprinkler center according to sprinkle riser height, irrigation interval, and addition level (Table 5). Factorial treatments that used the emulsified spent engine oil conditioner showed a decrease in EC values at distance X_1, followed by distance X_2, then distance X_3. This variation increases at treatment Oc. Meanwhile, factorial treatments that received the conditioner addition showed a decrease in EC values at heights h_1 and h_2, with a significant difference compared to height h_3. This effect increases with a decrease in irrigation interval from I_9 to I_5. The lowest EC values were recorded at the factorial treatment $h_1I_5O_1X_1$, reaching 4.12 dS m⁻¹, while treatment $h_3I_9OcX_3$ gave the highest EC values, reaching 12.17 dS m⁻¹. These results clarify the aforementioned reasons related to the specific effect of each of sprinkler riser height, irrigation interval, addition of emulsified spent engine oil, and horizontal distance from the sprinkler center.

Table 5: Effect of four-way interactions between experimental factors on electrical conductivity (EC) values (dS m⁻¹)

Irrigation interval * adding Conditioner * riser height * distance					
I	**O**	**h**	**X**		
			X_1	**X_2**	**X_3**
I5	O1	h_1	4.13	4.25	4.85
		h_2	4.99	4.93	6.75
		h_3	5.54	6.40	9.65
	OC	h_1	5.10	5.83	9.05
		h_2	6.13	9.04	9.83
		h_3	7.33	10.16	10.60
I9	O1	h1	5.46	6.73	8.57
		h2	5.72	7.42	10.14
		h_3	6.33	9.02	11.56
	OC	h_1	7.74	10.19	10.36
		h_2	8.07	10.76	11.08
		h_3	9.41	11.58	12.18
RLSD 0.05			0.47		

Table 6: Variance analysis (F- test) of soil moisture content (Pw) and Electric conductivity (dS m⁻¹)

S.O.V	**d. f**	**Soil moisture (Pw%)**	**Electric conductivity (Ec)**
h	2	201.86**	568.87**
I	1	379.7**	1427.77**
O	1	571.79**	1763.16**
X	2	233.46**	1124.12**
I.h	2	1.43^{ns}	24.85**
O.h	2	1.52^{ns}	3.83*
X.h	4	1.05^{ns}	16.11**
I.O	1	6.20*	1.35^{ns}
I.X	2	1.56^{ns}	24.19**
O.X	2	3.65*	52.25**
I.X.h	4	0.71^{ns}	3.80**
I.O.h	2	5.59**	4.68*
O.X.h	4	5.59**	30.15**
I.O.X	2	1.06^{ns}	56.81**
I.O.X.h	4	0.77^{ns}	15.88**

I=Irrigation interval h=riser height O= conditioner adding X= Distance

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