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Article

Effects of Dripper Type and Irrigation Water Quality on Soil Bulk Density and Maize Growth and Yield

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Abstract: Rationalization of irrigation water as global warming has negatively affected the availability of irrigation water. The field experiment was conducted to study the impact of the types of the dripper and the salinity of irrigation water rotation on the bulk density, maize growth, and yield using two kinds of drippers (turbo and spiral) and two levels of irrigation water with different salinity ratios (low, symbolized by L) and (high and symbolized by H). Irrigation water was added into three rotations (L, H), (H, L, H), and (L, H, L). The results showed an increase in bulk density values with the highest value for the spiral type as compared to the turbo type. Our results indicated that water quality had a significant influence on soil bulk density values with the highest bulk density values reaching for the (L, H), (H, L, H), (L, H, L), respectively. The results displayed a increase in plant height, leaf area, and yield by using the (L, H, L) as compared to (L, H) and (H, L, H), respectively. This work presented the possibility of the exploitation a high-salinity water which is existing source in southern region of Iraq in the rotation with fresh water to water the maize crop.

Keywords: irrigation water salinity; bulk density; plant height; electrical conductivity

1. Introduction

Drippers vary in the way that dissipate energy and water flowing through them, and one of the most popular methods used in designing emitters is to rely on friction and resistance to the flow of water through long paths, swirling motion, or even a series of nozzles. The use of poor-quality irrigation water and good-quality irrigation water will reduce the accumulation of salts in the soil body while allowing compensation for half of the plant's water needs [1]. High-pressure, frequent irrigation according to water requirement was superior in plant height, biological yield, and grain yield to low-drainage irrigation by 1, 5 and 21%, respectively [2]. In this regard, some researchers applied a successive and periodic strategy for the purpose of managing irrigation with a rotation system using low-salinity water and high-salinity water between irrigations. Al-Asadi et al. [3] and Xiukang et al. [4] presented in their studies that Iraqi lands are exposed to long-term and inevitable problems, including soil salinity, which is considered one of the main problems that devastate the country's agricultural future. Despite the dryness and salinity of the lands, some difficulties in obtaining integrated data regarding to the quantity and quality of groundwater in Iraq are presented, and they have caused significant losses in proportions in Arable lands. Arable lands, as some competent authorities, through field studies, gave the percentage of unsuitable lands at 45 million hectares (ha), or 76% of the total area of Iraq, while the cultivated area was estimated at 6 million ha [5].

Increasing the use of irrigation water salinity levels above (6 g L^{-1}) leads to the accumulation of salts in high proportions in the soil, which in turn works to raise the values of the apparent density of the soil and thus reduce porosity, as well as reduce the saturated hydraulic conductivity. Increasing the use of irrigation water salinity levels above (6 g L^{-1}) leads to the accumulation of salts in high proportions in the soil, which in turn raises the apparent density values of the soil and thus reduces porosity, as well as the decrease in saturated hydraulic conductivity. These changes affected the physical properties of the soil, which reduced the leaf area index and plant height of yellow corn, as well as the yield, which decreased by more than 25% when irrigated with water and salinity of 6 g L^{-1} [6,7]. It was found that the use of saline irrigation water for corn crops at a salinity level of 3 g L^{-1} for a short period was not clearly effective, as less than a 20% decrease in yield was observed, and this experiment used water over a period of three years [8]. A field study was conducted in Korbal plain, Iran to investigate the effect of irrigation methods exploitation wastewater on soil moisture and salinity distribution. Soil samples were taken (before and after irrigation) at three depths of 0-20, 20-40, and 40-60 cm. The results of statistical analysis showed that the salinity concentration at a depth of 0-20 cm in subsurface drip irrigation was 1.66 ds m^{-1} , while the minimum salinity value at a depth of 20-40 cm in drip irrigation was 0.92 ds m^{-1} . The use of wastewater in irrigation caused an increase in salinity levels in irrigated soil compared to freshwater, regardless of the amount of water used in irrigation [9].

Hussein et al. [10] and Albayati and Topak, [1] found that the use of salty irrigation water in the irrigation process leads to an increase in bulk density values, and they attributed the reason to the dispersal and breakdown of small soil aggregates and clay particles. Which works to bring them together and deposit them in the spaces within the aggregates, thus clogging those pores, forming semi-solid and compact layers, and this effect was more prominent in the surface layer. While, Dorraji et al. [11] and Huang et al. [12] found that increasing the salinity of the irrigation water led to a decrease in the rates of growing roots and a decrease in their branches in sandy loam soil for maize (*Zea mays* L.) crop, where values were recorded as 0.84, 0.77, and $0.56 \text{ g plant}^{-1}$ when using irrigation water with a salinity of 1.50, 4.00, and 8.00 ds m^{-1} , respectively. The use of irrigation water for maize crop with varying electrical conductivity (EC) of 3, 6, and 9 ds m^{-1} led to an increase in soil salinity as the salinity of the irrigation water increased. Thus, the rate of salinity levels increased with 0.2, 1.8, and 2.8 ds m^{-1} , respectively and this in turn led to a decrease in the dry weight of the maize plant by 33.66%. The yield also decreased from 3.95 Mg ha^{-1} to 1.87 Mg ha^{-1} [13,14].

Likewise, Li et al. [15] and Rajpar et al. [16] noted that the use of three irrigation water treatments with different EC including an irrigation water treatment with a salinity of 3.8 ds m^{-1} , a treatment of mixing 75% fresh water with 25% drainage water, and a treatment of mixing 50% fresh water and 50% drainage water, which gave grain yield as 78.81, 80.00 and 66.4%. Thus, the use of fresh irrigation water was reduced by 25 to 50%, and it was replaced by drainage water, accompanied with an insignificant decrease in yield. One of the problems facing Iraq is a sharp decline in the level of fresh surface water coming from the Turkish side, which has led to deterioration the chemical and physical properties in agricultural soil, thus limiting the areas suitable for agriculture. This decrease in water quantities in the Tigris and Euphrates rivers prompted researchers to encourage the use of modern irrigation methods as well as to resort to the use of drainage water and groundwater. Since groundwater has a high EC, the rotation method of using fresh and drainage water was used to conduct the irrigation process. Therefore, the overall goal of this study was to rationalize irrigation water and identify how the research factors affect the growth and yield of maize crops in the conditions of the southern region of Iraq. The specific objective was to study the effect of the type of dripper and the salinity of irrigation water rotation on the bulk density, growth, and yield of maize using two types of drippers (turbo and spiral) and two levels of irrigation water with different salinity ratios.

2. Materials and Methods

2.1. Study Site

The experiment was conducted in the field in Al-Rifai District - Dhi Qar Governorate, located on the geo-coordinates of latitude 31.7203291° N and longitude 46.1088035° E (Figure 1). There was no precipitation received during the maize growing season from August 1st to November 30, 2023 while the total precipitation received during the same period for ten years was 5.5 mm as presented in Table 1. Moreover, the average daily temperature was 22.7 °C and average total monthly solar radiation was 438.9 W m⁻² [17]. The average daily temperature during the crop growing season was higher than the average daily temperature for ten years 18.6 °C as shown in Table 1. The average total monthly solar radiation was higher than the average total monthly solar radiation for ten years 354.5 W m⁻².

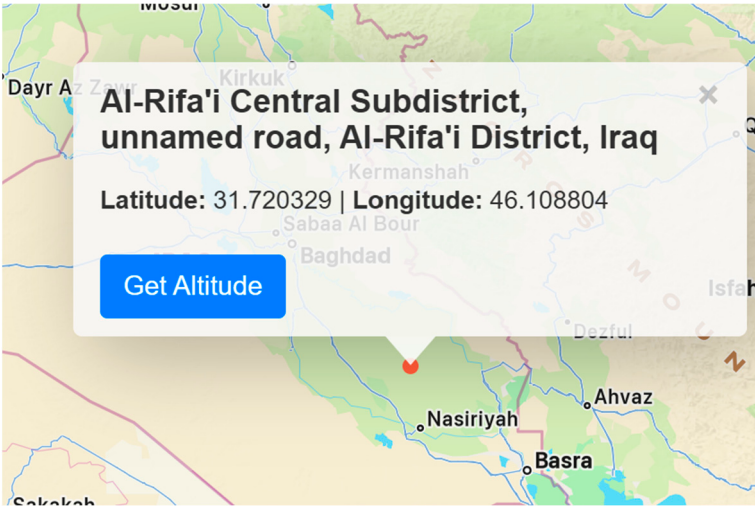


Figure 1. Study site map location.

Table 1. Summary of annual total precipitation (mm), average temperature (°C), and average total monthly solar radiation (W m⁻²) through the maize growing season for historic 10 years average weather data and 2023 season for study site.

Season	Aug.	Sep.	Oct.	Nov.	
Precipitation (mm)					Total
2023	0.0	0.0	0.0	0.0	0.0
Ten Year	1.8	0.2	1.1	2.4	5.5
Average Temperature (°C)					Avg
2023	35.0	25.8	15.8	14.1	22.7
Ten Year	27.7	22.3	15.8	8.5	18.6
Total monthly solar radiation (W m ⁻²)					Avg
2023	738.0	615.3	387.3	15.0	438.9
Ten Year	602.6	497.9	287.6	29.8	354.5

2.2. Experimental Procedure

The texture of the experimental soil was a silty clay loam. The process of amending and leveling the surface of the experimental soil was conducted, and the soil was plowed perpendicularly with smoothing [18]. After completing the soil preparation operations, soil samples were taken to different depths (from 0-20 cm and from 20-40 cm) after digging a soil core at the experimental site. The soil samples were air-dried and passed through a 2 mm sieves for the purpose of estimating some physical and chemical properties as shown in Table 2.

Table 2. Summary of some properties for soil samples were taken at depths 0–20 and 20–40cm.

Properties	Soil Depth (0-20 cm)	Soil Depth (20-40 cm)
Bulk density (g cm ⁻³)	1.36	1.37

Weighted diameter (mm)	0.13	0.11
Sand (g kg ⁻¹ soil)	158	150
Silt (g kg ⁻¹ soil)	476	478
Clay (g kg ⁻¹ soil)	366	372
Soil texture	Silty clay loam	Silty clay loam
pH	7.80	7.20
Total carbonate (g kg ⁻¹)	325.69	290.42
Organic matter (g kg ⁻¹)	3.35	2.63
EC ds m ⁻¹	2.67	3.85
Particle density (g cm ⁻³)	2.55	2.55
Porosity %	51	50
Field capacity %	31.37	32.84
Ca ⁺⁺ (dS L ⁻¹)	13.86	14.87
Mg ⁺⁺ (dS L ⁻¹)	8.06	10.08
Na ⁺ (dS L ⁻¹)	50.35	60.46
K ⁺ (dS L ⁻¹)	1.79	2.69
HCO ₃ ⁻¹ (dS L ⁻¹)	3.34	3.08
SO ₄ ⁻² (dS L ⁻¹)	17.46	17.84
Cl ⁻¹ (dS L ⁻¹)	57.93	61.74

pH= Soil Reaction, EC= Electrical Conductivity, ds m⁻¹ = desimines per meter, g kg⁻¹ soil = gram per kilogram.

A drip irrigation system was installed at the study site using a pump with a discharge capacity of 15 m³ h⁻¹ for the purpose of raising irrigation water and pushing it into the pipes of the system with equal pressures after controlling it using the return water lock. Two types of drippers were used in the experiment including: the spiral dripper, which is characterized by its spiral design that can help to reduce the clogging of the openings and ensures a continuous flow of water. The main advantage of the spiral dripper is its design ability to regulate the flow of water as the water passes through a spiral channel that leads to its exit slowly that reduces the opportunity of the dripper becoming clogged with sediment or dirt. The second type is the turbine dripper which has an internal design similar to turbines since it contains internal blades or channels that rotate as the water passes through them. This turbine design helps regulate the flow of water and decrease the water pressure to come out at a specific and constant rate. The system was operated, and the calibration process was conducted for the purpose of obtaining regular distribution and homogeneity (Figure 2). The field experiment was designed using a Randomized Completely Block Design (RCBD) with three replications. Irrigation was scheduled using a soil moisture sensor, where subsequent irrigation was performed when 50% of the moisture content was depleted at the field capacity. Two types of irrigation water were used fresh water with EC ranging from (1.35 - 1.6) ds m⁻¹ and drainage water with EC of (6.45 - 6.9) ds m⁻¹. Six experimental treatments were distributed randomly in each sector so that the total number of experimental units were 18 (Figure 2), which including two factors.



Figure 2. Field Experimental plots of maize crop with drip irrigation system near the city of Rifai, Dhi Qar Governorate, Iraq.

The first factor was types of drippers which were spiral, and turbo and the second factor were rotation of irrigation water salinity, which were A: Binary rotations (L and H), meaning low (L) salinity irrigation water (fresh water) with EC of (1.35 - 1.6) ds m^{-1} was used in the first irrigation. While in the second irrigation, high (H) salinity water (drainage water) with (6.45 - 6.9) ds m^{-1} was used. Thus, the irrigation process was repeated using fresh water (L) in the third irrigation and drainage water (H) in the fourth irrigation and so on. B: - Triple rotations (H, L, and H): In this rotation, drainage water (H) was used in the first irrigation, then fresh water (L) in the second irrigation, then drainage water (H) in the third irrigation, and starts again with drainage water (H) in the fourth irrigation, with fresh water (L) in the fifth irrigation, with drainage water (H) in the sixth irrigation, and so on. C: - Triple rotation (L, H, and L): - First irrigation was done using fresh water (L), then the second irrigation was used with drainage water (H), and the third irrigation was added with fresh water (L), and starts again with fresh water (L) in the fourth irrigation, with drainage water (H) in the fifth irrigation, with fresh water (L) in the sixth irrigation, and so on.

2.3. Statistical Analysis

Statistical analysis was conducted to examine the effect of the experimental factors on the studied traits, considering the effect of each individual factor on the trait, and then the effect of the two factors overlapping on the scientific trait studied in the experiment. The experimental data statistically analyzed according to analysis of variance (ANOVA) for all studied traits using the statistical program Genstat, version 10.30E 2010 [19]. Statistically significant differences were calculated between the averages of the coefficients, with the least significant difference at the 0.05 level.

3. Results

3.1. Soil Bulk Density

Table 3 and Figure 3 show the effect of the study parameters (dripper types and salinity rotation) on the bulk density values of the soil, as it turns out that it increased significantly compared to its values before conducting the experiment (Table 2). The values of bulk density for the soil as in Figure 3A varied according to the variety of drippers used, as it reached its highest values when using the spiral dripper compared to the turbo dripper and for all cycles. The spiral dripper type gave the highest values of bulk density, amounting to 1.58 gm cm⁻³, compared to the turbo dripper, which recorded the best readings, which was 1.42 gm cm⁻³ [20]. The results from Table 3 and Figure 3B showed that there were significant differences between soil bulk density values according to the different salinity rotation used in the experiment, as the lowest values reached 1.34 g cm⁻³ in the L.H.L rotation, while the H.L.H rotation recorded the highest values and amounted to 1.67 g cm⁻³. Table 3 and Figure 3C showed that the lowest values recorded in their interaction with the salinity rotations (L.H., H.L.H, and L.H.L) were 1.47, 1.52, and 1.27 g cm⁻³ for the turbo dripper type compared to the spiral dripper overlapping with salinity rotation. It is noted from the results that the bulk density values decreased for the turbo dripper overlapping with rotations compared to the other dripper overlapping with the same rotations, and the percentages of decrease were 4.53, 14.26, and 8.66%, respectively.

Table 3. Analysis of variance for tabular F values for the values of the studied characteristics.

S	df	Bulk density (g cm ⁻³)	Plant height (cm)	Leaf area (cm ²)	Yield (Mg ha ⁻¹)
Dripper type	1	62.22**	387.20**	3801.59**	573.29**
Rotation	2	74.57**	551.41**	5270.62**	1207.60**
Salinity					
D*R.S	2	6.81**	11.11*	7.03*	5.33*

R.S= Rotation salinity, D= Dripper type. **Significant at 0.01 level, *Significant at 0.05 level.

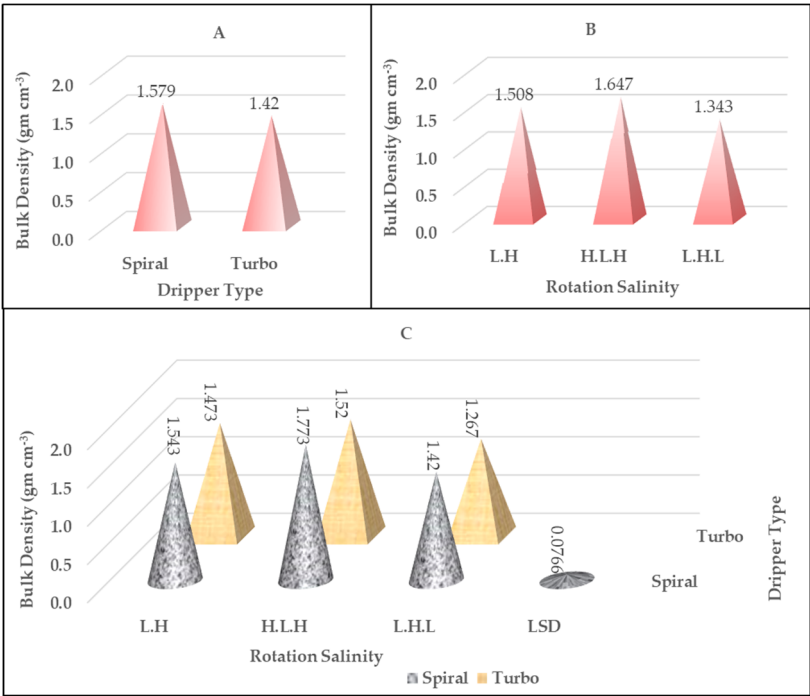


Figure 3. The effect of the type of dripper (A), the rotation salinity (B), and the interaction between them (C) on the soil bulk density values (g cm⁻³).

3.2. Plant Height

It is clear that there was a significant effect of the dripper type factor on plant height Table 3. When comparing the two dripper type treatments, it becomes clear that there was a significant difference in the plant height values as in Figure 4A. The treatment with the turbo dripper was superior and reached 173.33 cm compared to the spiral dripper and recorded 153.78 cm. The results presented in Figure 4B,C that the effect of the experimental parameters on the plant height values. There was a highly significant effect of the salinity rotation treatments in the use of fresh and drainage water overlapping with the type of dripper on the plant height values, as the salinity rotation treatment showed L.H.L overlapping with the dripper types (spiral and turbo) were significantly superior compared to the treatments L.H. and H.L.H, respectively. The plant height values ranged from 171.29 cm to 193.33 cm, compared to the rotation treatments overlapping with the dripper type, which ranged from (154.35 cm to 178.00 cm) and (135.67 cm to 148.65 cm), respectively.

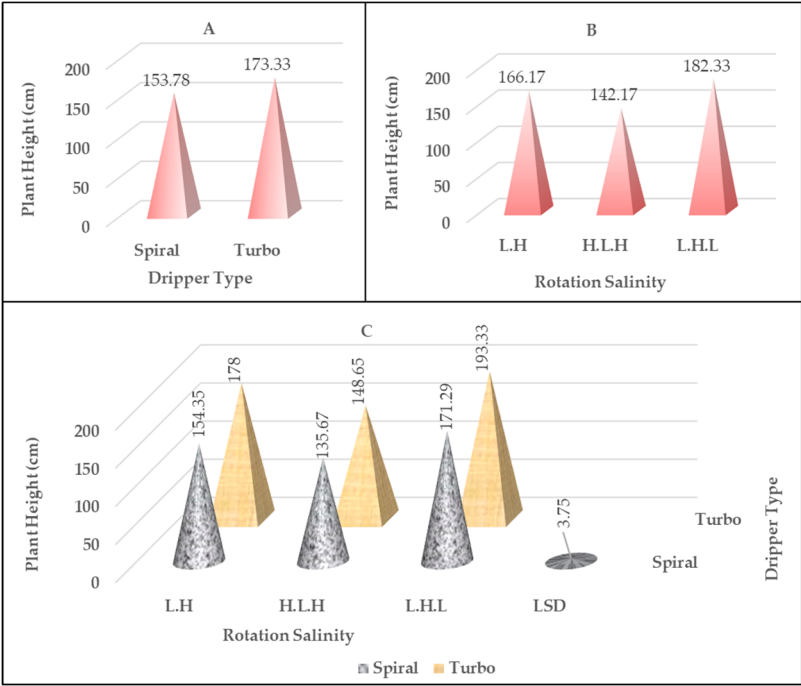


Figure 4. The effect of the type of dripper (A), the rotation salinity (B), and the interaction between them (C) on the values of plant height in cm.

3.3. Plant Leaf Area

Table 3 shows the results of the statistical analysis of the F test that there was a significant effect for both the factors of dripper type and irrigation water salinity rotation and their interaction on the leaf area values. It is noted from Figure 5B that there was a significant superiority in the leaf area values for the salinity rotation treatment L.H.L, as it was recorded as 974.75 cm² while the salinity rotation treatments L.H. and H.L.H gave the lowest values at an average of 933.11 cm² and 847.60 cm², respectively. Whereas regarding changing the values of leaf area with the type of dripper, the results in Figure 5A show that there was a significant superiority for the turbo dripper. It gave the highest value compared to the spiral dripper, as the values, as an average for the two treatments, were 950.27 cm² and 886.70 cm² for the two drippers, respectively. The results of Figure 5C indicate that there was a significant effect resulting from the interaction between the type of dripper and the salinity rotation on the leaf area values. It turns out that the most significant differences were recorded between the turbo dripper type compared to the spiral dripper for all salinity rotations.

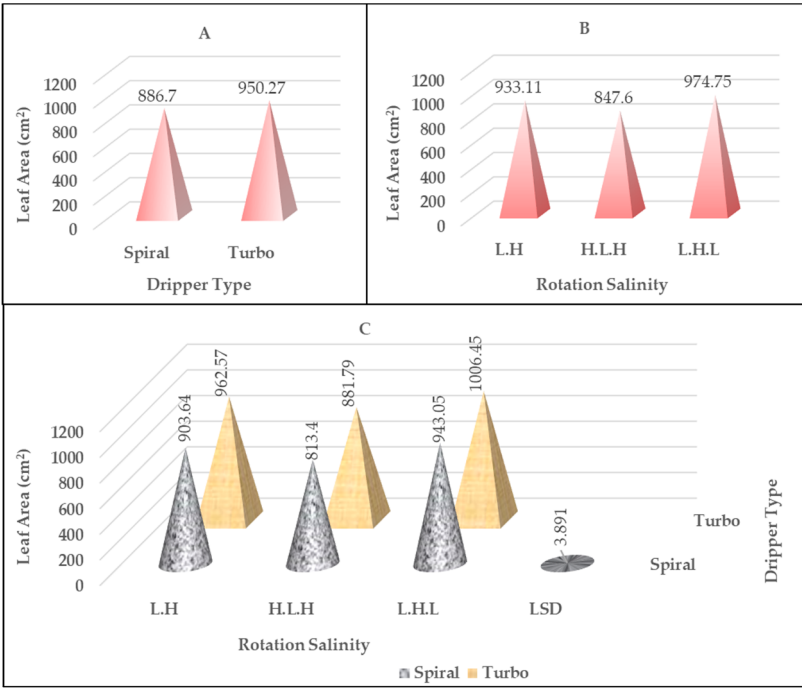


Figure 5. The effect of the type of dripper (A), the rotation salinity (B), and the interaction between them (C) on the leaf area values in cm².

3.4. Grain Yield

The results showed that there was a highly significant effect of both the salinity rotation factors and the dripper type and their interaction on yield values (Table 3). The yield values and their distribution vary with the type of drippers. The results in Figure 6A show that there was a significant superiority for the turbo dripper and the highest values were recorded an average of 9.05 Mg ha⁻¹ compared to the spiral dripper, where the values were an average of 8.78 Mg ha⁻¹. There was significant superiority in the yield for the salinity rotation L.H.L treatment, which gave an average 9.21 Mg ha⁻¹, while the salinity rotation L.H and H.L.H treatments recorded the lowest values, with an average of 8.98 Mg ha⁻¹ and 8.55 Mg ha⁻¹, respectively Figure 6B. There was a significant superiority of the interaction between the salinity rotation and the dripper type in the yield values Figure 6C. The L.H.L salinity rotation exhibited the highest significant differences in yield compared to the L.H. and H.L.H rotations across all drippers.

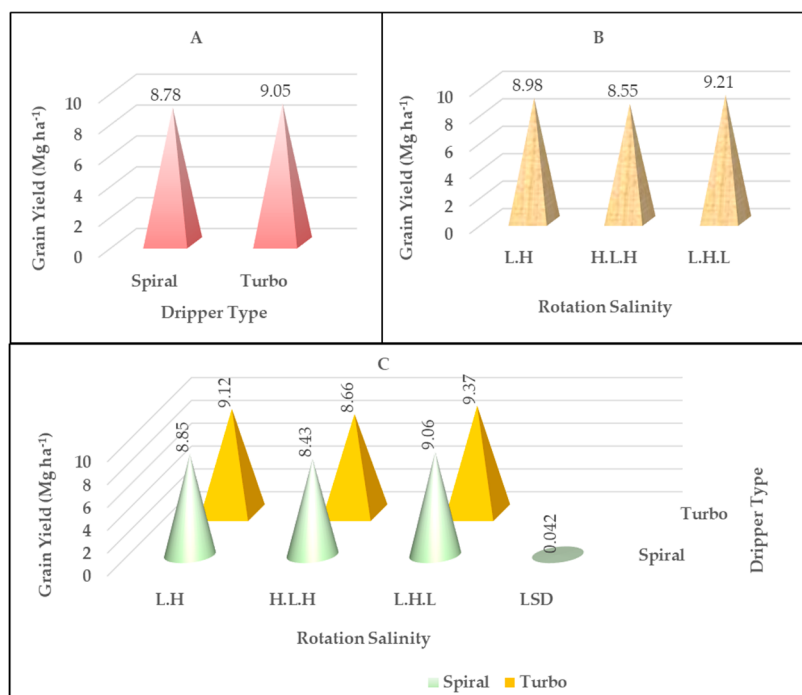


Figure 6. The effect of the type of dripper (A), the rotation salinity (B), and the interaction between them (C) on the values of grain yield in Mg ha⁻¹.

4. Discussion

4.1. Soil Bulk Density

The reason for the high values of bulk density for the H.L.H treatment due to the elevated levels of salinity in the soil, as well as the increased percentages of sodium exchanged and adsorbed on the exchange complex. This work deforms the soil aggregates and disperse their particles, leading to a negative result represented by the blockage of the pore spaces, a decrease in their percentage, and an increase in soil bulk density [21,22].

The decrease in the values of bulk density when using the turbo dripper due to an increase in the moisture content of the soil bed, which in turn increases the displacement of dispersed salts into the soil aggregates, encouraging the root system to spread [23]. Our results obtained from the effect of the type of dripper and the salinity rotation were consistent with the results by Yuan et al. [21].

4.2. Plant Height

The increased height of plants under the turbo dripper type may be attributed to the higher moisture content of the soil, which leads to the displacement of salts horizontally and vertically from the dripping source compared to the spiral dripper [24]. Increasing the height of plants in the L.H.L salinity rotation by interfering with the type of dripper (spiral and turbo) is to increase the efficiency of washing salts and improves the physical properties of the soil, which was reflected positively in the increase in vegetative growth, which is a response to the growth and spread of roots [25]. However, in the treatments in which the use of drainage water increased, it decreased. Plant height values are a result of the state of water stress to which the cultivated plant is exposed because of the increase in EC of irrigation water. Which results in unfavorable (negative) effects on the nutritional balance (mineral elements) and the vital processes that occur within the plant such as the process of photosynthesis (food making) and inhibiting the work of enzymes [26]. The results that reported by Hafez et al. [25] and Bouazzama et al. [26] was supported our results that plant height increased with turbo dripper and salinity rotation L.H.L treatment.

4.3. Plant Leaf Area

The reason for the increase in leaf area values may be due to the use of a rotation with low-salinity irrigation water. As a result, this led to improving the physical properties of the soil, such as increasing its aggregates, decreasing its bulk density, and increasing its porosity, as well as the density and spread of its roots, which was reflected in an increase in vegetation growth and leaf area values [27]. The superiority of the turbo dripper may be due to its increased discharge, leading to improved physical properties because of increased moisture content, and this is reflected in increased cell growth and division and then leaf area [28]. The use of a spiral dripper did not reduce soil salinity because of its decrease of discharge, which led to a decrease in leaf area due to high salt accumulation [29]. These results are consistent with what was found by Arbat et al. [29] who observed higher leaf area values for maize crops when irrigated with low-salinity water interspersed with drippers with good drainage efficiency.

4.4. Grain Yield

This increase in yield was proportional to the increase in vegetative growth, which was reflected in an increase in the size of the root system and its spread, and thus had a positive effect on increasing the crop yield [30]. Increasing yield may be due to the use of a salinity rotation in which the level of salinity decreases, which in turn improves the physical properties of the soil. All of this provides the appropriate environment for the plant to perform its physiological and biological activities and thus increases the efficiency of transporting water and nutrients from its source to the main and important part of the plant, the site where the grains gather [31]. The reason for the reduction in yield in the spiral dripper and high salinity irrigation water rotations because the decrease in soil moisture content and the increase in the accumulation of salt levels in the zone was very close to the drippers [14]. These results are consistent with what was found by Phullan et al. [31] and Awe et al. [14] that crop yields increase by performing appropriate irrigation according to water demands by using a quality dripper that resists clogging and can offer a reliable water discharge.

5. Conclusions

Iraq faced some challenges such as the water scarcity, and the world in general, and the problem of desertification, have negatively affected the environment and the climate of Iraq. Therefore, investigators in this field must find an optimal solutions and proposals, including making the use of wastewater and high-salinity well water present in southern Iraq without negatively affecting the properties of the soil and agricultural crops. Therefore, it was mentioned previously in this work, the rotation system utilizing fresh and drainage water for irrigation to equalize the use of freshwater by 50% in the rotation (L.H.) and performed better in terms of the physical character of the soil and the yield compared to the rotation L.H.L. This study showed that the possibility of employing high-salinity water (drainage water) as an available source in southern Iraq, which be mixed with the fresh water to irrigate the maize crop.

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