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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 growth and yield of Barley Plant (Hordeum vulgare L.)

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I. Abstract:

A field experiment was conducted to study the effect of sprinkle riser height in a fixed sprinkler irrigation system at three riser 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 barley plant growth and yield represented by plant height , dry matter , grain yield and water use efficiency for grain yield (WUE(g)) . The results showed a significant superiority of sprinkler riser height h_1 in achieving the highest values plant height(cm) , dry matter (ton h^{-1}) , grain yield (ton h^{-1}) and WUE(g) (kg $h^{-1}m^{-3}$), which gave values that reached 102.0cm,7.116 ton h-1 ,7.141 ton h-1 and 1.776 kg$h^{-1}m^{-3}$ respectively compared to the two heights h_2 and h_3. The irrigation interval I_5 was achieved the highest values for the aforementioned yield components compared to the irrigation interval I_9, which reached respectively (97.0cm,7.721 ton h-1 ,7.430 ton h-1 and 1.848 kg $h^{-1}m^{-3}$, the addition of emulsified conditioner (O_1) achieved the highest values compared to the non-addition treatment (Oc) which reached 98.3cm,7.633 ton h-1 , 7.281 ton h-1 , and 1.811 kg $h^{-1}m^{-3}$ respectively. The highest values of plant height, dry matter, grain yield and WUE(g) was reached at close distance from the sprinkler and decrease with distance from sprinkler.

Keywords *: Sprinkler riser height, emulsified spent engine oil conditioner, irrigation interval, plant height, water use efficiency.*

II. Introduction

Pressure on environmental resources, particularly available freshwater resources and productive agricultural soils, is increasing due to the growing global demand to ensure food security, especially for cereal crops, in line with the steady rise in world population. This has placed these environmental resources, represented by water available for human and agricultural use, in a critical position leading to their depletion and consequent scarcity. These crises are exacerbated by severe climatic changes, manifested in decreased rainfall rates, rising temperatures, and reduced water releases, especially in arid and semi-arid regions, including Middle Eastern countries such as Iraq. This results in escalating challenges due to water scarcity, changing climate patterns, and the consequent degradation of soil physical, chemical, and fertility properties (FAO, 2023).

To overcome these challenges in order to achieve optimal agricultural production, improve water use efficiency, and rationalize water requirements in line with the optimal plant needs, modern irrigation techniques, particularly fixed-sprinkler irrigation, have gained great importance. These techniques provide higher irrigation efficiency compared to traditional surface irrigation and better uniformity of water distribution within the irrigated area, which can maximize crop productivity under water shortage conditions (Noory et al., 2025). However, water loss in sprinkler irrigation due to evaporation and drift outside the sprinkler circle, resulting from high wind speeds, low relative humidity, and high temperatures, is considered a governing constraint of sprinkler irrigation systems. To avoid these obstacles and achieve optimal performance of the sprinkler irrigation system, and to obtain the optimal soil moisture content while ensuring the preservation of irrigation water resources and soil properties from degradation, the appropriate selection of a sprinkler head that suits the type of cultivated crop is one of the influential hydraulic factors and criteria affecting water distribution in the field and the uniformity of its distribution under uncontrolled conditions, this is due to the evaporation and dispersion of sprinkler water, which can only be

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mitigated by adjusting the sprinkler head height in the sprinkler irrigation system (Maroufpoor et al., 2019; Mohamed et al., 2019).

To ensure the sustainability and continuity of crop cultivation and to improve water use efficiency, the irrigation interval which are the time period between successive irrigations has been used as one of the successful solutions and constitutes a critical element in irrigation management (Bian et al., 2024). Determining the appropriate irrigation interval can improve soil porosity, increase aeration rates, and enhance soil microorganism activity (Li et al., 2021). It also contributes to reducing salinity phenomena, improves nutrient use efficiency, reduces water stress on plants, and increases crop yield (Wang et al., 2023). To improve the performance of soils suffering from constraints due to drought conditions, water scarcity, and the general degradation of their properties, the use of non-traditional soil amendments that play roles in improving various soil properties and stimulating plant growth and yield is required. Among these is the use of spent engine oil emulsion as an amendment. The technology of emulsifying oil amendments by adding emulsifying agents to form an oil/water mixture aims to improve the efficiency and effectiveness of adding these amendments to the soil. This results in oil droplets smaller than 2 micrometers, which improves their penetration and infiltration into soil pores and their spread into the depths, thereby increasing soil aggregate stability, increasing the weighted mean diameter, and reducing bulk density (Dheyab, 2025). Furthermore, coating soil aggregates and pores with hydrophobic emulsified oil materials increased moisture conservation by limiting capillary water movement and reducing soil salinity stress, thereby increasing water use efficiency and yield components (Hasan et al., 2019).

Barley (Hordeum vulgare L.) is considered a strategic crop of great economic importance, suitable for these resource-limited environments due to its ability to adapt to harsh environmental conditions and its high nutritional value. It is the fourth largest cereal crop in the world after wheat, corn, and rice. Barley is also characterized by its relative tolerance to drought and salinity, making it an ideal crop for cultivation in these regions (Munns and Gilliham, 2015). This study aims to demonstrate the effect of sprinkler riser height on barley growth and productivity indicators, and its interaction with irrigation interval and the addition of emulsified spent engine oil on barley growth indicators, yield, and water use efficiency.

III. 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). Composite soil samples were collected from the field for 30-60 cm depths, 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), Jackson, (1958), Page et al., (1982), and Richards, (1954) were used to determine the physical and chemical properties. 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% w/w (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, 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. at the end of experiment and before harvest, the height of plants, the dry matter of plant the total grain yield was determined. The water use efficiency (WUE) was conducted on 21/4/2024. The data was analyzed using the Genstat DE12.1 statistical program.

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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

IV. Results and Discussion.

1- Plant Height

The results in table (5) showed a highly significant effect of the sprinkler riser height factor on plant height values (cm) at the end of the growing season. significant differences were found between all treatments (Figure1). the plant height increased with a decrease in the sprinkler riser height. the highest values were at a riser height of 1m (h_1), followed by 1.25m (h_2), then 1.50m (h_3), which reached (102.0, 94.1 and 85.5 cm) respectively. Treatment h_1 showed an increase percentage of 8.39% and 19.29% compared to treatments h2 and h3 respectively, while height h2 achieved an increase percentage of 10.05% compared to height h_3, The reason for increased plant height with lower riser height is attributed to the superiority of the hydraulic characteristics of lower riser heights, especially at the height (1m), in terms of increased uniformity coefficient and decreased dispersion index, ensuring more homogeneous distribution and better coverage of water within the irrigated area and consistency of its spread. This, in turn, positively affects the pattern of irrigation water distribution and reduces its loss due to dispersion or evaporation, in addition to ensuring the delivery of a larger amount of added irrigation water to the plant's root system, these results agree with what was found by Mohamed et al., (2019), who found the superiority of a 1 m sprinkler riser height compared to both 1.5 m and 0.5 m heights due to increased consistency and homogeneity of the added water depth distribution at the 1m height even at intermediate and far distances compared to the accumulated irrigation water depth at the sprinkler center at the 0.5m height and the low water depth reaching far distances from the sprinkler center at the 1.5 m height. which, improved the soil's physical properties represented by increased soil water retention capacity (Jasim and Abbas, 2023), in addition to improved soil structure and aggregate stability, and increased soil porosity and decreased bulk density, which increased salt leaching efficiency, which positively affected plant growth and height.

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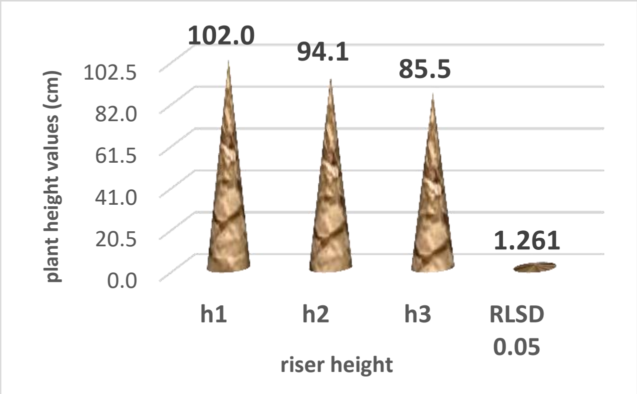

Figure (1) Effect of sprinkler riser height on plant height values (cm) .

The results in table (5) showed a highly significant effect of the irrigation interval factor on plant height values. The figure 2 shows the superiority of the 5-day irrigation interval treatment (I_5) in achieving the highest plant height values, reaching 97.0 cm compared to the 9-day irrigation interval (I_9) (90.7 cm), with an increase percentage of 6.94%. , this is attributed to the increase in soil moisture content due to the closer irrigation periods at the shorter interval, which increased salt leaching efficiency outside the root zone boundaries, thereby reducing the effort exerted by the plant to absorb water, which lead to increases the biological activities of the barley plant, positively reflecting on cell division and increased plant length compared to the longer irrigation interval. These results agree with what was found by Al-mehmdy and Al-Hashemi, (2025), who found the superiority of a 3-day irrigation interval in achieving the highest plant height reached 79.87 cm compared to a 6-day irrigation interval which gave values of 68.20 cm, attributing the reason to the fact that increasing the number of irrigations reduces plant water stress, positively reflecting on plant tissue development and increased height, in addition to improvement in some soil physical properties such as bulk density and soil penetration resistance. c that water stress is one of the most important constraints on the growth and productivity of the wheat plant, as it contributes to shorter plant height, reduced leaf area and leaf growth, and has a negative impact on growth processes, cell division and elongation, which negatively reflects on yield and dry matter accumulation in the plant, making it unable to exploit its physiological capabilities to the highest level (Al-desuquy et al., 2014). While soil water deficit leads to crop water stress, making the rate of root water absorption less than the transpiration rate, which in turn hinders cell growth and reproduction during the growth stage (Zhang et al., 2017). Furthermore, Puertolas et al., (2020) and Zhang et al., (2025) indicated that short irrigation intervals improve soil water status, increasing its uptake by plants compared to longer irrigation intervals, and this enhances cell expansion and increases the photosynthetic rate.

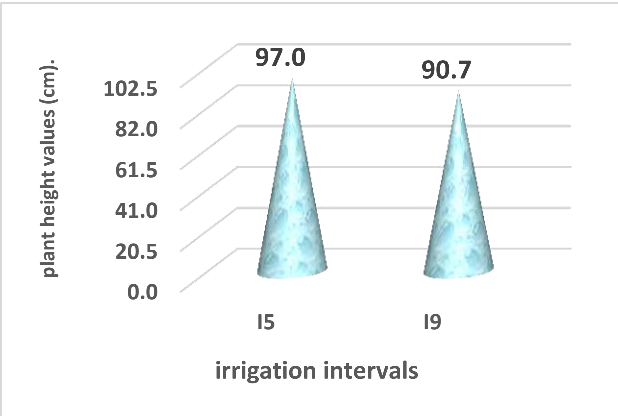

Figure (2) Effect of irrigation interval on plant height values (cm) .

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The results in table (5) show a highly significant effect of adding emulsified spent engine oil on plant height values (cm). The addition of the conditioner (O_1) led to an increase in plant height values compared to the control treatment (O_C) with a significant difference (Figure3), where the average plant height values were (98.3 and 89.4 cm) for the addition and non-addition treatments respectively. with an increase percentage of 9.95% ,this is attributed to the fact that adding emulsified spent engine oil as a conditioner leads to improved soil physical and moisture properties, increasing the soil's ability to retain water, which in turn contributes to leaching salts away from the root zone, leading to lower salt concentrations and reduced the effort required to obtain water and nutrients, positively reflecting on improving the plant's physiological characteristics and increasing its height. This agrees with what Dheyab, (2025) found, an increase in wheat plant height values resulting from the use of emulsified spent engine oil compared to the control treatment, in addition to the un-emulsified crude oil treatment, attributing the reason to the properties of the formed crude oil emulsion consisting of small oil droplets less than (2 micrometers), giving it a higher ability to penetrate and spread into soil pores and voids to greater depths compared to un-emulsified crude, which significantly reflects positively on wheat yield parameters.

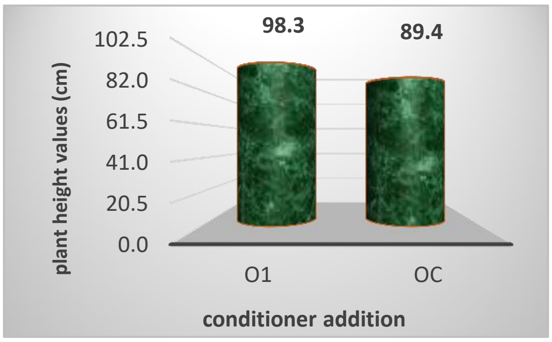

Figure (3) Effect of conditioner addition on plant height values (cm).

The results in table (5) showed a highly significant effect of the horizontal distance factor from the sprinkler center on plant height values (cm). The figure 4 shows an increase in plant height values when approaching the sprinkler center, the highest plant height values were recorded for treatment close to the sprinkler center in the first third (X_1) at 98.6 cm, compared to distance X_2 and distance X_3, which reached 94.0 cm and 89.0 cm respectively. the reason for the decrease in plant height with distance from the sprinkler center, due to the lack of uniformity in the distribution of irrigation water. and increased dispersion coefficient, which in turn reduces the water depth reaching those distances, leading to a decrease in the amount of water available to the plant due to wind speed resulting in evaporation and dispersion of irrigation water droplets. this negatively reflects on vegetative growth characteristics, including plant height. These results are consistent with what was found by Wang et al., (2023), who found a decrease in wheat plant lengths with distance from the sprinkler center due to variation in the added water depth with different distances from the sprinkler center. also, water affected by crop shading tends to accumulate near the sprinkler center, while gradually decreasing away from it. Ortiz et al., (2012) explained, the distance close to the sprinkler center at 1.5 meters is characterized by more homogeneous water distribution and higher moisture content compared to other distances, achieving the highest plant height with different sprinkler riser heights.

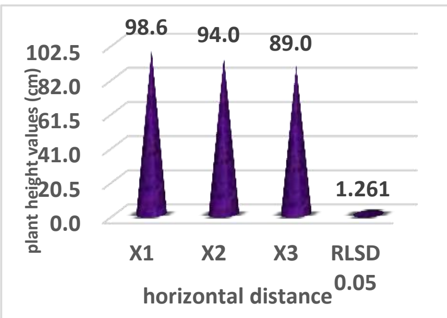

Figure (4) Effect of horizontal distance from sprinkler center on plant height values (cm) at the end of the growing season.

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The results shown in the table (5) indicate the presence of a highly significant effect of the interaction between the irrigation interval factor and the addition of emulsified spent engine oil conditioner on plant height values (cm), the table 2 shows that the variation in plant height values between irrigation intervals I_5 and I_9 varies according to the difference in the conditioner addition treatment interacting with them. The highest differences between I_5 and I_9 appeared at the non-addition treatment O_C and the least at the conditioner addition treatment O_1. The addition level O_1 achieved the highest values at irrigation interval I_5 for the factorial treatment I_5O_1 compared to the factorial treatment I_5O_C with a significant difference, as the values reached (101.0, 95.7 cm) respectively. Meanwhile, the highest values for the non-addition level were at irrigation interval I_5 for the interaction treatment I_5O_C compared to treatment I_9O_C (93.1 and 85.7 cm) respectively. This is attributed to the role of the emulsified oil conditioner in increasing the soil's ability to retain moisture by improving soil physical properties, in addition to mitigating the negative impact of wetting and drying processes during and between irrigations for the aforementioned reasons related to increased moisture content and its relationship with reducing the energy of water droplets impacting the soil surface and increasing salt leaching efficiency.

Table (2) Effect of experimental factors and their interactions on plant height values (cm) .

irrigation interval * addition of conditioner			
I	**O_1**	**Oc**	**RLSD 0.05**
I_5	101	93.1	**1.456**
I_9	95.7	85.7	

addition of conditioner * riser height				
O	**h_1**	**h_2**	**h_3**	**RLSD 0.05**
O_1	105.9	98	91.0	**1.783**
O_C	98.1	90.1	80.1	

riser height * horizontal distance				
h	**X_1**	**X_2**	**X_3**	**RLSD 0.0**
h_1	108.0	101.4	96.6	**2.183**
h_2	99.1	94.7	88.4	
h_3	88.7	85.9	82.0	

addition of conditioner * riser height * horizontal distance				
O	h	**X_1**	**X_2**	**X_3**
O_1	**h_1**	108.1	106.2	103.2
	h_2	104.8	98.2	91.0
	h_3	94.17	91.5	87.2
Oc	**h_1**	107.8	96.5	89.9
	h_2	93.33	91.1	85.8
	h_3	83.25	80.1	76.8
RLSD 0.05		**3.088**		

addition of conditioner * riser height * irrigation interval				
O	**I**	**I_5**	**I_9**	**RLSD 0.05**
O_1	**h_1**	109.1	102.6	**2.521**
	h_2	99.5	96.5	
	h_3	94.2	87.7	
Oc	**h_1**	102.7	93.3	
	h_2	94.67	85.5	
	h_3	81.83	78.2	

The results in table (5) show a highly significant effect of the interaction between sprinkler riser height and the addition of emulsified spent engine oil on plant height values. The table (2) shows that the variations between sprinkler riser heights h_1, h_2, and h3 vary according to the difference in the interacting conditioner addition treatments, the highest variations between heights h_1, h_2, and h_3 and their interaction with the non-addition treatment O_C appeared, and the least at the conditioner addition treatment O_1. The highest plant height values were recorded using the conditioner treatment (O_1) and at height h_1 in the factorial treatment h_1O_1 at 105.9 cm, followed by height h_2 then height h_3, which gave values of 98.0 cm and 91.0 cm respectively. This is attributed to the role of the homogeneous distribution and spread of the emulsified oil conditioner in the soil, thus surrounding soil aggregates with the water-repellent emulsified oil material and protecting them from breakdown, which increased the soil moisture content and salt leaching efficiency, this encouraged increased plant biological activity and the resulting efficiency of water absorption by roots, thus increasing plant lengths.

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The results in table (5) show a highly significant effect of the interaction between sprinkler riser height and the horizontal distance from the sprinkler center on plant height values (cm). table (2) shows that the variations in plant height values between sprinkler riser height treatments h_1, h_2, and h3 vary according to the difference in distance from the sprinkler center. The highest variations appeared at distances close to the sprinkler center X_1, then intermediate X_2, and the least at distance X_3. Despite this, distance X_1 achieved the highest plant height values compared to distances X_2 and X_3, especially at height h_1 compared to the other two heights. The highest plant height values were recorded at height h_1 and distance X_1 in the factorial treatment h_1X_1, which reached 108.0 cm, while height h_3 achieved the lowest values at distance X_3 in the factorial treatment h_3X_3 at 82.0 cm. Meanwhile, height h_2 gave intermediate values, this is attributed to the resultant effect of the interacting factors and their impact on reducing the energy of irrigation water droplets at low sprinkler heights, which is enhanced by increasing proximity to the sprinkler center, accompanied by increased soil moisture content, increased aggregate stability, and improved structure, which increased soil porosity and decreased bulk density and soil penetration resistance, positively reflecting on increased plant lengths.

The results in table (5) show a significant effect of the triple interaction between sprinkler riser height, irrigation interval, and the addition of emulsified spent engine oil conditioner on plant height values (cm), the results in the table (2) show that irrigation interval I_5 led to a convergence of plant height values between heights h_1 and h_2, and the difference in plant height values increases with increased sprinkler riser height at height h_3, with height h_1 excelling in recording the highest values regardless of the conditioner level. Also, height h1 surpassed heights h_2 and h_3 at both addition levels O_1 and O_C in achieving the highest plant height values for both irrigation intervals I_5 and I_9, which reached (109.1 and 102.8 cm) and (102.6 and 93.4 cm) respectively. Also, increasing the irrigation interval from I_5 to I_9 reduced plant height values at sprinkler height h_3 compared to heights h_1 and h_2. The lowest plant height values were recorded for factorial treatments under irrigation interval I_9 and conditioner addition (O_C) and at height h_3, particularly for treatment $h_3I_9O_C$ which reached 78.3 cm, while the highest plant height values were at irrigation interval I_5 and conditioner addition (O_1) and at height h1 in the factorial treatment $h_1I_5O_1$ at 109.1 cm. This is attributed to the resultant effect of the factors and their interactions and their impact on improving soil physical properties.

The results in table (5) show the presence of a highly 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 plant height values (cm).a significant differences are observed (Table2), these plant height values increase with a decrease in both sprinkler riser height and horizontal distance from the sprinkler center and with conditioner addition. The highest plant height values were recorded at sprinkler riser height (h_1), conditioner addition (O_1), and horizontal distance (X_1) represented by the factorial treatment $h_1O_1X_1$ at 108.2 cm, followed by the second height (h_2) for the same conditioner addition treatment (O_1) compared to the third height (h_3) with a significant difference between treatments. while the lowest plant height values were at sprinkler riser height (h_3), control treatment (O_C), and the far horizontal distance from the sprinkler center (X_3) represented by the factorial treatment $h_3O_CX_3$ which was at 76.8 cm. this is attributed to the resultant effect of the interaction of the experimental factors represented by sprinkler riser height, emulsified spent engine oil conditioner, and horizontal distance from the sprinkler center.

2- Dry matter

The results in table (5) showed a highly significant effect of the sprinkler riser height factor on dry matter values of the barley plant (ton h^{-1}). a significant difference is evident among all treatments (Figure5), It is generally observed that dry matter values of the vegetative part increase with lower sprinkler height of 1m (h_1) achieved the highest values, followed by height 1.25m (h_2), then 1.50m (h_3), with average (7.116, 6.740, and 6.337-ton ha^{-1}) respectively. Treatment h_1 showed an increase percentage of 5.57% and 12.29% compared to treatments h_2 and h_3 respectively, while height h_2 achieved an increase percentage of 6.35% compared to height h_3, this is attributed to the homogeneity of irrigation water distribution at low sprinkler heights due to increased uniformity coefficient and decreased dispersion index, accompanied by improvement in the studied soil physical properties, this increases soil moisture and reduces water stress on plant roots for water and nutrient absorption, which works to encourage increased plant physiological processes, thus enhancing barley plant growth. These results agree with what was found by De Juan et al., (2010) and Ortiz et al., (2012), who found higher vegetative yield values at a sprinkler riser height of 1m compared to a height of 2.5m, attributing the reason for this increase to the increased water depth added to the irrigated area due to the regular distribution of irrigation water at 1 m height compared to 2.5 m, achieving the highest productivity parameters in increasing yield components, including vegetative yield.

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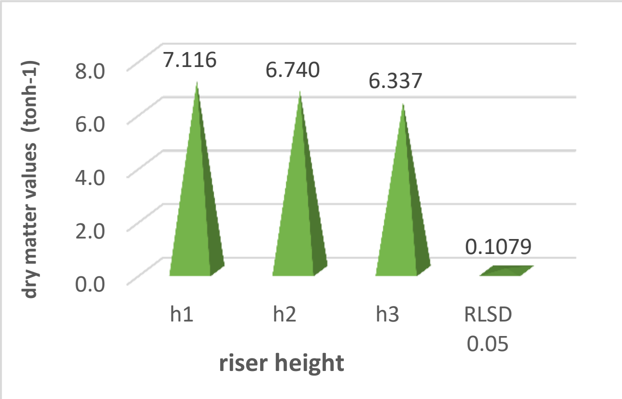

Figure (5) Effect of sprinkler riser height on dry matter values (ton h-1).

The results in table (5) show a highly significant effect of the irrigation interval factor on dry matter values of the vegetative part (ton h^{-1}), the results in fig 6 show the superiority of the 5-day irrigation interval treatment (I_5) in achieving the highest dry matter values of the vegetative part is observed, which reached 7.721-ton ha^{-1}compared to the 9-day irrigation interval (I_9) which gave 5.741-ton ha^{-1}, with an increase percentage of 34.48%. The difference in dry matter yield values with different irrigation intervals is attributed to a decrease in the plant-available water content with increased irrigation interval, leading to yield reduction due to water and nutrient deficiency (Ismail and Ozawa, 2009).

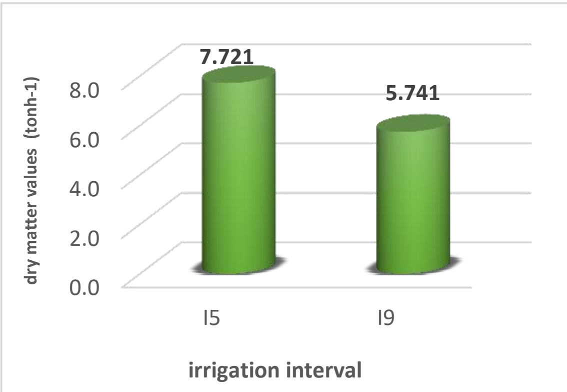

Figure (6) Effect of irrigation interval on dry matter values (ton ha^{-1}).

The results in table (5) show a highly significant effect of adding emulsified spent engine oil on dry matter values of the vegetative part (ton h^{-1}), the addition of the conditioner (O_1) led to an increase in dry matter values of the vegetative part compared to the control treatment (O_C), where the average dry matter values of the vegetative part were (7.633 and 5.829 ton ha^{-1}) for the addition and non-addition treatments respectively (Fig 7), with an increase percentage of 30.94%. this is attributed to the role of the oil emulsion in providing an optimal environment for the plant by improving soil physical properties and increasing the soil's ability to retain water, which positively reflects on the vegetative growth of the plant (Hasan et al., 2019). Manivannan et al., (2007) explained, the quality and quantity of plant yield depend on plant cell division and turgor pressure, and this is affected by water stress to which the plant is exposed due to soil moisture deficit.

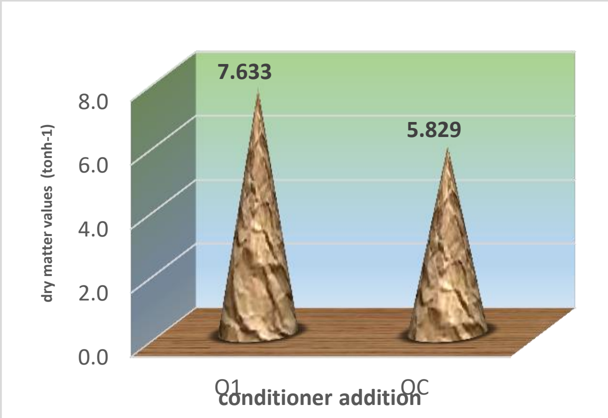

Figure (7) Effect of conditioner addition on dry matter values (ton h^{-1}).

The results in table (5) showed a highly significant effect of the horizontal distance factor from the sprinkler center on dry matter values of the vegetative part (ton h^{-1}) , the results in figure 8 shows an increase in dry matter values of the vegetative part when approaching the sprinkler center. the highest values were recorded at treatments close to the sprinkler center in the first third (X_1) at 7.371 ton ha^{-1}, with an increase percentage of 9.58% and 20.91% compared to distances X_2 and X_3 respectively, which reached values of 6.729 ton ha^{-1} and 6.096 ton ha^{-1} respectively. while, distance X_2 recorded an increase percentage of 10.33 % compared to distance X_3. the reason for this is attributed to the reasons related to the lack of homogeneity in irrigation water distribution uniformity and increased dispersion coefficient with distance from the sprinkler center, in addition to the increased energy of sprinkler water droplets and their negative impact on soil properties at distances far from the sprinkler center, which negatively affected soil structure and aggregate breakdown, reduced its moisture content, and decreased salt leaching efficiency at those distances, this leads to a decrease in the amount of water available to the plant, which negatively reflects on dry of the barley yield, these results agree with what was found by AbdulKarem and Dheyab, (2022), who found a decrease in dry matter of barley yield with distance from the sprinkler center, due to decreased moisture content and salt leaching efficiency and the impact of sprinkler water droplet energy at far distances, negatively reflecting on yield components including the dry matter.

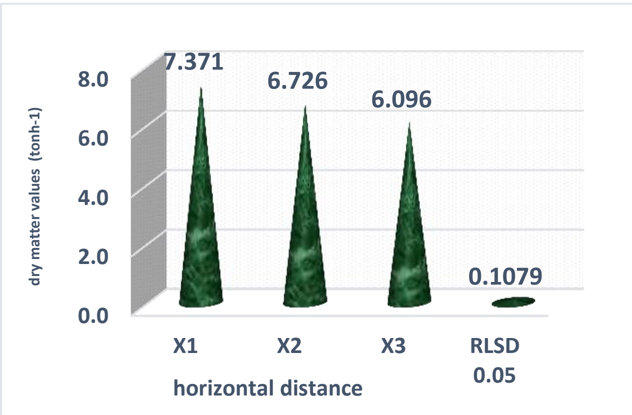

Figure (8) Effect of horizontal distance from sprinkler center on dry matter values (ton h^{-1}).

The results in table (5) show a highly significant effect of the interaction between sprinkler riser height and the addition of emulsified spent engine oil on dry matter values of the vegetative part (ton ha^{-1}), the results in figure 9 show that the significant variations between sprinkler riser heights h_1, h_2, and h_3 vary according to the difference in the interacting conditioner treatments, the highest variations between h_1, h_2, and h_3 and their interaction with the non-addition treatment (O_C) appeared, and the least at the conditioner addition treatment (O_1). This is attributed to

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the addition of the oil emulsion improved soil properties including moisture retention, reducing the negative impact of increased sprinkler riser height and the resulting decrease in sprinkler water droplet energy and its impact on the soil surface, with a consequent positive effect that enhanced the increase in dry matter of the barley plant's vegetative part. the highest dry matter values of the vegetative part were recorded at treatment O_1 and at height h_1 in the factorial treatment h_1O_1 at 7.944 ton ha^{-1}, followed by height h_2 then height h_3, which gave values of 7.640 ton ha^{-1} and 7.316 ton ha^{-1} respectively, the lowest value of dry matter recorded at Oc combined with h3 5.359 ton h-1

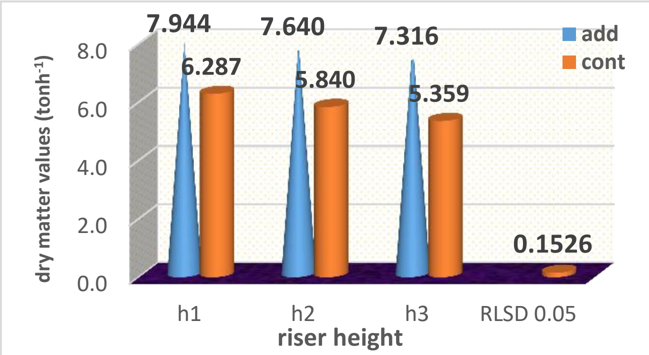

Figure (9) Effect of the interaction between sprinkler riser height and conditioner addition on dry matter values (ton h-1).

3- Grain Weight

The results in table (5) showed a highly significant effect of the sprinkler riser height factor on grain weight values (ton ha^{-1}).a significant differences are observed among all treatments (Fig10). An increase in grain weight is observed with a decrease in the sprinkler riser height. Sprinkler riser height of 1m (h_1) achieved the highest grain yield values, followed by sprinkler riser height of 1.25m (h_2), then 1.50m (h_3) reaching (7.141, 6.571, and 6.049 ton ha^{-1}) respectively. Treatment h_1 showed an increase percentage of 8.39% and 19.29% compared to treatments h_2 and h_3 respectively, while height h_2 achieved an increase percentage of 10.05% compared to height h_3. This is attributed to the increased uniformity coefficient and decreased dispersion index at low sprinkler heights, especially at the height (1m), ensuring more homogeneous distribution of irrigation water within the irrigated area and reducing its loss by dispersion or evaporation by wind, which positively affected the amount of water added within the irrigated area and ensuring the delivery of the added irrigation water depth to the plant's root system, improving its growth and spread, increasing the efficiency of water and nutrient absorption, completing physiological processes, increasing cell elongation and growth, increasing plant dry matter and grain weight yield, in addition to improved soil structure and increased aggregate stability, which improved the efficiency of leaching salts away from the root proliferation zone, reducing the effort required for water and nutrient absorption and increasing photosynthetic efficiency. These results agree with what was found by Ortiz et al., (2012), who found increased root spread and yield increase at 1m height compared to 2.5 m height for sprinkler irrigation system, attributing the reason to the decreased amount of water added at the high sprinkler height due to low uniformity coefficient values at those heights.

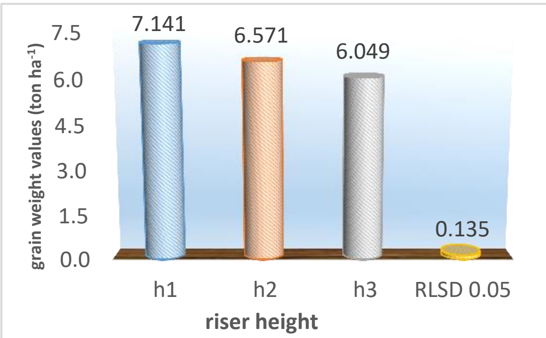

Figure (10) Effect of sprinkler riser height on grain weight values (ton ha^{-1}) for barley crop.

The results in table (5) show a highly significant effect of the irrigation interval factor on grain weight values. the 5-day irrigation interval treatment (I_5) achieving the highest grain weight values 7.430 ton ha^{-1} compared to the 9-day irrigation interval (I_9) (5.744 ton ha^{-1}), with an increase percentage of 29.35% , this is attributed to the occurrence of water stress at the longer irrigation intervals, which in turn leads to a reduction in grain weight and shortening of their filling period due to decreased metabolic rates associated with stomatal closure and premature leaf area senescence, decreased photosynthetic rate and decreasing the accumulated dry matter quantity, which negatively reflects on crop growth and reduces grain weight yield (Ibrahim et al., 2010), Gholamin and Khayatnezhad. (2010) explained that crop water stress significantly affects the decline in grain yield, and the percentage of decrease depends on stress intensity, duration, and crop growth stages. These results agree with Chen et al., (2021), who found that a 7-day irrigation interval gave the highest wheat grain yield compared to 10-day and 13-day intervals, attributing the reason to a significant increase in wheat crop root length and weight, leading to a change in photosynthetic capacity, which positively reflects on wheat grain yield.

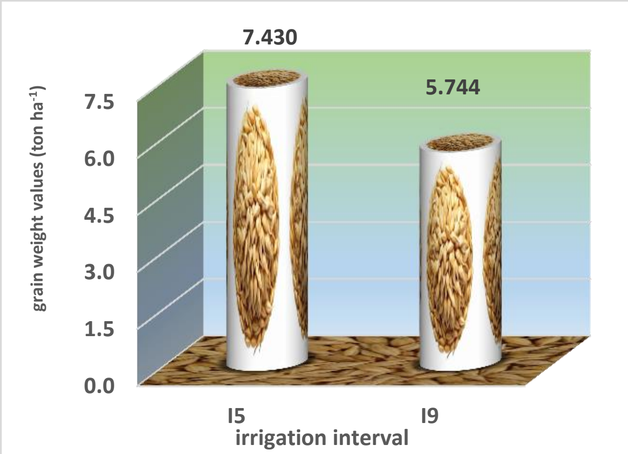

Figure (11) Effect of irrigation interval on grain weight values (ton ha^{-1}) for barley crop.

The results in table (5) show a highly significant effect of adding emulsified spent engine oil on grain weight values (ton ha^{-1}) for barley crop, the addition of the conditioner (O_1) led to an increase in grain weight values compared to the control treatment (O_C) with a significant difference, with average (7.281 and 5.894 ton ha^{-1}) for the addition and non-addition treatments respectively fig(12) , with an increase percentage 23.53%, this is attributed to the aforementioned reasons related to adding emulsified spent engine oil conditioner and its role in coating soil particles and aggregates, making their surfaces hydrophobic, resulting in improved soil structure, which in turn positively

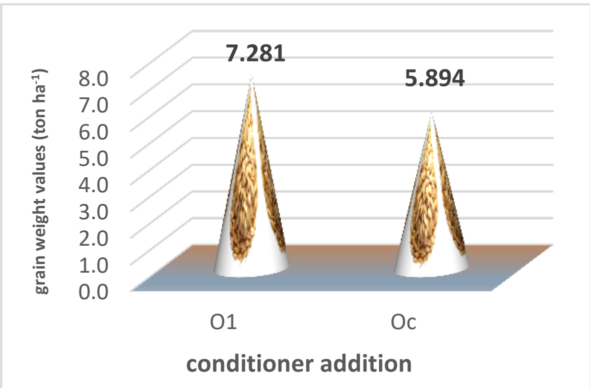

Figure (12) Effect of conditioner addition on grain weight values (ton ha^{-1}) for barley crop.

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reflects on increased aggregate stability, accompanied by increased soil porosity and decreased bulk density, thus increasing the soil's ability to retain water and increasing salt leaching efficiency away from the root zone, reducing salt concentrations and increasing grain yield (Beckwith et al., 2005; Hasan et al, 2019 and Dheyab, 2025).

The results in table (5) showed a highly significant effect of the horizontal distance factor from the sprinkler center on grain weight (ton ha^{-1}). The results in fig 13 show the highest grain weight values were recorded at treatments close to the sprinkler center in the first third (X_1) at 7.355 ton ha^{-1}, with an increase percentage of 15.01% and 22.35% compared to distance (X_2) and distance (X_3) respectively, as the values were 6.395 ton ha^{-1} and 6.011 ton ha^{-1} respectively. while, distance X_2 recorded an increase percentage of 6.38% compared to distance X_3. The reason for the increase in grain yield at distances close to the sprinkler is attributed to the increased soil moisture content at those distances, due to the superiority of irrigation water distribution consistency, and decreased droplet energy, which was coupled with their small size, enabling them to improve soil properties which in turn reflected on increased grain yield.

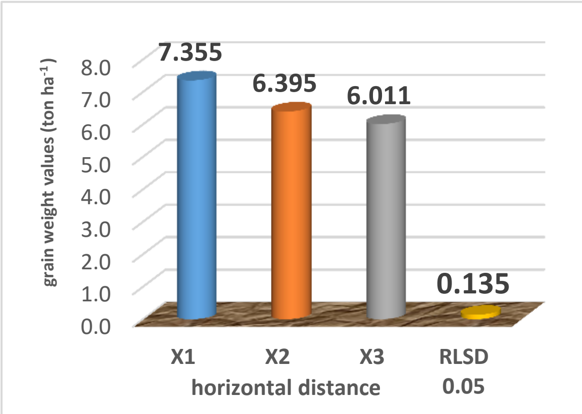

Figure (13) Effect of horizontal distance from sprinkler center on grain weight values (ton ha^{-1}) for barley crop.

The results in table (5) show the presence of a highly significant effect of the interaction between the sprinkler riser height factor and the addition of emulsified spent engine oil factor on grain weight values (ton ha^{-1}). The result in table (3) shows that the variations between conditioner treatments O_1 and O_C vary according to the difference in the interacting sprinkler riser height treatments h_1, h_2, and h_3. The highest variations between O_1 and O_C and their interaction with treatment h_1 appeared, and the least at treatment h_3. The highest grain weight values were recorded

Table (3) Effect of experimental factors and their interactions on grain weight values (ton ha^{-1}) for barley crop.

riser height *conditioner addition				
O	**h_1**	**h_2**	**h_3**	**RLSD 0.05**
O_1	**8.036**	**7.203**	**6.603**	**0.191**
O_c	**6.246**	**5.940**	**5.495**	
irrigation interval * horizontal distance				
I	**X_1**	**X_2**	**X_3**	**RLSD 0.05**
I_5	**8.170**	**7.350**	**6.769**	**0.191**
I_9	**6.540**	**5.440**	**5.253**	

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at treatment O_1 and at height h1 in the factorial treatment h_1O_1 at 8.036 ton ha^{-1}, followed by height h_2O_1 then height h_3O_1, which gave values of 7.203 ton ha^{-1} and 6.603 ton ha^{-1} respectively. while, the lowest values were recorded at the non-addition treatment O_C and at height h_3 in the factorial treatment h_3O_C, reaching 5.495 ton ha^{-1}. this is attributed to the role of homogeneous distribution and spread of the emulsified oil conditioner in the soil, thus surrounding soil aggregates with the water-repellent emulsified oil material and protecting them from breakdown, which increased soil moisture content and salt leaching efficiency, this encouraged root system spread and increased plant biological activity and the resulting water absorption efficiency, thus increasing grain yield.

The results in table (5) show a significant effect of the interaction between the of irrigation interval and horizontal distance from the sprinkler center factor on grain weight values (ton ha^{-1}) for barley crop. The table 2 shows that the significant variation between horizontal distance treatments from the sprinkler center in grain weight varies according to the variation in irrigation interval. The highest variations between X_1, X_2, and X_3 in grain weight values interacting with irrigation interval I_5 appeared, and decrease at irrigation interval I_9. The reason for the increase in grain weight values at treatments close to the sprinkler center at the short irrigation interval is attributed to the aforementioned reasons related to increased added water volume and improvement of soil physical properties, especially increased soil porosity, which in turn increased the soil's ability to retain water and its effect in reducing sprinkler water droplet energy at distances close to the sprinkler. So, the highest grain weight values were at 8.170 ton ha^{-1} at the horizontal distance treatment (X_1) and irrigation interval (I_5) represented by the factorial treatment I_5X_1, while the lowest values were given at irrigation interval treatment I_9 and the far horizontal distance from the sprinkler center X_3 and their interactions represented by the factorial treatment I_9X_3, which was at 5.253 ton ha^{-1}.

4- Water Use Efficiency for Grain Yield

The results in table (5) showed a highly significant effect of the sprinkler riser height factor on water use efficiency values calculated based on grain weight (WUE(g)) (kg ha^{-1} m^{-3}) . A significant difference are observed among all treatments (Figure 14), and there is an increase in WUE(g) values with a decrease in sprinkler riser height. Sprinkler riser height of 1m (h_1) achieved the highest grain yield values, followed by sprinkler riser height of 1.25m (h_2), then 1.50m (h_3) reaching (1.776, 1.635, and 1.505 kg $ha^{-1}m^{-3}$) respectively. Treatment h1 showed an increase percentage of 8.01% and 18.00% compared to treatments h_2 and h_3 respectively, while height h_2 achieved an increase percentage of 8.63% compared to height h_3, this is attributed to the superiority of hydraulic characteristics represented by increased uniformity coefficient and decreased

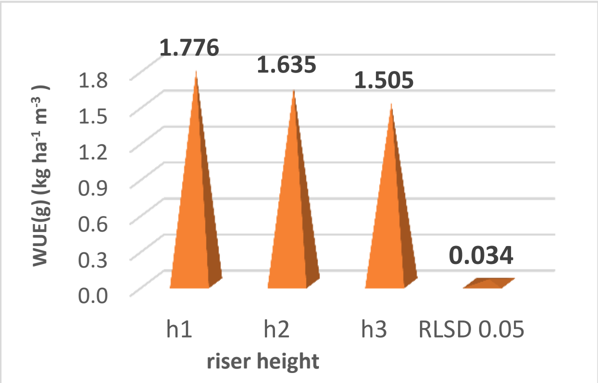

Figure (14) Effect of sprinkler riser height on Water Use Efficiency values calculated based on grain weight (kg $ha^{-1}m^{-3}$).

dispersion index at low sprinkler heights, especially at the height (1m), ensuring more homogeneous distribution of water within the irrigated area, consistency of its spread, and reducing loss of irrigation water resulting from dispersion or evaporation by wind, which positively affected the irrigation water depth added within the irrigated area at 1m height compared to heights 1.25 m and 1.50 m. This is positively affected improving soil structure and

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increasing aggregate stability, which increased salt leaching efficiency away from the root zone, positively reflecting on increasing grain yield components and increasing WUE. This agrees with what was found by De Juan et al., (2010), who found that the highest water use efficiency. This was confirmed by Ortiz et al., (2012), who found increased water use efficiency values at 1m height compared to 2.5m, attributing that to lower heights having more regular water distribution, achieving the highest productivity indicators in addition to the highest water use efficiency compared to a sprinkler riser height of 2.5 m.

The results in table (5) show a highly significant effect of the irrigation interval factor on WUE(g) (kg ha^{-1} m^{-3}) values. The results in Fig (15) show, the superiority of the 5-day irrigation interval treatment (I_5) in achieving the highest WUE(g) values is, reaching 1.848 kg $ha^{-1}m^{-3}$compared to the 9-day irrigation interval (I_9), which gave values of 1.429 kg $ha^{-1}m^{-3}$, with an increase percentage of 29.32% , this is attributed to the long irrigation periods, led to a state of water stress on plant roots to provide necessary water and nutrients, especially during the critical stage of grain maturation, filling, and formation (Zabn and AlSajri, 2022) . Adhikary et al., (2009) and Ibrahim et al., (2010) indicated that exposing the wheat crop to a state of water stress will negatively affect metabolic rates associated with stomatal closure and premature leaf area senescence, which in turn reduce the photosynthetic rate, which are fundamental traits with a clear effect on improving wheat productivity, leading to a decrease in accumulated dry matter quantity and grain yield formation and a decrease in WUE(g). These results agree with what was found by Eid et al., (2013), who found an increase in WUE(g) values when irrigating at an interval of three times per week compared to twice and once a week, attributing that to the clear improvement in wheat yield and increased grain yield due to the soil remaining moist, reducing the effort exerted by plant roots to obtain water and nutrients, positively reflecting on grain yield and increasing WUE(g).

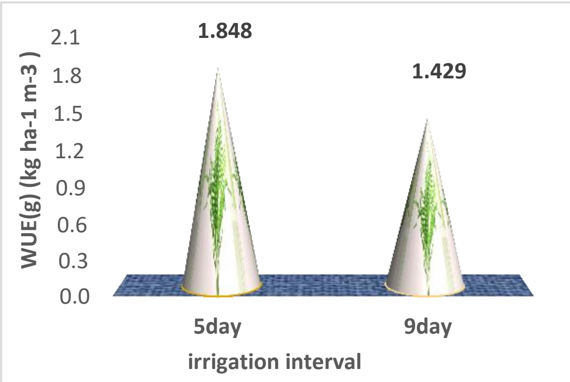

Figure (15) Effect of irrigation interval on Water Use Efficiency values calculated based on grain weight (kg $ha^{-1}m^{-3}$).

The results in table (5) show a highly significant effect of adding emulsified spent engine oil on WUE(g) values (kg $ha^{-1}m^{-3}$). The addition of the conditioner (O_1) led to an increase in WUE(g) values compared to the control treatment (O_C) with a significant difference (Figure16), where the average WUE(g) values were (1.811 and 1.466 kg $ha^{-1}m^{-3}$) , respectively. with increase percentage 23.53% , this is attributed to the role of adding emulsified spent engine oil conditioner in improving soil properties and increasing its moisture retention capacity, reducing soil bulk density, and increasing its porosity. This, in turn, improved soil structure, which positively reflected on increased aggregate stability, and increased salt leaching efficiency away from the root zone, reducing salt concentrations, which in turn increased yield components including grain yield and WUE(g) values. These results agree with what was found by Dayf et al., (2025) and confirmed by Dheyab, (2025), who found an increase in WUE(g) for wheat yield in soil treated with emulsified crude oil, which gave values of 1.72 kg $ha^{-1}m^{-3}$ compared to the control treatment which reached 1.27 kg m^{-}3.

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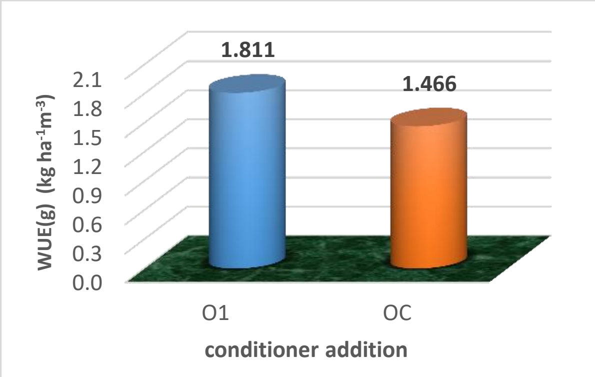

Figure (16) Effect of conditioner addition on Water Use Efficiency values calculated based on grain weight (kg ha^{-1}m^{-3}).

The results in table (5) show a highly significant effect of the horizontal distance factor from the sprinkler center on WUE (g) values (kgha^{-1}m^{-3}). The results in Fig (17) shows an increase in WUE(g) values when approaching the sprinkler center. The highest values were recorded at treatments close to the sprinkler center in the first third (X_1) at 1.830 kgha^{-1}m^{-3}, with an increase percentage of 15.02% and 22.40% compared to distance (X_2) and distance (X_3) respectively, as their values reached 1.591 kgha^{-1}m^{-3} and 1.495 kgha^{-1}m^{-3} respectively. while, the distance X_2 recorded an increase percentage of 6.42% compared to distance X_3. The reason for the increase in WUE(g) at distances close to the sprinkler is attributed to the increased soil moisture content at those distances, due to the superiority of irrigation water distribution consistency, decreased droplet energy, which was coupled with their small size, enabling them to improve soil properties

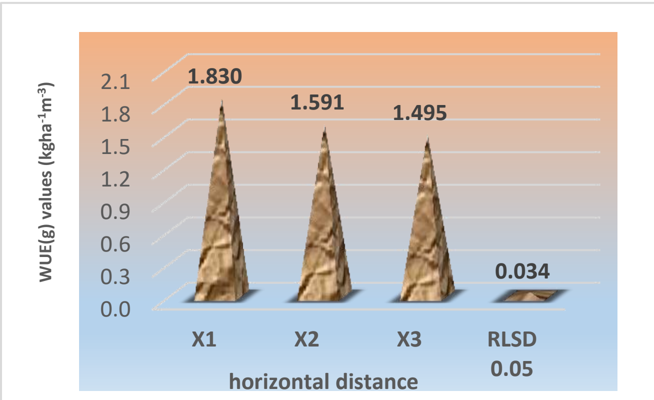

Figure (17) Effect of horizontal distance from sprinkler center on Water Use Efficiency values calculated based on grain weight (kg ha^{-1}m^{-3}).

which in turn reflected on increased WUE(g). These results agree with AbdulKarem and Dheyab, (2022).
The results in table (5) show a highly significant effect of the interaction between the of sprinkler riser height factor and the addition of emulsified spent engine oil factor on WUE(g) values. Table 4 shows that the variations between conditioner treatments O_1 and O_C vary according to the difference in the interacting sprinkler riser height treatments h_1, h_2, and h_3, the highest variations between O_1 and O_C and their interaction with treatment h_1 appeared, and the

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least at treatment h_3. The highest WUE(g) values were recorded at treatment O_1 and at height h_1 in the factorial treatment h_1O_1 at 1.999 kgha^{-1}m^{-3}, followed by height h_2O_1 then height h_3O_1, which gave values of 1.792 kgha^{-1}m^{-3} and 1.643 kgha^{-1}m^{-3} respectively. while, the lowest values were recorded at the non-addition treatment O_C and at height h_3 in the factorial treatment h_3O_C, reaching 1.367 kg ha^{-1} m^{-3} , this is attributed to the role of homogeneous distribution and spread of the emulsified oil conditioner in the soil, thus surrounding soil aggregates with the water-repellent emulsified oil material and protecting them from breakdown, which increased soil moisture content and salt leaching efficiency , this encouraged root system spread and increased plant biological activity and the resulting water absorption efficiency and increased yield components including grain yield and increased WUE(g). Also, the improvement in soil properties, in turn, increased the soil surface's ability to absorb sprinkler water droplets and reduce their impact energy on the soil surface, which is enhanced by low sprinkler riser height, leading to an increase in the variations between h_1, h_2, and h_3 in WUE(g) values at treatment O_1 compared to treatment O_C.

Table (4) Effect of experimental factors and their interactions on Water Use Efficiency values calculated based on grain weight (kgha^{-1}m^{-3}).

riser height * conditioner addition				
O	**h_1**	**h_2**	**h_3**	**RLSD 0.05**
O_1	1.999	1.792	1.643	**0.048**
O_C	1.554	1.478	1.367	
irrigation interval * horizontal distance				
I	**X_1**	**X_2**	**X_3**	**RLSD 0.05**
I_5	2.032	1.828	1.684	**0.048**
I_9	1.627	1.353	1.307	

The results in the table (5) show a significant effect between the irrigation interval and horizontal distance from the sprinkler center factors on WUE(g) values (m^{-3}). The results in table 4 shows that the significant variation between horizontal distance treatments from the sprinkler center in WUE(g) values varies according to the variation in irrigation interval. The highest variations between X_1, X_2, and X_3 in WUE(g) values interacting with irrigation interval I_5 appeared, and decrease at irrigation interval I_9, this is attributed to the aforementioned reasons related to increased added water volume and improvement of soil physical properties, especially increased soil porosity, which in turn increased the soil's ability to retain water and its effect in reducing sprinkler water droplet energy at distances close to the sprinkler. So, the highest WUE(g) values were at 2.032 kgha^{-1}m^{-3} at the horizontal distance treatment X_1 and irrigation interval I_5 represented by the factorial treatment I_5X_1, while the lowest values were given at irrigation interval treatment I_9 and the far horizontal distance from the sprinkler center X_3 and their interactions represented by the factorial treatment I_9X_3, which recorded 1.307 kgha^{-1}m^{-3}.

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Table (5) variance analysis (F- test) plant height(cm) , dry matter (ton h^{-1}) , grain yield (ton h^{-1}) and water use efficiency ($kgh^{-1}m^{-3}$)

S.O.V	d.f	Plant height	Dry matter	Grain yield	WUE(g)
h	2	339.05**	103.43**	129.75**	129.75**
I	1	150.69**	2009.61**	926.53**	926.53**
O	1	296.78**	1667.83**	627.32**	627.32**
X	2	114.92**	277.59**	208.38**	208.38**
I.O	1	3.88*	0.60^{ns}	0.27^{ns}	0.27^{ns}
I.h	2	2.71^{ns}	0.12^{ns}	0.00^{ns}	0.00^{ns}
O.h	2	3.98^{ns}	3.81*	13.89**	13.89**
I.X	2	0.88^{ns}	2.09^{ns}	4.45*	4.45*
O.X	2	1.62^{ns}	1.79^{ns}	0.38^{ns}	0.38^{ns}
h.X	4	3.22*	1.04^{ns}	0.43^{ns}	0.43^{ns}
I.O.h	2	6.47*	0.27^{ns}	0.00^{ns}	0.00^{ns}
I.O.X	2	0.56^{ns}	2.09^{ns}	0.23^{ns}	0.23^{ns}
I.h.X	4	1.33^{ns}	0.85^{ns}	0.00^{ns}	0.00^{ns}
O.h.X	4	10.86**	1.68^{ns}	0.43^{ns}	0.43^{ns}
I.O.h.X	4	1.23	0.85^{ns}	0.00^{ns}	0.00^{ns}
ns = non-Significant *= Significant 0.05 **= high Significant 0.001					

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