



The Effect of Saline Water Irrigation and Mineral Fertilization in Moisture, Salt and Thermal Distribution in The Soil

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Abstract

This research was conducted as a field experiment in Muhammadliyah District, Baghdad Governorate, during the spring of 2024. The primary objective of this work is to study the effect of saline water and mineral fertilization on moisture, salt, and temperature distributions in soils. Three irrigation systems namely freshwater irrigation, alternate irrigation with fresh and saline water, and saline water irrigation only besides two types of mineral fertilization were applied. Soil moisture content, EC, and soil temperature were measured at different depths throughout the growing season using GS3 sensors. Findings indicated that saline water irrigation improved soil moisture content based on effective accumulation due to salts. Electrical conductivity recorded the highest values under the saline irrigation treatment, to the detriment of both plant growth and potato yield. Higher mineral fertilization generally bettered plant height and increased Lagging up productivity with the highest yield coming in the treatment of freshwater irrigation and high fertilization.

Keywords:

Moisture, saline water, mineral fertilization, thermal distribution.

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Introduction

Rapid population growth has increased the need for enhanced agricultural production (Chen et al., 2015). The water requirement for producing food is higher in rainfed agriculture in dry and semiarid regions, which typically consumes more than 90% of irrigation water (Laouamer et al., 2020). The major constraint to sustainable agricultural development in arid regions is the availability of freshwater resources (Ma et al., 2019; Khamees et al., 2023). Saline water irrigation has been rapidly increasing in significance to help solve freshwater scarcity in the region (Xiaowen et al., 2023; Ati & Dawod, 2024; Dawod et al., 2024). On-the-ground and at-regional levels agricultural soil monitoring is essential in implementing soil and water management practices aimed at keeping salt away from the root zone such that its impact on plant growth and thus productivity is reduced (Jayapriya, 2021; Black, 1965). Agricultural soils remain in an unstable condition and change in salinity hazard (Ati et al., 2020; Tedeschi et al., 2023; Ati et al., 2025).

The study of water consumption in Iraq, which is characterized either as an arid or semi-arid region, acquires a more important approach to it because irrigation becomes one of the critical ways to use water since rainfalls are so insufficient in such regions, plus water scarcity that negatively impacts the quantity of water resources needed to satisfy crop requirements (Nandy & Dubey, 2024). Water exploitation therefore calls for effective and optimum use of available water, and the first and pivotal step in planning for the best management of available water is estimating the water needs of different crops (Sredić, et al., 2024). Workable irrigation technologies and management practices have attracted the attention of researchers, due to freshwater scarcity and its availability (Mehmdy et al., 2020). Finally, every drop of water is crucial for optimized and sustainable use, leaving no room for error when it comes to the irrigation of crops) (Nasr & Wahib, 2024; Nasr & Ati, 2023). A major most modern irrigation technology to increase irrigation effectiveness and reduce water waste is drip irrigation, which delivers water without any wastage by applying and monitoring it very precisely to the root area (Kacar et al., 2009; Al-Lami et al., 2023 a,b). Potatoes come in as the fourth major food crop-area in the world, with a coverage of 18.13 million hectares and production of 353.53 million tons in 2021 (FAO), after rice, wheat, and maize. The increase in the frequency of drought stress has occurred with yearly warming of the atmosphere (Adesina & Thomas 2020), seriously compromising global potential for potato production and food security (Su & Wang 2019). The location of an experiment was used to study the distribution of moisture, salt, and soil temperature, as well as potato yield, in case of irrigation with fresh and saline waters and their alternation (Majdanishabestari & Soleimani, 2019; Guo et al., 2023).

Material and Methods

The field experiment was carried out in Baghdad Governorate / Mahmoudiya District - Yusufiya City during the spring season of the year 2024. Soil samples were taken from a planted soil at a 0-0.30 m depth. The soil samples were air-dried, then ground and sieved through a 2 mm sieve. Some properties of the soil include soil texture which was silt loam with electrical conductivity equals 1.85 dS m⁻¹, the pH value being 7.23, volumetric moisture content at field capacity and at permanent wilting point being 0.32 and 0.154 cm³cm⁻³ respectively, organic matter, and carbonate mineral content being 238 and 11.34 g kg⁻¹, respectively, soil (Veera Jeyendra Prakash & Manivel Muralidaran, 2016).

Experiment Design

A. Irrigation water quality

- Irrigation with fresh river water during the growing season (EC =1-1.2 dSm⁻¹) (I₁).

- Irrigation with salt water 2 times ($EC = 3-4 \text{ dSm}^{-1}$) + irrigation with fresh river water 1 time ($EC = 1-1.2 \text{ dSm}^{-1}$) during the growing season (I_2).
- Irrigation with saline water ($EC = 3-4 \text{ dSm}^{-1}$) during the growing season (I_3).

B. Mineral fertilization

- When planting, the fertilizer prescription recommends applying 100 kg (P) ha⁻¹ and urea fertilizer, which contains 46% nitrogen (N), three times, the fertilizer guideline recommends applying 300 kg N ha⁻¹ three times. Apply the first application after 20 days of planting, the second 30 days after the first application, and the third 25 days after the second application. recommends administering K₂SO₄ on three occasions. (Ali, 2012) (F1).
- Apply 150 kg of P ha⁻¹ and 400 kg of N (urea) fertilizer three times: 20 days after planting, 30 days after the first application, and 25 days after the second application. In addition, administer potassium sulfate fertilizer k₂SO₄ three times (F2).

We conducted the experiment using (RCBD) with three replications, following the split block design. To compare the means of the different treatments, we utilized the LSD at a significance at the level ($P > 0.05$). Potato tubers (Riviera) grade E was planted on 20/January/2024 after using minimum tillage using the Disk Harrow machine. Determine the amount and periods irrigation depended on sensors reading of volumetric water content was measured using GS3 sensors at 35% depletion of available water. The GS3 (Figure 1) represents the third generation of sensors, which is more complex, accurate and easy to use, and can measure three temperature characteristics: soil temperature, salinity and soil moisture.

General specifications of the sensor GS3.

1. Measurement of volumetric water content: The sensor's measurement range is from 0.0 cm³/cm³ in air to 0.80 cm³/cm³ in water. The sensor's accuracy is $\pm 0.15\%$, depending on soil mineral composition.
2. Measurement of electrical conductivity (salinity): The sensor's accuracy is $\pm 0.10\%$. If the soil salinity exceeds 10 dS/m, calibration of the sensor readings is required.
3. Measurement of soil temperature: The sensor's measurement range is from -40°C to 60°C , with an accuracy of $\pm 1.0^{\circ}\text{C}$.



Figure 1. GS3 sensor

Irrigation water was applied when 35% of the available soil moisture in the active root zone was depleted, up to the field capacity. Soil moisture and electrical conductivity were continuously monitored using sensors,

allowing for the tracking of salinity changes in the soil profile at depths of 0.15 m and 0.30 m at four-hour intervals throughout the growing season. The final readings of soil electrical conductivity were determined based on temperature variations during the agricultural season, utilizing multiple comparison equations. Following the completion of the germination phase, the irrigation schedule was implemented according to the experimental treatments, commencing on Feb. 20, 2024, and continuing until Apr. 30, 2024. An operating pressure of 50 kPa was maintained, resulting in the highest uniformity coefficient of 94.21%, the highest irrigation application efficiency of 92.34%, and the highest distribution uniformity of 91.74%, with the lowest variation ratio of 16.57%. To calculate the depth of water used, the following equation was applied:

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

d : depth of added water (mm)

θ_{fc} : volumetric moisture content at field capacity ($\text{cm}^3\text{cm}^{-3}$)

θ_w : volumetric moisture content before irrigation ($\text{cm}^3\text{cm}^{-3}$)

D : effective root zone depth (mm)

Estimation Of Electrical Conductivity

Hence, the reference is made on the electrical conductivity (EC) of soil solution, which is directly proportional to the concentration of salts dissolved in the soil. It is generally measured directly by the sensors GS3, which are used to measure a Pore water conductivity. The linear relationship between electrical conductivity and the dielectric constant of the sensors surrounding the soil and salinity of soil pore water was proved in the study by Hilhorst (2000). The indicator of interest has been taken to be the electrical conductivity of soil solution ($\sigma\rho$). Besides, this indicator can be checked directly relatively quickly after extraction, which was another time-saving alternative. Many studies have been carried out to ascertain the relations between $p\sigma$ and $b\sigma$. Hilhorst (2000) identified a linear relationship between the electrical conductivity of the dielectric permittivity of the soil surrounding the sensors (σb) and the electrical conductivity of the soil pore water ($\sigma\rho$) when using sensors placed in the soil, specifically GS3 sensors, at a fixed time interval within a defined soil volume (Decagon Devices, 2014). The electrical conductivity of the pore water is calculated using the following equations:

$$\sigma\rho = \frac{\varepsilon\rho \sigma b}{\varepsilon b - \varepsilon\sigma b = 0} \quad (2)$$

$\sigma\rho$: Electrical conductivity of pore water (dS m^{-1}).

$\varepsilon\rho$: Real part of the permittivity of the soil pore water, representing the electrical conductivity of the soil, which depends on soil temperature. It can be calculated using Equation (3).

σb : Total (or maximum) electrical conductivity, based on GS3 sensor readings, representing the combined electrical conductivity of soil, air, and water (dS m^{-1}).

εb : Real part of the soil's dielectric permittivity, representing the real component of maximum electrical conductivity, dependent on soil volumetric water content. It can be calculated using Equation (4).

$\varepsilon\sigma b = 0$: Real part of soil dielectric permittivity when the total electrical conductivity $\sigma b = 0$ (representing the full effective polarization of sensors in dry soil).

The value of ε_p , which depends on soil temperature, is calculated using the equation:

$$\varepsilon_p = 80.3 - 0.37 * (T_{\text{soil}} - 20) \quad (3)$$

T_{soil} represents the soil temperature measured by GS3 sensors (°C).

The value of ε_b , which depends on the volumetric water content of the soil, is calculated using:

$$\varepsilon_b = \frac{\varepsilon_{\text{Raw}}}{50} \quad (4)$$

ε_{Raw} : The unprocessed volumetric water content reading from the sensors (m^3/m^3)

In dry soil, $b = 0$, meaning its dielectric permittivity is zero.

The value of $\sigma \varepsilon_b$ is 4.1 for agricultural and organic soils.

For inorganic soils and other growing media, $b = 0$ is set to 6 to ensure more accurate soil EC readings (Hilhorst, 2000).

The electrical conductivity of the soil solution represents the electrical conductivity reading of the saturated soil paste extract. Therefore, the EC of pore water must be linked to bulk density to determine the soil solution EC within a specific volume, using the following equation:

$$\Phi = f = 1 - \frac{Pb}{PS} \quad (5)$$

Φ : Soil porosity (cm^3/cm^3)

Pb : Bulk soil density (Mg/m^3)

PS : Particle density (Mg/m^3), typically a constant value of (2.65)

The final electrical conductivity of the soil solution can then be determined using the following equation:

$$\text{Solution EC} = \frac{\sigma_p \theta + \sigma_d (\Phi - 0)}{\Phi} \quad (6)$$

σ_e Solution EC: The electrical conductivity of the saturated soil pastes extract (σ_e or EC_e) in dS/m^{-1} .

σ_p : The electrical conductivity of pore water in dS m^{-1} .

θ : The volumetric water content of the soil in $\text{m}^3 \text{m}^{-3}$.

σ_d : The electrical conductivity of distilled water, which is zero (dS m^{-1}).

Φ : Soil porosity.

The electrical conductivity was determined using the saturated paste method, soil extract, and 1:1 soil-to-water ratio with an EC-Meter (Ino Lab WTW). Calibration was performed between these methods, using the following equation:

$$Y = 0.3608 X - 0.6094 \quad (R^2 = 0.957)$$

Where:

X = E_{Ce} of the saturated paste extract

Y = EC of the 1:1 soil-to-water slurry

Calibration was also conducted between the 1:1 soil extract EC values and the readings of GS3 sensors placed in the soil throughout the growing season. According to Hilhorst (2000), EC readings were taken every four hours throughout the crop growth period, and the final soil EC reading was determined based on temperature variations during the growing season.

Calculation of Dissolved and Accumulated Salts in Soil. The amount of dissolved and accumulated salts in the soil due to irrigation was calculated following the methods of Richards (1954) and Phocaides (2001)

$$\text{TDS (mg L}^{-1}\text{)} = \text{EC (dSm}^{-1}\text{)} \times 640 \quad (7)$$

At the end of the experiment, we are measuring growth characteristics included plant height in centimeters, and yield of potato tubers ($\mu\text{g ha}^{-1}$).

Result and Discussion

The results are shown in table 1. There is a variation in the volumetric moisture content for the irrigation treatments I1, I2, and I3. The highest average volumetric moisture content during the season was recorded for irrigation treatment I3, and it was $0.324 \text{ cm}^3\text{cm}^{-3}$. It was closely followed by irrigation treatment I2 at $0.291 \text{ cm}^3\text{cm}^{-3}$. The lowest average volumetric moisture content was observed for irrigation treatment I1, and it was $0.228 \text{ cm}^3\text{cm}^{-3}$. The reason for the higher moisture content in soils irrigated with saline water compared to river water or alternating ways of irrigation is that saline water creates the process of salt accumulation in the irrigated soil after the irrigation water has evaporated; the effect becomes more noticeable as the salt concentration in the irrigation water is increased. Thus, the moisture content measurement before irrigation would also be high because the salts that are accumulated in the soil have a water-retaining characteristic, in that it would retain more water, i.e., influence the amount of water to be applied through irrigation (Ati et al., 2020; Abdulrazzaq et al., 2018).

Table 1. The moisture content for Potato with different irrigation treatments on depth 0.15 m

	Port1– m^3/m^3 VWC I ₁ V ₁ : GS3	Port2– m^3/m^3 VWC I ₂ V ₁ : GS3	Port3– m^3/m^3 VWC I ₃ V ₁ : GS3
Avg.	0.228	0.291	0.324
Min.	0.192	0.186	0.281
Max.	0.330	0.359	0.363

The highest average volumetric moisture content at a depth of 0.30 m was recorded for irrigation treatment I₃, reaching $0.337 \text{ cm}^3\text{cm}^{-3}$, followed by irrigation treatment I₂ at $0.276 \text{ cm}^3\text{cm}^{-3}$. The lowest average was observed for irrigation treatment I₁, which reached $0.229 \text{ cm}^3\text{cm}^{-3}$ (Table 2). The reason for this is attributed to the presence and accumulation of salt due to the use of saline irrigation water, which led to water retention in the soil and resulted in high values of soil moisture content when evaluated using the GS3 sensor. This, in turn, reduced the amount of water added to the irrigation treatment I₃. Furthermore, the presence of salt in the soil caused difficulty in water absorption by the plants. This was followed by the alternating irrigation

treatment (I_2), with a lower moisture content than the saline water irrigation treatment and a higher moisture content than the freshwater irrigation treatment (I_1). The reason for this is that the addition of saline water irrigation followed by a freshwater irrigation resulted in the leaching of salts and reduced salt accumulation within the alternating irrigation treatment. As for the moisture distribution within the freshwater irrigation treatment I_1 , it was natural and organize because the moisture in this treatment was nearby to the field capacity (Razzak et al., 2018; Nasr & Ati, 2023).

Table 2. The moisture content for Potato with different irrigation treatments on depths 0.30 m

	Port1- m^3/m^3 VWC $I_1 V_2$: GS3	Port2- m^3/m^3 VWC $I_2 V_2$: GS3	Port3- m^3/m^3 VWC $I_3 V_2$: GS3
Avg.	0.229	0.276	0.337
Min.	0.207	0.221	0.266
Max.	0.361	0.362	0.391

Table 3 presents that the salinity distribution in the soil profile during the potato growing season for a depth of 0.15 meters. The salt distribution based on EC Solution sensor readings varied across the three irrigation treatments I_1 , I_2 and I_3 . The highest average electrical conductivity recorded by the sensors during the growing season was observed under the I_3 irrigation treatment, which averaged 2.857 dSm^{-1} throughout the growing season, followed by the I_2 irrigation treatment, which averaged 2.322 dSm^{-1} . The lowest total electrical conductivity was recorded under the I_1 irrigation treatment, with an average of 0.910 dSm^{-1} throughout the growing season.

Table 3. The electrical conductivity for Potato with different irrigation treatments at a depth of 0.15 m

	Port1- Ms/cm EC $I_1 V_1$: GS3	Port2- Ms/cm EC $I_2 V_1$: GS3	Port3- Ms/cm EC $I_3 V_1$: GS3
Avg.	0.910	2.322	2.857
Min.	0.419	1.153	1.953
Max.	1.127	3.810	3.972

For a depth of 0.30 meters (as shown in Table 4), the highest total electrical conductivity of the sensors was 3.991 dSm^{-1} for the irrigation treatment I_3 , followed by the irrigation treatment I_2 with a value of 3.841 dSm^{-1} . The lowest total electrical conductivity of the sensors was 2.180 dSm^{-1} for the irrigation treatment I_1 throughout the growing season.

Table 4. The electrical conductivity for Potato with different irrigation treatments on depth 0.30 m

	Port1- Ms/cm EC $I_1 V_2$: GS3	Port2- Ms/cm EC $I_2 V_2$: GS3	Port3- Ms/cm EC $I_3 V_2$: GS3
Avg.	2.183	3.841	3.991
Min.	2.530	3.126	3.370
Max.	3.991	4.135	4.341

The thermal distribution in the topsoil as observed in Table 5, the thermal distribution in the topsoil during the growing season of the potato crop for a depth of 0.15 meters, based on the sensor readings, varied for the different irrigation treatments I_1 , I_2 and I_3 . The highest average for soil temperature was observed in the irrigation treatment I_3 . the highest soil temperature reached 22.4°C in the irrigation treatment I_3 , followed by

the irrigation treatment I_2 with a value of 21.4°C. The lowest temperature was recorded in the irrigation treatment using freshwater river (I_1), which was 21.2°C throughout the growing season.

Table 5. The thermal distribution for Potato with different irrigation treatments at a depth of 0.15 m

	Port1 -°C Temp I_1 V ₁ : GS3	Port2 -°C Temp I_2 V ₁ : GS3	Port3 -°C Temp I_3 V ₁ : GS3
Avg.	21.2	21.4	22.4
Min.	16.5	18.3	19.0
Max.	27.8	29.5	29.8

For a depth of 0.30 meters (as shown in Table 6), the highest soil temperature was observed in the irrigation treatment I_3 , reaching 23.6°C, followed by the irrigation treatment I_2 with a value of 22.7°C. The lowest soil temperature was recorded in the irrigation treatment I_1 , with a value of 20.8°C throughout the growing season (Al-Mehmdy et al., 2020).

Table 6. The thermal distribution for Potato with different irrigation treatments at depth 0.30 m

	Port1 - °C Temp I_1 V ₂ : GS3	Port2 - °C Temp I_2 V ₂ : GS3	Port3 - °C Temp I_3 V ₂ : GS3
Avg.	20.8	22.7	23.6
Min.	18.3	19.7	20.1
Max.	26.1	27.5	27.7

The results are shown in table 7, the average height in cm for irrigation water quality treatments I_1 , I_2 , and I_3 . That there is a significant effect for treatment I_1 compared to treatments I_2 and I_3 . Water quality had a highly significant effect on the plant's height due to water salinity. Treatment I_1 showed the highest average height of 76.43 cm, and the lowest height of I_3 treatment 53.33 cm that's mean the plant's response to saline stress because of the osmotic effect on the plant's high (Allen et al., 1998). The results also show the significant role of mineral fertilization in increasing plant height, the average highest plant height of 75.04 cm (F_2) compared to the (F_1) 59.70 cm. The treatment that giving the highest yield potato is I_1 of 41 $\mu\text{g ha}^{-1}$ and the lowest yield potato is 30 $\mu\text{g ha}^{-1}$ for I_3 treatment and the result showed that the F_2 treatment of mineral fertilization giving the highest yield potato for I_1 treatment which reached 42 $\mu\text{g ha}^{-1}$.

Table 7. Effect of mineral fertilization and water quality on the plant height (cm) and tubers yield ($\mu\text{g ha}^{-1}$) under drip irrigation system.

Water Quality EC (dSm-1)	Plant height (cm plant-1)			Yield of potato tubers ($\mu\text{g ha}^{-1}$)		
	Mineral fertilization			Mineral fertilization		
	F1	F2	Mean	F1	F2	Mean
I_1	65.01	87.85	76.43	39	42	41
I_2	63.67	81.05	72.36	37	40	39
I_3	50.43	56.23	53.33	28	31	30
Mean	59.70	75.04		35	38	

LSD 0.05 EC=2.1, MF=2.8, EC×MF=3.32 EC= 2.9, MF=3.1, EC×MF=4.2

For sustainable agricultural practices and long-term prosperity, it is vital to maintain a healthy balance of NPK components (Alalaf et al., 2023; Yassin et al., 2023). Potassium increases the growth of tubers. In addition to promoting the overall health of plants, potassium is critical for regulating water absorption. Plants

may experience wilting and inadequate nutrient uptake if the soil contains insufficient potassium, which can impede their capacity to assimilate water efficiently (Al-Falahi, et al. 2022). Agricultural productivity and crop quality may ultimately suffer as a result. Achieving optimal growth and abundant productivity in crops can be accomplished by emphasizing the application of fertilizers containing a significant proportion of potassium (AL-Taey & Burhan, 2021).

Conclusion

The study recommends careful management of saline water use to minimize negative impacts on soil and plants, as well as optimizing fertilization strategies to enhance productivity under challenging conditions.

Conflict of Interest

The authors declare that they have no competing interests.

Author Contributions

All authors' contributions are equal for the preparation of research in the manuscript.

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