Study of Moisture and Salt Distribution in the Root Dustribution Zone of Wheat Irrigated with Main Outfall Drain (MOD) Water in the Northern Sector/Abu_Ghraib Area

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Abstract

A field experiment was carried out in the northern sector of the Main Outfall Drain (MOD) water, which is the first part of the (MOD) water, starting from the outfall of the Al-Ishaqi project in the north of Baghdad to Wasit Governorate. The study site was chosen in Abu Ghraib / 12 of Al-Fakhriyah District during fall 2022-2023. Experimental treatments included: The first treatment (I_1) is Irrigation with (MOD) water throughout the growing season (after depleting 50% of available water). The second treatment (I_2) is irrigation with the (MOD) water throughout the growing season + 20% leaching requirements, while the third treatment (I_3) is irrigation with (MOD) water throughout the growing season + 40% leaching requirements. The results showed that the volumetric moisture content at all stages of wheat growth and for all soil depths of 0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m was good, with a moisture content higher than the moisture at the permanent wilting point of 0.15 cm^3/cm^3, which means provides available water for the plant. The results also showed a decrease in electrical conductivity with depth and for all treatments, and it was reduced in the 20% and 40% leaching requirements. However, the distribution and accumulation of salts in the soil profile decreased with the increase in the ratio of the leaching requirements for irrigation water and the irrigation frequency for all treatments and depths.

Keywords: salty water, leaching requirements, salt distribution, moisture distribution, wheat

Introduction

The (MOD) water (Tigris and Euphrates) represents the central pillar of the drainage network in Iraq, as it serves a total area of approximately 6 million dunums of central and southern Iraq. It is an open waterway that begins from the Ishaqi irrigation project north of Baghdad, penetrating the lands of the alluvial plain between the two rivers. It ends in the Shatt al-Basra and from there to the Arabian Gulf, with a total length of approximately 565 km, and the surface width of the drainage ranges from 46 m at its beginning to 100 m at its end (Abdul Sattar and Ibrahim 2013). Evaluating the performance of irrigation systems requires monitoring the movement and distribution of moisture content in terms of place as vertical and horizontal distribution and time as moisture distribution after and before irrigation and during the period between them, as well as evaluating the movement and distribution of salts inside and outside the effective depth of the plant's root. This evaluation can contribute to improving irrigation scheduling and increasing WUE while at the same time monitoring salinity levels, their locations, and the potential for increased soil salinity levels resulting from irrigation succession. Monitoring moisture and salt distribution under irrigation systems and developing simulation models to describe this distribution help improve the performance of irrigation systems and increase water use efficiency. The distribution and accumulation of salts are according to a distribution pattern that simulates the movement and distribution of moisture content after irrigation and redistribution during the period between irrigations, depending on the irrigation system applied (Phogat *et al.*, 2013; Jabbar *et al.*, 2020; Ati *et al.*, 2020). Several researchers pointed out the difficulty of evaluating the distribution of salts clearly and consistently under irrigation systems due to continuous spatial and temporal change and the correlation of this distribution to the content and distribution of moisture in soil. They indicated that the distribution of salts is not homogeneous and has a continuous change in the horizontal and vertical direction, sometimes an increase and at other time a decrease and other continuous change with time. Changing moisture content increases after irrigation and decreases, due to water consumption and evaporation from the soil, in addition to the changes occurring in the redistribution of soil moisture and the subsequent change in the distribution of soil salts (Zhang *et al*., 2014; *Alwazzan and Ati, 2022; Alwazzan and Ati., 2024*). Hence, the idea of the study is to achieve the following goals: Study of the interaction effect of irrigation with (MOD) water on moisture and salt distribution with leaching requirements in the northern sector of the (MOD) water /Abu Ghraib area.

Materials and methods of work

conducted a field experiment in the northern area of the MOD, which extended from the mouth of the Ishaqi Project in the north of Baghdad to the Wasit Governorate. The length of this sector is 206 kilometers and it caters to agricultural projects covering an area of roughly 2,320,000 dunums. The research location was selected in Abu Ghraib/12 of Al-Fakhriyah District during the fall season of 2022-2023 (Figure 1). The research area has a predominantly level terrain, with a slope gradient of less than 2%. The soil composition of the field is defined as sedimentary, characterized by a silt loam texture. Soil samples were obtained from 10 places in the field, namely at depths of 0-0.20 m and 0.20-0.40 m, in order to assess the physical and chemical characteristics of the soil. We individually combined soil samples from each depth and obtained a representative sample. In the laboratory, we dried the soil samples by exposing them to air. Afterwards, we pulverized and filtered them using a sieve with a diameter of 2 mm. The samples were utilized to assess the physical and chemical characteristics of the soil in the field prior to planting, employing the techniques outlined in Black *et al.* (1965). Soil particle size distribution was measured using the pipette method. The bulk density of the soil was determined using the Core method. The relationship between the volumetric water content and the soil matric potential was determined by applying water tensions of 33 and 1500 kPa using pressure membrane. Some chemical properties of the soil were determined. The electrical conductivity (EC) and pH of the 1:1 soil extract were measured. Soil organic matter was determined using the potassium dichromate method, and carbonate minerals were determined

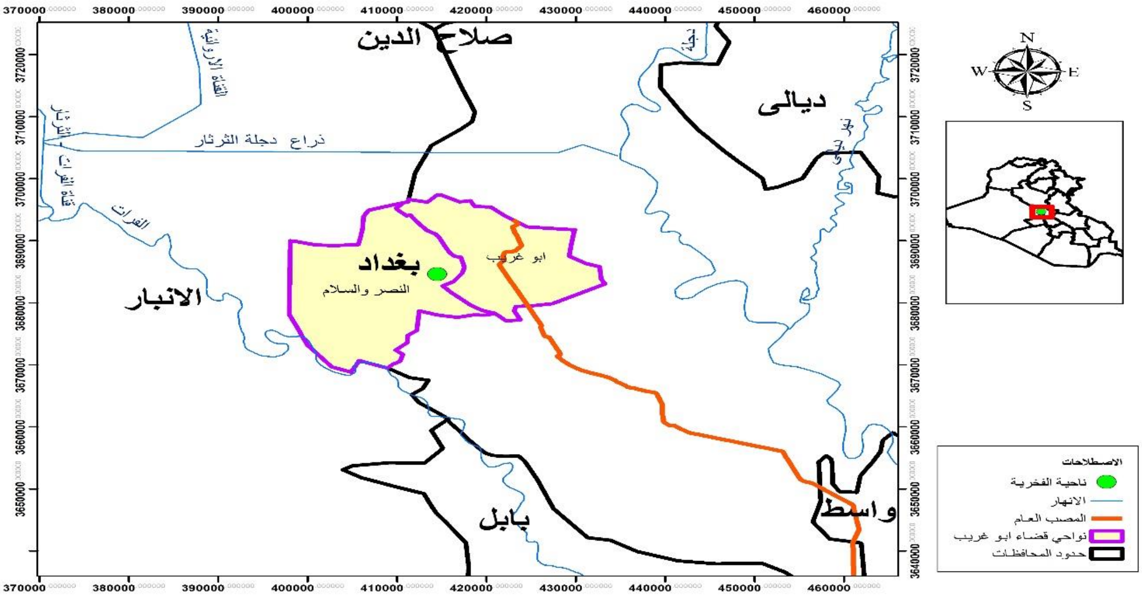

Figure 1. location of study area.

using a Calcimeter. Available soil nitrogen was extracted using 2 M potassium chloride solution, available soil phosphorus was extracted using 0.5 M sodium bicarbonate solution, and the color was developed using ammonium molybdate and ascorbic acid. Available soil potassium was extracted using 0.5 M calcium chloride and determined using a flame photometer.

Table 1 displays the physical and chemical characteristics of the soil in the field prior to planting. We analyzed the chemical properties of MOD water by collecting samples at various time intervals. The results of this analysis, classified according to the FAO's irrigation water categorization system (Phocaides, 2001), are presented in Table 2.

Experimental treatments and statistical design

1. Irrigation with (MOD)water throughout the growing season (after depleting 50% of the available water) (I_1)
2. Irrigation with (MOD) water throughout the growing season + 20% leaching requirement (I_2)
3. Irrigation with (MOD) water throughout the growing season + 40% leaching requirement (I_3)

The experiment employed a randomized complete block design (RCBD) with four repetitions. The experiment data was subjected to statistical analysis using the Genstat Discovery Edition 4 (2012) software. The arithmetic means of the treatments were compared using the least significant difference test at a significance threshold of 0.05, as described by Steel and Torrie (1960).

Table (1) Some physical and chemical characteristics of field soil before planting

Property	Units	Soil depth (m)	
		0 – 0.20	0.20 – 0.40
Sand	g kg^{-1}soil	332	244
Silt		541	520
Clay		127	236
Soil texture		Silt loam	Silt loam
Bulk soil density	µg m^{-3}	1.60	1.65
Porosity		0.40	0.38
Volumetric moisture content at 33 kPa	cm^3/cm^3	0.33	0.31
Volumetric moisture content at 1500 kPa		0.15	0.13
Electrical conductivity 1:EC 1	dS m^{-1}	4.30	3.60
pH		7.10	7.13
Available nitrogen	mg kg^{-1} soil	23.11	25.03
Available potassium		166	185
Available phosphorus		11.22	13.24
Organic matter	g kg^{-1} soil	7.2	4.71
Carbonate minerals		220	225

Table (2) Chemical characteristics of irrigation water

Property	Unit	Before planting	December	March	April
EC	dS m^{-1}	4.6	4.2	4.2	4.0
pH	---	7.40	7.21	7.2	7.22
TDS	ppm	3400	3120	3140	3050

Agricultural operations

The experiment was carried out on a land area of 2500 m^2, with dimensions of 65.7 m × 38 m. The land was plowed with a moldboard plow perpendicular to a depth of 0.25 m. The soil was harrowing with tandem disc harrows and preliminary and final leveled using a shovel. The area specified for the experiment was divided into three main blocks that included irrigation treatments, and each block was divided into four replicates. The area of one experimental unit was 45 m^2 (15 m length × 3 m width). A distance of 3 m was left between one block and another and 2 m between replicates to prevent irrigation and fertilization treatments from interacting with each other. Thus, the number of experimental units was 12 experimental units. Babylon 113 wheat variety was planted in the field on 20/11/2022, with a seeding rate of 160 kg ha^{-1}. The weed control process was carried out by spraying Pallas herbicide and manual weeding whenever necessary. The field was covered with nets at the stage of forming spikes to protect them from birds. The plants were harvested on May 1, 2023. The experimental land was fertilized with triple superphosphate fertilizer before planting, 200 kg ha^{-1}, while urea and potassium sulfate fertilizers were added in two batches: the first batch in the vegetative growth stage and the second in the flowering stage, at 200 kg ha^{-1} and 240 kg ha^{-1}, respectively. The micronutrients were sprayed in two stages: the first, the vegetative growth stage, and the second, the flowering stage, with a concentration of 60 ppm for each of zinc, iron, manganese, and 20 ppm copper per spray, noting that the spraying process takes place early in the morning. A diesel-powered pump was installed to draw water from the (MOD) directly using a spiral rubber tube with an inner diameter of 0.07 m. The pump pushes water through a linen tube with a diameter of 0.07 m and a length of 100 m. The process of evaluating the soil moisture content took place continuously throughout the experiment, and when the soil moisture content indicates that 50% of the available water has been depleted, irrigation is performed by adding the Depth of water necessary to reach the moisture content at the field capacity of the field soil using the moisture tension curve of the soil and for a period calculated based on drainage and the amount of water the plant needs per irrigation (m^3/hour). This applies to all field irrigation treatments. The equation mentioned in (Allen *et al*., 1998) was used to calculate the water depth that must be added to compensate for the depleted moisture.

$$d = \left(\theta_{fc} - \theta_w\right) \times D \quad \dots\dots \qquad (1)$$

Since:
d= depth of water added (mm)
θ_{fc} = Volumetric water content at field capacity (cm^3/cm^3)
θ_w = Volumetric water content before irrigation (cm^3/cm^3)
D = Soil depth, which is equal to the effective root depth (m)

Leaching requirements were calculated according to the equations in the Irrigation Water Quality Index (IWQI) issued by the FAO.

$$LR = \frac{EC_{iw}}{(5(EC_e) - EC_{iw})} \quad \dots\dots \qquad (2)$$

Since:
L.R. = Minimum Leaching requirements for salinity control expressed as a decimal
ECiw = Added irrigation water salinity dS m^{-1}
ECe = Soil salinity dS m^{-1}

The soil moisture content was estimated using the gravimetric method to monitor moisture changes. Soil samples were taken using an Auger, the process of sampling was as follows: A soil sample was taken 12, 24, 36, and 48 hours after each irrigation, at a fixed depth for each treatment of 0.10, 0.20, 0.30, and 0.40 m. A microwave oven was used to dry soil samples taken from the field in order to estimate the soil moisture content of the soil models. The oven was calibrated according to the method suggested by (Zein, 2002) and the Origin Lab program was used to plot moisture distribution data. These measurements were performed during three stages: end of elongation, 100% flowering, and physiological maturity. After completing the moisture determination, the samples were ground with a wooden hammer, passed through a 2 mm sieve, and the dry weight was recorded. Soil suspension was prepared by adding distilled water at a ratio of 1:1 (soil: water) for the purpose of measuring electrical conductivity. Thus, the moisture and salt distribution was evaluated at the same distances and depths as specified above.

Results and discussion

According to Figure 2, the irrigation treatment with MOD water resulted in a volumetric moisture distribution of 0.372, 0.353, 0.336, and 0.317 cm^3/cm^3 at 12, 24, 36, and 48 hours after irrigation, respectively. The measurements were taken at depths of 0.00-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 meters below the soil surface. These measurements were taken at the conclusion of the elongation stage after 12, 24, 36, and 48 hours, respectively. After 12 hours of irrigation, the moisture content reached its peak values of 0.372, 0.344, 0.294, and 0.265 cm^3/cm^3 at all depths, respectively. Subsequently, the values exhibited a progressive decline over time, ultimately reaching their minimum values 48 hours following the irrigation procedure. These values were recorded as 0.317, 0.277, 0.216, and 0.213 cm^3/cm^3 for the corresponding depths.

Fig. 3 shows that the amount of moisture in soil was highest at a depth of 0.0 to 0.10 m when measured over a period of 12, 24, 36, and 48 hours. The measured values were 0.389, 0.365, 0.342, and 0.323 cm^3/cm^3, respectively. This remark was correct at the last step of the elongation stage. Moreover, Figure 2 demonstrates that all depths reached their highest values within a 12-hour timeframe after the irrigation method. The results for the depths of 0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m were 0.389, 0.376, 0.311, and 0.296 cm^3/cm^3, respectively. Afterwards, the numbers showed a gradual decrease over time, eventually reaching their lowest point 48 hr. after the irrigation process. The depths at which these values were measured were 0.323, 0.289, 0.269, and 0.231 cm^3/cm^3, respectively.

Fig. 4 depicts the moisture volume distribution for the irrigation treatment with MOD water during the full growth season. Following the watering operation, the leaching needs experienced a 40% rise at 12, 24, 36, and 48 hr. Following the elongation stage, we assessed the moisture distribution at depths ranging from 0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m below the soil surface. The moisture content at depth of 0-0.10 m was the highest compared to other depths over the measurement periods of 12, 24, 36, and 48 hr., with values of 0.421, 0.397, 0.388, and 0.383 cm^3/cm^3, respectively. Following 12 hours of irrigation, we measured the moisture content as 0.421 cm3 for the depth range of 0-0.10 m, 0.398 cm3/cm3 for 0.10-0.20 m, 0.375 cm^3/cm^3 for 0.20-0.30 m, and 0.337 cm^3/cm^3 for 0.30-0.40 m. Following the irrigation technique, the readings gradually decreased over time and ultimately reached their lowest point 48 hours later. The depths at which these values were measured are 0.383, 0.331, 0.311 and 0.286 cm^3/cm^3, respectively.

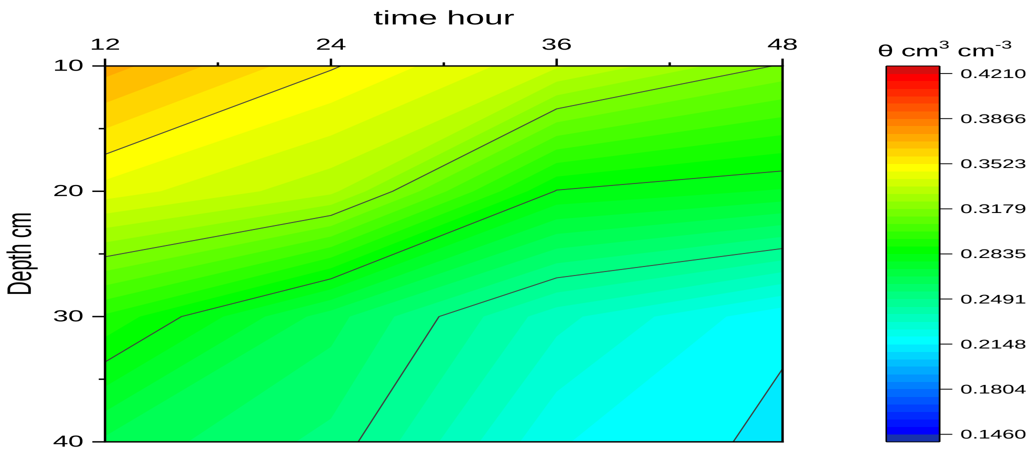

Figure (2). Volumetric moisture distribution (cm^3/cm^3) for the irrigation with (MOD) water at the end of the elongation stage

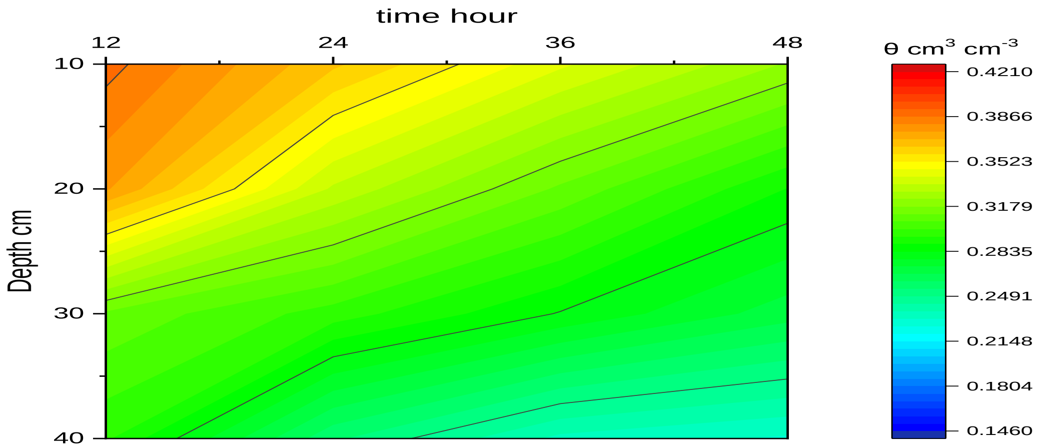

Figure (3) Volumetric moisture distribution (cm^3/cm^3) for the irrigation with (MOD) water + 20% leaching factor at the end of the elongation stage

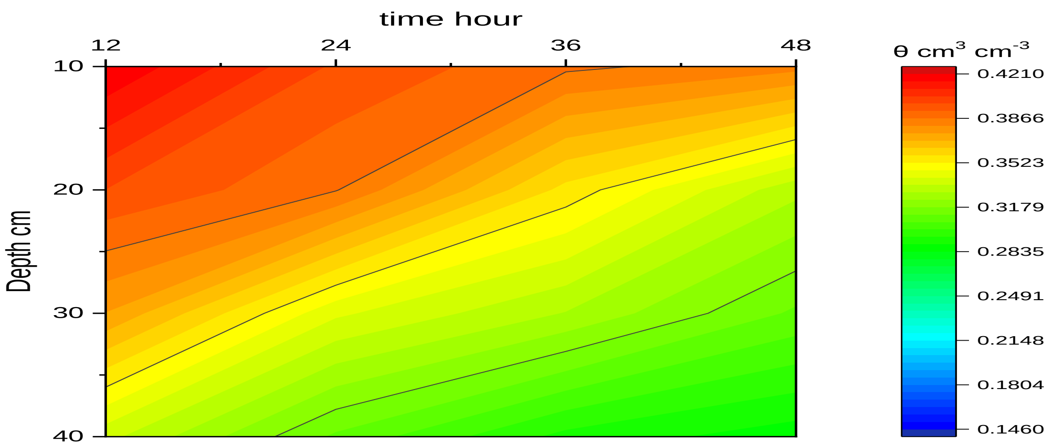

Figure (4) Volumetric moisture distribution (cm^3/cm^3) for the irrigation with (MOD) water + 40% leaching factor at the end of the elongation stage.

Figure 5 illustrates the spatial arrangement of moisture content in the irrigation treatment with MOD water during the growth season. After the 100% blossoming stage, the moisture level peaked 12 hours after watering. The moisture content values for depths of 0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m were 0.221, 0.216, 0.210, and 0.205 cm^3/cm^3, respectively. Afterwards, the levels gradually decreased over time and eventually reached their lowest point 48 hr. after the irrigation process. The depths were measured as 0.209, 0.167, 0.158, and 0.146 cm^3/cm^3, respectively. The soil moisture levels were higher at depths of 0-0.10 m compared to depths of 0.10-0.20 m, 0.20-0.30 m, and 0.30-0.40 m during time intervals of 12, 24, 36, and 48 hours. The volumetric moisture content measured at these depths was 0.221, 0.215, 0.216, and 0.209 cm^3/cm^3, respectively. MOD water irrigates the soil during the growing season, as seen in Figure 6. Additionally, it measures the volume of water that has to be flushed out after specific time intervals (12, 24, 36, and 48 hr.) of irrigation at depths varying from 0.010 to 0.30-0.40 meters below the surface. The highest moisture content was seen 12 hours after irrigation, with measurements of 0.325, 0.315, 0.292, and 0.228 cm^3/cm^3 at depths of 0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m, respectively. Afterwards, the results showed a gradual decrease over time, ultimately reaching their lowest values 48 hr. after the irrigation process. The recorded values for the same depths were 0.300, 0.263, 0.258, and 0.211 cm^3/cm^3, respectively.

Fig. 7 illustrates the distribution of moisture volume for the irrigation treatment utilizing MOD water during the full growing season. The leaching needs exhibit a 40% increase at 12, 24, 36, and 48 hours subsequent to watering. Upon reaching the final stage of 100% blooming, we assess the moisture distribution at certain depths ranging from 0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 meters below the soil surface. We quantified the θ at different depths. The water level at a depth of 0.10 m exceeded the levels at all other depths over the measurement periods of 12, 24, 36, and 48 hr. The corresponding volumes for these times were 0.398, 0.377, 0.371, and 0.366 respectively, respectively. After a 12-hour period of watering, we found that the highest levels of moisture content were seen at depths ranging from 0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m. The measurements for these depths were 0.398, 0.357, 0.317, and 0.289 cm^3/cm^3 respectively. Subsequently, numerical values exhibited a progressive decline over a period of time, ultimately reaching their minimum point 48 hours following the completion of the irrigation procedure. We measured the values at depths of 0.366, 0.318, 0.292, and 0.249, respectively.

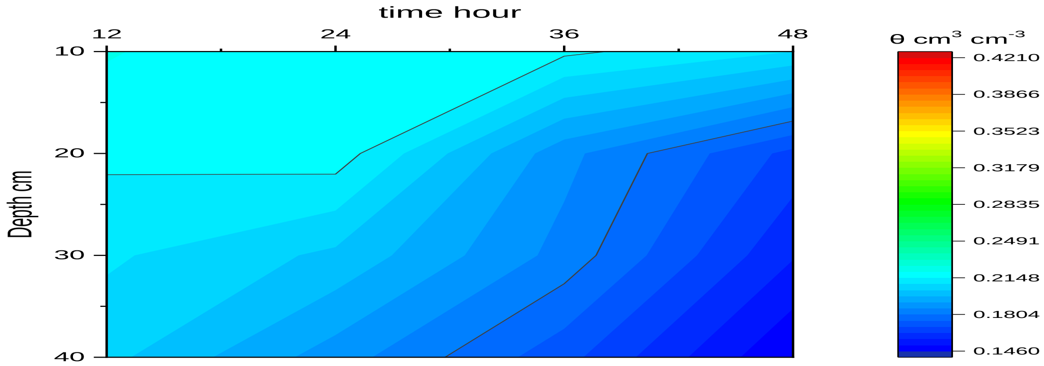

Figure (5) Volumetric moisture distribution (cm^3/cm^3) for the irrigation treatment with (MOD) water at the end of the 100% flowering stage

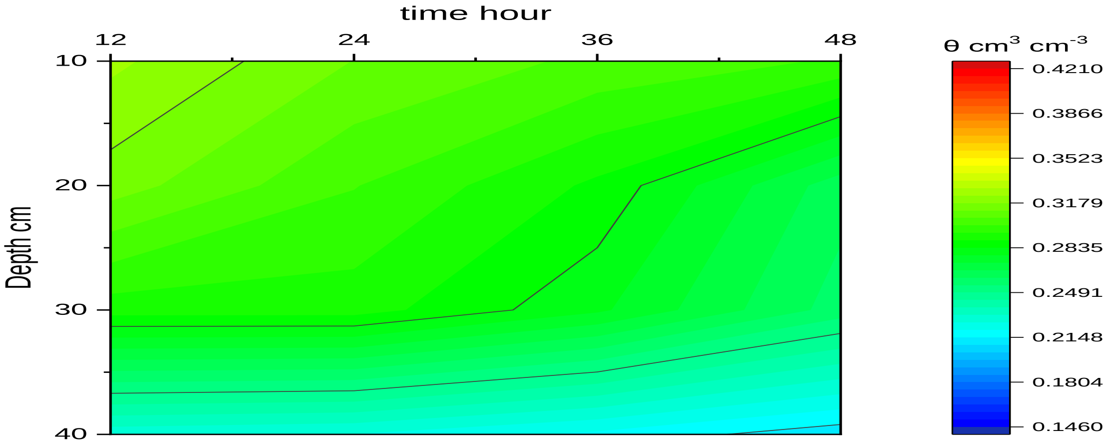

Figure (6) Volumetric moisture distribution (cm^3/cm^3) for the irrigation treatment with (MOD) water + 20% leaching factor at the end of the 100% flowering stage

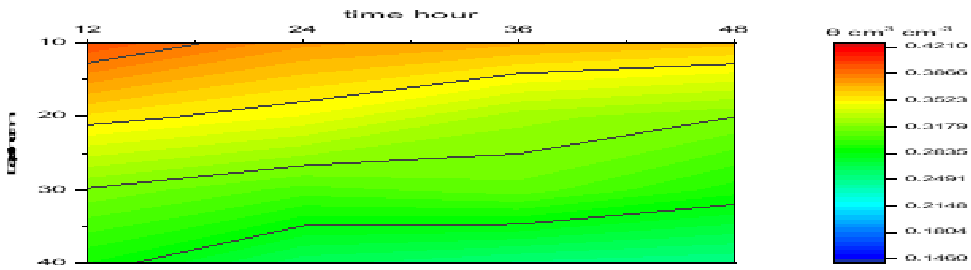

Figure (7) Volumetric moisture distribution (cm^3/cm^3) for the irrigation treatment with (MOD) water + 40% leaching factor at the end of the 100% flowering stage

Figure 8 displays the quantity of MOD water watered at 12, 24, 36, and 48 hr. following the irrigation operation. The depths examined were 0.00-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m beneath the surface of the soil at the last stage of physiological development. The maximum amount of moisture at a depth of 0-0.10 m was 0.271, 0.265, 0.256, and 0.245 respectively after 12, 24, 36, and 48 hours, respectively.

After 12 hours of irrigation, we noticed that the moisture content values for all depths achieved their maximum values: 0.271, 0.246, 0.230, and 0.225 cm^3/cm^3, respectively. Subsequently, the values exhibited a progressive decline over time, ultimately reaching their minimum values 48 hours following the irrigation procedure. These values were measured at 0.245, 0.221, 0.208, and 0.192 cm^3/cm^3 at corresponding depths, respectively. Fig. 9 demonstrates that the θ was greatest at a depth of 0.00-0.10 m when compared to all other depths examined at 12, 24, 36, and 48 hours. The moisture content reached values of 0.375, 0.356, 0.345, and 0.330 cm^3/cm^3 at these respective time intervals. During the last stage of physiological maturity, plants that were irrigated with MOD water throughout the growth season, along with an additional 20% leaching needs, displayed this pattern. Twelve hours following the irrigation procedure, measurements of 0.375, 0.365, 0.331, and 0.310 cm^3/cm^3 were recorded for the depths 0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m, respectively, as shown in Figure 7. Subsequently, the values exhibited a progressive decline over time, ultimately reaching their minimum values 48 hours following the irrigation procedure. The corresponding depths measured these values at 0.330, 0.311, 0.288, and 0.241 cm^3/cm^3, respectively. Figure 10 illustrates the amount of water administered during the cultivation period with MOD water, as well as the corresponding quantities of leaching after 12, 24, 36, and 48 hours. Upon reaching the stage of physiological development, we conducted measurements at depths of 0.010, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m below the soil's surface. At depths ranging from 0 to 0.10 m, the moisture content was higher than at any other depths for the measurement periods of 12, 24, 36, and 48 hours, with values of 0.401, 0.377, 0.379, and 0.376 cm^3/cm^3, respectively. After 12 hours of irrigation, we found that the moisture content values were highest at depths of 0-0.10, 0.10-0.20, 0.20-0.30 and 0.30-0.40 m, with values of 0.401, 0.377, 0.347, and 0.299 cm^3/cm^3, respectively. Subsequently, the values exhibited a progressive decline over time, ultima reaching their minimum values 48 hours following the irrigation procedure. The corresponding depths recorded these values as 0.376, 0.328, 0.299, and 0.259 cm^3/cm^3, respectively.

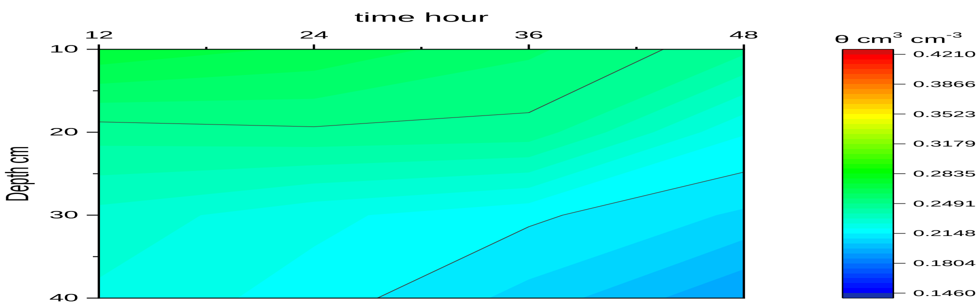

Figure (8) Volumetric moisture distribution (cm^3/cm^3) for the irrigation treatment with (MOD) water at the end of the physiological maturity stage

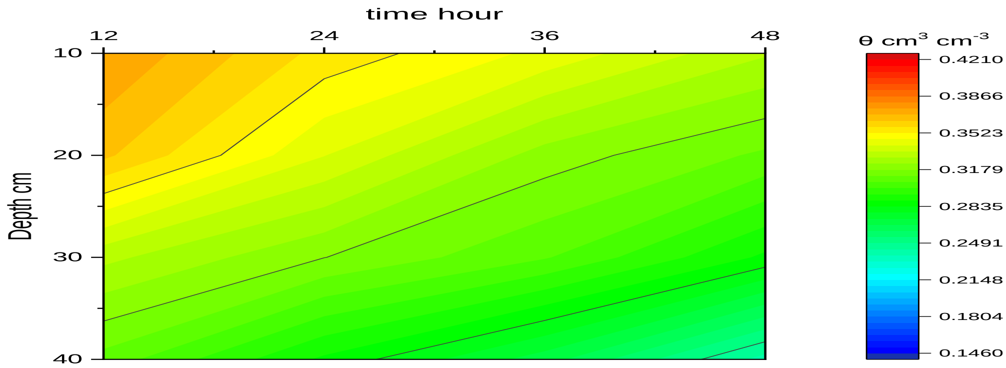

Figure (9) Volumetric moisture distribution (cm^3/cm^3) for the irrigation treatment with (MOD) water + 20% leaching factor at the end of the physiological maturity stage

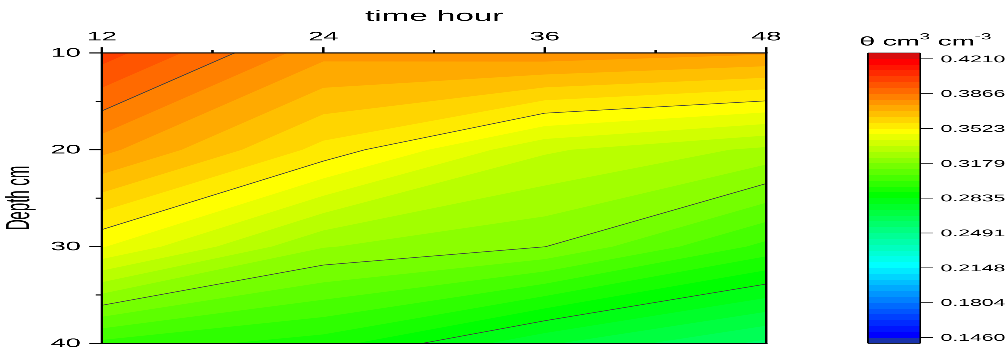

Figure (10) Volumetric moisture distribution (cm^3/cm^3) for the irrigation treatment with (MOD) water + 40% leaching factor at the end of the physiological maturity stage

The results obtained from Figures 2–10 demonstrate a consistent moisture distribution pattern, with the highest moisture content seen at depths ranging from 0 to 10.10 m. Moreover, as the depth grew, there was a discernible decline in moisture, leading to a reduction in θ across all treatments. The flow of water in unsaturated soil is mostly controlled by structural stress, which is affected by the amount of irrigation water supplied and the gravitational force that governs both vertical and horizontal movement. The homogeneity of the initial soil moisture content governs the quantity of water required, which is ascertained by the depth of the wheat's effective root during the earliest stages of germination irrigation. The irrigation treatments delivered a comparable amount of water, accounting for the leaching effect (Al Hasnawi *et al*., 2022; Razzak *et al*., 2018; Naji and Ati, 2019; Ati *et al*., 2020). After the elongation stage, which lasted for 32 days and received a rainfall depth of 122.10 mm, the moisture content in all treatments increased compared to their baseline values at beginning of growth season. Consequently, the volumetric moisture content values for all treatments increased, exceeding the field capacity of 0.33 cm^3/cm^3 (Table 1).

Moreover, the simultaneous occurrence of increased plant growth, greater soil surface coverage, and decreased temperatures and evaporation rates led to an increase in the volumetric moisture content. The results also revealed that θ values were decreased in comparison to those seen during midseason. The reduced influence of climatic conditions in the middle of the season improves the ability of the soil to hold rainwater. The study also noted an increase in volumetric moisture content levels towards, the end of the season compared to the beginning. The increase may be ascribed to many factors, including the accumulation of moisture in the soil profile due to the higher volume of irrigation water utilized during the season, as well as the proliferation of vegetation covering the soil surface. These characteristics result in decreased rates of evaporation and increased water content retention. Concurrently, the measurements surpassed the original moisture levels at the start of the season due to the significant development of the plant and its broad coverage of the soil. In contrast, the plant was originally of limited size and did not encompass a significant area. The enhanced plant surface area, exposed to sunshine, led to an escalation in evaporation from the soil surface. Consequently, the moisture level decreased compared to its value at the end of the season, as a result of rainfall happening in two separate time periods: during the growth and filling stage of the beans, which lasted for 25 days and had a rainfall rate of 48.40 mm, and during the physiological maturity stage, which lasted for 30 days and had a rainfall rate of 58.70 mm. In addition, the amount of moisture in the soil was higher than the permanent threshold of 0.15 cm^3/cm^3 at all stages of wheat growth and at all soil depths (0-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m). As a result, the plants had a plentiful water source. This suggests that the water is readily available for the plant. Furthermore, we observed a steady increase in the moisture content across all treatments between the middle and end of the growing season, as we methodically augmented the water quantity at the different stages of plant development. Beginning of the cultivation period, we provided water to the crops using a soil depth measurement of 0.20 m. Consequently, the soil depth expanded to 0.40 m, leading to an increased amount of water available during the middle and end of the growth season. The volumetric moisture content is influenced by the ratios of the leaching factors and the quantity of irrigation water supplied. End the growing season, it was evident that the volumetric moisture content had increased in the irrigation treatments that utilized regular downstream water with 20% and 40% leaching factors, in comparison to the treatments that exclusively employed MOD water.

Figures 11, 12, and 13 depict the impact of various irrigation techniques of MOD water on the salinity levels of the soil throughout three distinct phases of wheat growth: full flowering, the conclusion of the elongation stage, and physiological maturity. The findings indicate that the salts disperse and accumulate in a manner that closely mimics the movement and distribution of water after irrigation, as well as the fluctuations that occur during the period between irrigations and depending on the irrigation techniques employed (Zhang *et al*., 2014; Ati *et al*., 2014; Ati *et al.*, 2017). The findings also showed a decrease in electrical conductivity as the depth increased in all treatments, with the 20% and 40% leaching treatments displaying somewhat lower values. During the cultivation period, we administered a total of 206, 237, and 268 mm of water to the irrigation treatments utilizing MOD water. In the, second treatment, we added a 20% leaching factor to the water, while the third treatment, we added a 40% leaching factor to the water. The lesser deposition of salts throughout the growth season can be attributed to the irrigation treatment with MOD water. The electrical conductivity values demonstrate a rise at depths of 10 and 20 cm in all treatments. The increase in electrical conductivity values is caused by intensified evaporation from the soil surface and the accumulation of salts. The water conductivity values for all treatments and development phases declined as a result of rainfall, in comparison to the soil electrical conductivity values before the agricultural season. In the Abu _ Ghraib region, the rainfall during the 2022-2023 agricultural season was 254 mm. When using MOD water for irrigation during the crop's physiological maturity stage, the electrical conductivity values at depths of 0.00-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m from the soil surface were measured to be 4.00, 4.27, 3.52, and 3.21 $dS.m^{-1}$, respectively. The electrical conductivity levels were measured at different depths below the soil's surface: 0.00-0.10, 0.10-0.20, 0.20-0.30, and 0.30-0.40 m. The measurements were taken at 2.73, 2.74, 2.77, and 1.92 $dS\ m^{-1}$, respectively. These measurements were obtained during the crop's final growth stage at physiological maturity, using MOD water and a 20% leaching factor for irrigation.

 Volume 2024

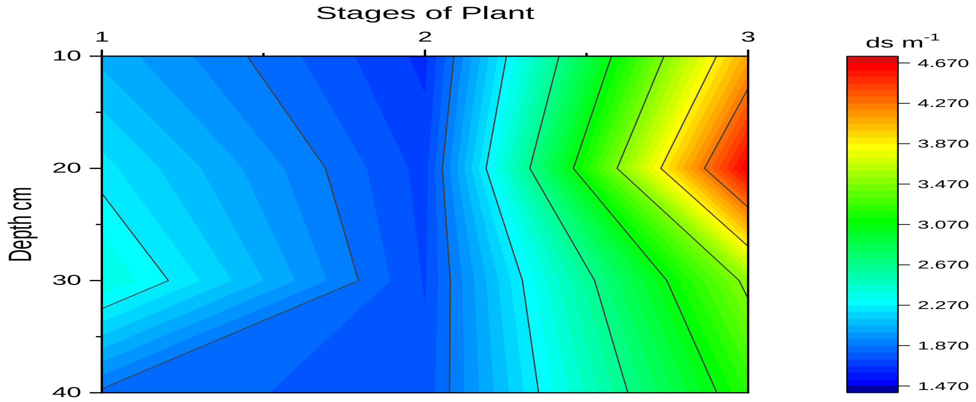

Figure (11) Salt distribution (dS m^{-1}) for irrigation treatment with (MOD) water during wheat crop growth periods

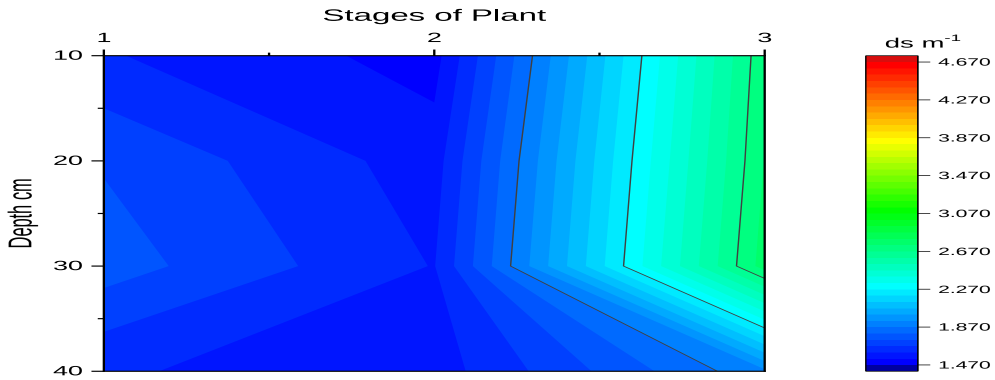

Figure (12) Salt distribution (dS m^{-1}) for irrigation treatment with (MOD) water +20% leaching factor during wheat crop growth periods

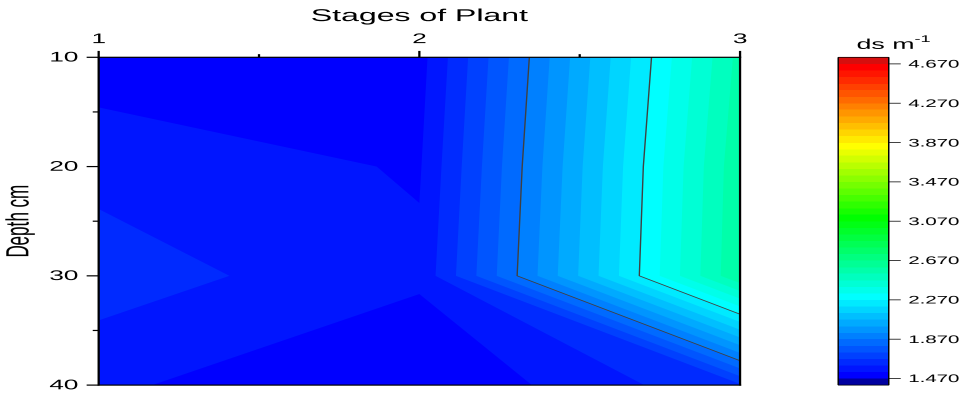

Figure (13) Salt distribution (dS m^{-1}) for irrigation with (MOD) water +40% leaching factor during wheat crop growth periods

The electrical conductivity levels were 2.56 dS m^{-1} at a depth of 0.010 m, 0.10-0.20 m, 0.20-0.30 m, and 0.30-0.40 m below the soil's surface, in that order, at the end of the physiological maturity stage and when the crop was irrigated with MOD water plus a 40% leaching factor. The results also show that the distribution and accumulation of salts in the soil profile decrease with an increase in the leaching factor of the irrigation water and frequency of irrigation for all treatments and depths. The decrease in the distribution and accumulation of salts in the soil profile with an increase in the leaching factor of the irrigation water and frequency of irrigation for all treatments and depths can be attributed to the depth of the irrigation water added to the irrigation treatment with MOD water without the leaching factor, as well as the increase in the calculated depth resulting from the increased effective root depth of the wheat crop by 0.40 m. Thus, the amount of accumulated salt decreased with the increase in amount of water added compared to the beginning of the season. The reason is due to the depth of rainfall in the agricultural season 2022-2023 (254 mm). This means displacing salts from the top towards the lower depths. The displacement of salts outside the borders of the root zone may be due to rain in quantities sufficient to wash away the salts, in addition to increasing the amount of water added as the growing season progresses. Conducting electrical conductivity measurements made it clear that the seasonal rainfall exposed the experimental field to a sufficient amount of water to affect the distribution and redistribution of salts in soil profile. Although salts may have been displaced to depths beyond 40 cm, the experimental investigation was limited to the effective root depth of wheat, which is 40 cm.

Conclusions and recommendations

The importance of the study application came based on the cooperation mechanism concluded between the National Center for Water Resources Management/Ministry of Water Resources and the College of Agricultural Engineering Sciences/University of Baghdad.

We can be recommended to adopt irrigation with salt water, including (MOD) water, in years in which rainfall is expected to reach half the water requirement of the wheat crop, which is capable of leaching salts out of the effective root of wheat. Taking into account the correct irrigation scheduling and the use of a washing requirement of no less than 20% in areas that suffer from a scarcity of fresh water, especially in arid and semi-arid areas, as well as giving heavy irrigation at the end of the growing season that is sufficient to leaching salts from root zone and transfer them to the drainage (In the current study, the depth of rainfall was sufficient to solve this problem, as the average rainfall during the stages of seed growth, filling, and physiological maturity was 117.10 mm).

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