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Relationship Of Infiltration with Soil Gypsum Content, Water Salinity, And Water Addition Method

M. H. Nimah * **I. Kh. H. Al-Hadeethi** **A. M. Hazim**

Department of Soil Sciences and Water Resources, College of Agriculture, University of Anbar

***Correspondence to:** Muhammad Hamid Nimah, Department of Soil Sciences and Water Resources, College of Agriculture, University of Anbar, Iraq.
Email: muh22g2002@uoanbar.edu.iq

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Abstract

This laboratory experiment was conducted at the College of Agriculture of the University of Anbar to study the effect of soil gypsum content, water salinity level, and application method (continuous and intermittent water addition) on cumulative water infiltration rates in soil. Three soil types containing 90 g kg^{-1}, 197 g kg^{-1}, and 463 g kg^{-1} gypsum were packed into 40-cm-long transparent columns up to a height of 30 cm in bulk densities approximating field conditions. Saline water was applied at electrical conductivity levels of 2, 4, and 8 dS m^{-1} using both continuous and intermittent application techniques. Cumulative infiltration was measured over time by tracking the volume of absorbed water. Results indicated that infiltration increased with higher gypsum content, peaking at 14.70 cm after 30 minutes in the soil with 463 g kg^{-1} gypsum, while the lowest rate of 10.91 cm was observed in the soil with 90 g kg^{-1} gypsum. Conversely, higher water salinity reduced infiltration, with values decreasing from 10.90 cm at 2 dS m^{-1} to 6.00 cm at 8 dS m^{-1}. Under continuous irrigation, infiltration reached 13.7, 10.7, and 8.3 cm for increasing salinity levels, whereas intermittent irrigation resulted in 12.09, 9.5, and 7.5 cm, respectively. These findings emphasize the combined effects of gypsum content, salinity, and irrigation technique on soil water dynamics.

Keywords: Gypsum content, Cumulative infiltration, Water salinity, Application technique.

علاقة الغيض بمحتوى التربة من الجبس وملوحة الماء وأسلوب اضافته

محمد حميد نعمه * عصام خضير حمزة الحديثي عبود محمد هزيم

قسم علوم التربة والموارد المائية، كلية الزراعة، جامعة الانبار

*المراسلة الى: محمد حميد نعمه، قسم علوم التربة والموارد المائية، كلية الزراعة، جامعة الانبار، العراق.

البريد الالكتروني: muh22g2002@uoanbar.edu.iq

الخلاصة

أجريت تجربة مختبرية في مختبرات كلية الزراعة جامعة الانبار. لدراسة تأثير محتوى الجبس في التربة ومستويات ملوحة المياه واسلوب الإضافة (إضافة مستمرة ومتقطعة) في الغيض التراكمي للتربة. جلبت عينات تربة بمحتوى جبسي بلغ 90، 197 و463 غم كغم$^{-1}$. وعبئت في أعمدة شفافة بطول 40 سم وطول عمود التربة 30 سم وبكثافة ظاهرية مساوية تقريبا لكثافة الحقل. استعملت ثلاثة مستويات من المياه المالحة 2، 4 و8 ديسيسمنز م$^{-1}$ واضيفت مستويات المياه بأسلوبين مستمر ومتقطع. قيس الغيض التراكمي من خلال العلاقة بين حجم الماء الممتص مع الزمن. أظهرت النتائج ان الغيض التراكمي ازداد مع زيادة المحتوى الجبسي اذ بلغت اعلى قيمة له عند زمن 30 دقيقة 14.70 سم عند المحتوى الجبسي 463 غم كغم$^{-1}$ واقل قيمة 10.91 سم عند المحتوى الجبسي 90 غم كغم$^{-1}$. اما تاثير مستوى ملوحة ماء الري فقد انخفضت قيم الغيض مع زيادة مستويات الملوحة فبلغت اعلى قيمة 10.90 سم عند مستوى ملوحة 2 ديسيسمنز م$^{-1}$ واقل قيمة لمعاملة 6 سم عند مستوى ملوحة 8 ديسيسمنز م$^{-1}$ اما أسلوب الإضافة فبلغت 13.7 و10.7 و8.3 سم لمستويات ملوحة المياه 2 و4 و8 ديسيسمنز م$^{-1}$ مع أسلوب الإضافة المستمر على التتابع. وبلغت 12.09 و9.5 و7.5 سم لمستويات ملوحة المياه 2 و4 و8 ديسيسمنز م$^{-1}$ مع أسلوب الإضافة المتقطع على التتابع.

كلمات مفتاحية: المحتوى الجبسي، الغيض التراكمي، المياه المالحة، أسلوب الاضافة.

Introduction

Gypsiferous soils are characterized by the presence of varying amounts of gypsum (calcium sulfate dihydrate, $CaSO_4$ $2H_2O$), which significantly influences the soil's water retention and movement, thereby affecting plant growth (17). These soils pose several challenges that limit their agricultural use, primarily due to their distinctive physical and chemical properties. The gypsum content directly affects water transport functions in soil, including infiltration, sorptivity (S), water diffusivity (D), penetrability (λ), and hydraulic conductivity (K) (16).

Infiltration, defined as the process by which water enters the soil through its surface, is a key parameter in the design, evaluation, and modeling of surface irrigation systems. Accurate estimation of infiltration is essential for predicting water advance and recession, soil erosion, and the total water intake during irrigation events (10, 11, 12 and 13) describes infiltration as the vertical movement of water from the soil surface into its profile. The significance of water infiltration has been widely recognized in the fields of irrigation, soil science, and hydrology (3).

Infiltration is a critical soil physical property in both agricultural and engineering applications, particularly in the design of drainage and reclamation projects, as well as in estimating the required irrigation water for salt infiltration. It is a fundamental parameter for managing soil and water problems related to environmental and agricultural sustainability (20). Understanding the soil's hydraulic behavior is essential for predicting field-scale water movement and solute transport. When salts dissolve in irrigation water, they alter the water's physical and chemical properties. As it moves through the soil, it interacts with the soil exchange complex, resulting in changes in both the chemical composition and physical characteristics of the soil solution.

Of late, there has been growing interest in using saline water as an alternative to freshwater in irrigation, especially in regions experiencing water scarcity. However, applying saline water requires careful management due to its complex chemical and physical effects on soil properties. (7) observed that infiltration values increased with higher gypsum content, while (4) reported a direct relationship between cumulative infiltration and soil gypsum levels. Conversely, (16) found that increased irrigation water salinity reduced infiltration rates. Regarding irrigation techniques, several studies have shown that intermittent water application improves water distribution within the soil (1, 14, 15 and 21). Therefore, the objective of this study was to investigate the relationship between gypsum content, irrigation water salinity, and application technique, as well as their combined effects on cumulative infiltration in gypsiferous soils.

Materials and Methods

This laboratory experiment was conducted using a complete random design (CRD), and a site was chosen at latitude N 33°32'26.1" and longitude E 43°57'30.2" in the Jazerat Al-Karma area. A soil pedon was prepared at the site with a depth of 1 m and the gypsum content was measured at depths of 20, 40, and 70 cm.

Experimental Factors:

Gypsum content: Three levels of gypsiferous soil profile were taken, namely G1 (90 g kg^{-1}), G2 (197 g kg^{-1}), and G3 (463 g kg^{-1}). The soil samples were air-dried, ground, and passed through a 2 mm sieve. Selected physical and chemical properties of the study site are shown in Table 1 (24).

Table 1: Physical and Chemical Characteristics of Soil.

Parameters	Unit	G1	G2*	G3*
Soil texture		Loam	–	–
Sand	(g kg^{-1})	442	–	–
Silt		332	–	–
Clay		226	–	–
Bulk density	(Mg m^{-3})	1.36	1.30	1.23
Particle density	(Mg m^{-3})	2.62	2.55	2.50
Porosity	(m^3 m^{-3})	0.480	0.490	0.508
Hydraulic conductivity, Ks	(cm min^{-1})	0.0418	0.0566	0.0689
Volumetric moisture at saturation	(cm^3 cm^{-3})	0.46	0.51	0.69
Volumetric moisture at 33 kPa		0.298	0.24	0.20
Volumetric moisture at 1500 kPa		0.099	0.09	0.07
pH		7.43	7.82	7.87
EC	(dS m^{-1})	1.92	2.04	2.70
Gypsum content	(g kg^{-1})	90	197	463
Calcium carbonate		164	142	139
Organic matter		9.32	4.58	3.80
Na^+	(mmol L^{-1})	2.9	2.0	1.7
K^+		2.6	1.7	1.0
Ca^{2+}		136.4	285.7	389.7
Mg^{2+}		7.2	6.2	5.4
Cl^-		3.1	5.3	7.4
SO_4^{2-}		13.5	16.4	23.7

*Texture could not be measured for treatments G2 and G3 due to precipitation caused by high gypsum content.

Levels of water salinity:

Three well water salinity levels were applied i.e., S_1=2, S_2=4, and S_3=8 dS m^{-1}.

Table 2: Water Characteristics.

Parameter	Unit	Water Salinity		
		Low	**Medium**	**High**
EC	dS m^{-1}	2.63	4.71	8.87
pH	–	7.62	7.85	8.33
Na^+	mmol L^{-1}	20.51	38.21	72.12
K^+		0.09	0.11	0.16
Ca^{2+}		5.20	8.20	14.20
SO_4^{2-}		4.00	6.90	12.20
Mg^{2+}		1.40	2.06	4.02
SAR	–	20.61	26.64	40.50

Water application technique:

Saline water was applied using two irrigation techniques: Continuous application (A1): The entire volume of saline water required was applied in a single dose, allowing water to flow uninterrupted until it reached the bottom of the soil column.

Intermittent application (A2): The required quantity was added intermittently, with dissimilar continuous addition, where the addition time was equal to the cutting time for all transactions. The amount of water added depended on the size of the soil column pore space. When the water reached the end of the column, it was cut off using a valve to control the opening and closing.

Soil column preparation: Transparent plastic columns 0.40 m in length and 0.05 m in internal diameter were used to create soil columns 0.30 m in length (Fig. 1). A layer of glass wool was placed at the bottom of the column, followed by a layer of washed gravel with diameters ranging from 0.0002 to 0.0004 m as a filter. A base with a diameter slightly larger than the outer diameter of the column was placed at the end of the column, and a small tube with a diameter of 0.01 m was fixed inside it to collect the filtrate during the washing process. Soil columns were prepared by packing each column group with air-dried soil samples, with gypsum contents of 90, 197, and 463 g kg^{-1} for 18 columns per replicate.

The soil sample was then placed in a smaller-diameter column. This column was pulled slightly upwards using a rotating technique. Simultaneously with the pulling of the first column, the outer wall of the column was tapped with a rubber hammer from top to bottom and from bottom to top while continuously rotating the soil column (5). The columns were capillary moistened from the bottom using distilled water to maintain homogeneity of moisture distribution throughout the column for 24 hours. The columns were fixed to an aluminum stand with rings of the same diameter as the tube, facilitating the transportation of the tubes.

Infiltration measurement: Infiltration was measured under controlled laboratory conditions using vertically oriented glass columns. The soil was packed into the columns to achieve a bulk density approximately equal to the field density, which was 1.35. Water was added to the surface of each column using a specially designed device to enable the calculation of the amount of absorbed water and control the rate of water addition. The device allowed the height of a fixed water column, 0.01 m above the soil surface, to be controlled (Fig. 1). After the columns were prepared, the depth of the absorbed water was measured over time, cumulatively, starting from 1 minute until the amount of added water was depleted.

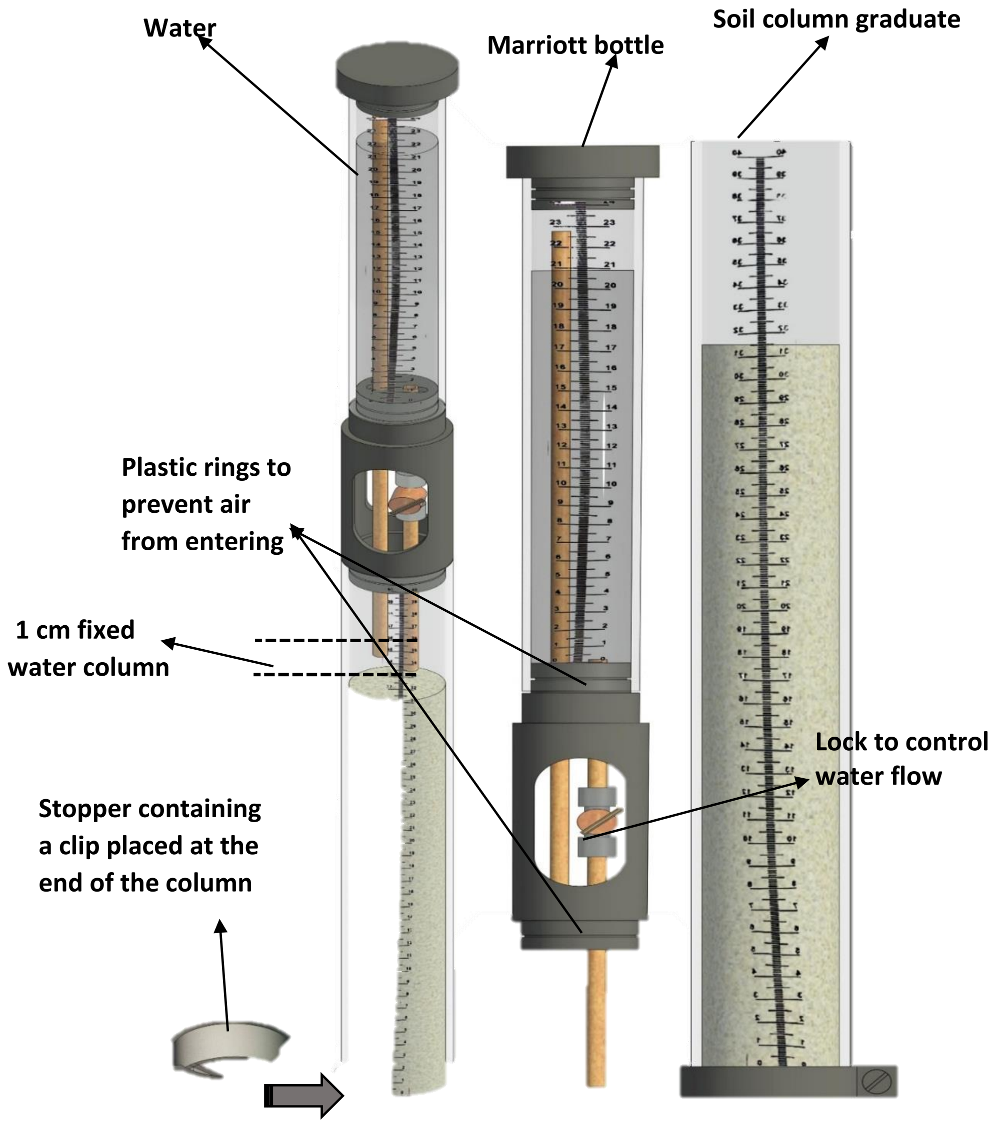

Fig. 1: Parts of the device used in the experiment to control the addition of water.

Results and Discussion

Effect of Gypsum Content on Cumulative Infiltration: As shown in Fig. 2, water infiltration into the soil occurred rapidly during the initial stages and gradually slowed down over time. After 30 min, the cumulative infiltration measured was 10.91 cm, 14.90 cm, and 18.30 cm for soils containing 90 g kg^{-1}, 197 g kg^{-1}, and 463 g kg^{-1} gypsum, respectively. These findings suggest a positive relationship between gypsum content and the amount of water infiltrated. In other words, higher gypsum levels appeared to enhance the soil's ability to absorb water.

This behaviour may be attributed to the solubility of gypsum, which improves the interaction between water and soil particles, allowing water to penetrate more easily. Additionally, Fig. 2 indicates that the depth reached by the wetting front within the same 30-minute period varied with gypsum content recorded at 24.5 cm, 26.5 cm, and 29 cm for the three gypsum levels mentioned.

As gypsum concentration increased, the wetting front advanced more rapidly and required less time to reach the bottom of the soil column. This could be due to the manner in which gypsum dissolves and enhances the soil's wettability, making water movement more efficient.

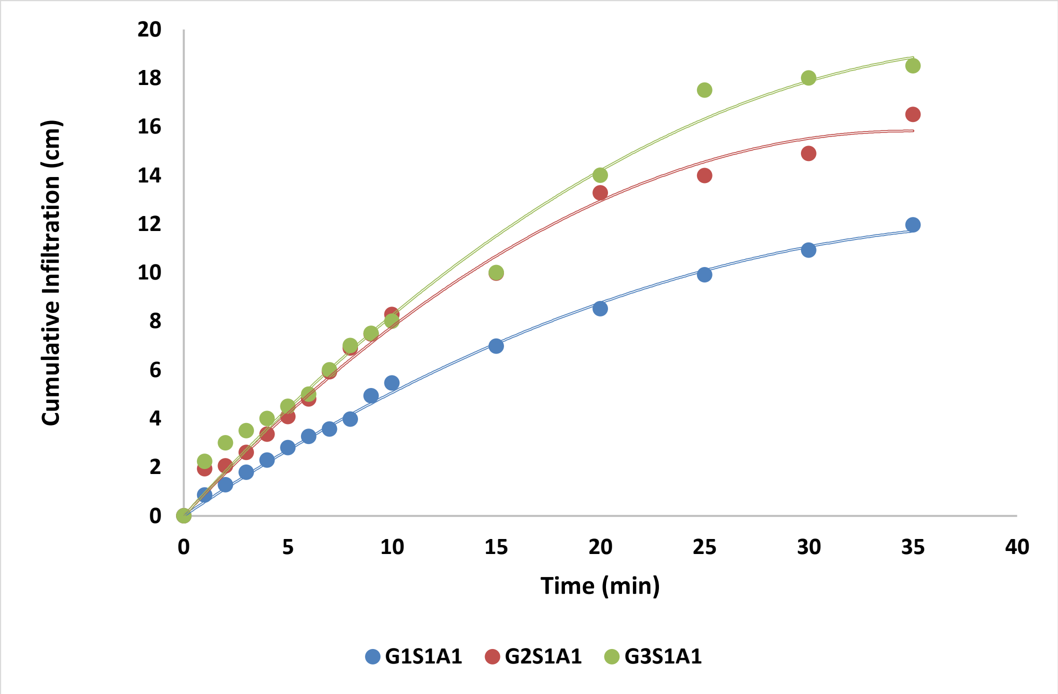

Fig. 2: Effect of gypsum content on cumulative infiltration.

Effect of Salinity Level and Application Technique on Cumulative Infiltration: Figures 3 - 5 illustrate the impact of salinity levels of irrigation water (2, 4, and 8 dS m^{-1}) on cumulative infiltration in soils with varying gypsum content. Generally, cumulative infiltration decreased with increasing salinity of the applied water across all three soil types.

Fig. 3 presents the results for soil with 90 g kg^{-1} gypsum content. After 35 minutes, the highest cumulative infiltration reached 11.96 cm when water with a salinity of 2 dS m^{-1} was used. In contrast, the lowest infiltration recorded was 6.5 cm at a salinity level of 8 dS m^{-1}.

In terms of application technique, continuous application consistently resulted in higher infiltration compared to the intermittent technique. At 35 minutes, cumulative infiltration values under continuous application were 11.96, 10.01, and 8.68 cm for salinity levels of 2, 4, and 8 dS m^{-1}, respectively. Under intermittent application, the values were slightly lower, at 11.01, 9.15, and 6.50 cm for the same respective salinity levels. This is because under intermittent addition, greater moisture distribution occurs with a smaller amount of water, unlike continuous addition, consistent with (22).

Fig. 4 shows the effect in soil with 197 g kg^{-1} gypsum content. Additionally, infiltration was most pronounced under low salinity and continuous application. The highest value recorded was 16.5 cm at 2 dS m^{-1} with continuous addition, while the lowest was 8.799 cm under the highest salinity level 8 dS m^{-1} using the intermittent technique.

Regarding the addition technique, cumulative infiltration values increased with the continuous addition technique and decreased with the intermittent addition technique. The cumulative infiltration values at 35 minutes reached 16.50, 12.50, and 9.99 cm for water salinity levels of 2, 4, and 8 dS m^{-1}, respectively, using the continuous addition technique. They reached 13.60, 12.58, and 8.89 cm for water salinity levels of 2, 4, and 8 dS m^{-1}, respectively, using the intermittent addition technique.

Fig. 5 illustrates the effect of water salinity levels on soil with a 463 g kg^{-1} gypsum content. The highest cumulative infiltration value at 35 minutes reached 18.50 cm at a salinity level of 2 dS m^{-1}, and the lowest value reached 12.00 cm at a salinity level of 8 dS m^{-1}. As for the addition technique, the cumulative infiltration values increased with the continuous addition technique and decreased with the intermittent addition technique, as the cumulative trickle values at a time of 35 min reached 18.50, 15.0, and 13.50 cm for water salinity levels of 2, 4 and 8 dS m^{-1} with the continuous addition technique in sequence. They reached water salinity levels of 2, 4, and 8 dS m^{-1}, corresponding to 16.50, 14.50, and 12.00 cm, with the intermittent addition technique applied in sequence (23).

In contrast, freshwater or low-salinity water tends to have a stronger interaction with gypsum, enhancing its solubility and promoting water movement through the soil, which in turn increases cumulative infiltration. As salinity levels rise, this affinity diminishes, thereby reducing gypsum solubility and slowing water movement.

Additionally, saline water often contains high concentrations of calcium and sulfate ions, which intensify the effect of the common ion phenomenon (10). This phenomenon is closely linked to the solubility product constant (K_{sp}), as discussed in (6 and 9). An increase in the ionic activity of calcium or sulfate in the soil solution tends to shift the balance of the solubility product equation ($K_{sp}{}^{=}(Ca^{++})\ (So_4{}^{=}) = 2.5x10^{-5}$), resulting in decreased gypsum solubility as the system strives to maintain equilibrium, given that the K_{sp} is constant.

Moreover, gypsum dissolution may follow a first-order kinetic model (2), where the net dissolution rate dC/dt within a given soil layer is a function of the concentration difference between a saturated gypsum solution (C_s) and the actual concentration at a given time (C), expressed by the equation ($dC/dt = K(Cs-C)$). In this model, K represents the dissolution coefficient, and the difference (C_s - C) reflects the solution's saturation deficit.

In groundwater, typically more concentrated than river water, the difference between Cs and C tends to be smaller, leading to a lower net rate of gypsum dissolution under saline conditions (18 and 19). At the same time, salty water (such as well water) reduces the effect of gypsum dissolution for the reasons mentioned above. This finding is consistent with the results of (15), who reported that irrigation with salty water resulted in a general reduction in cumulative infiltration.

Once the intermittent water application technique is used, the amount of water added is reduced, which eliminates the effect of water pressure that influences the rate of water movement, unlike the continuous application technique. Additionally, a decrease in structural stress may occur after the initial cut, and soil particles may rejoin, which in turn reduces vertical water flow.

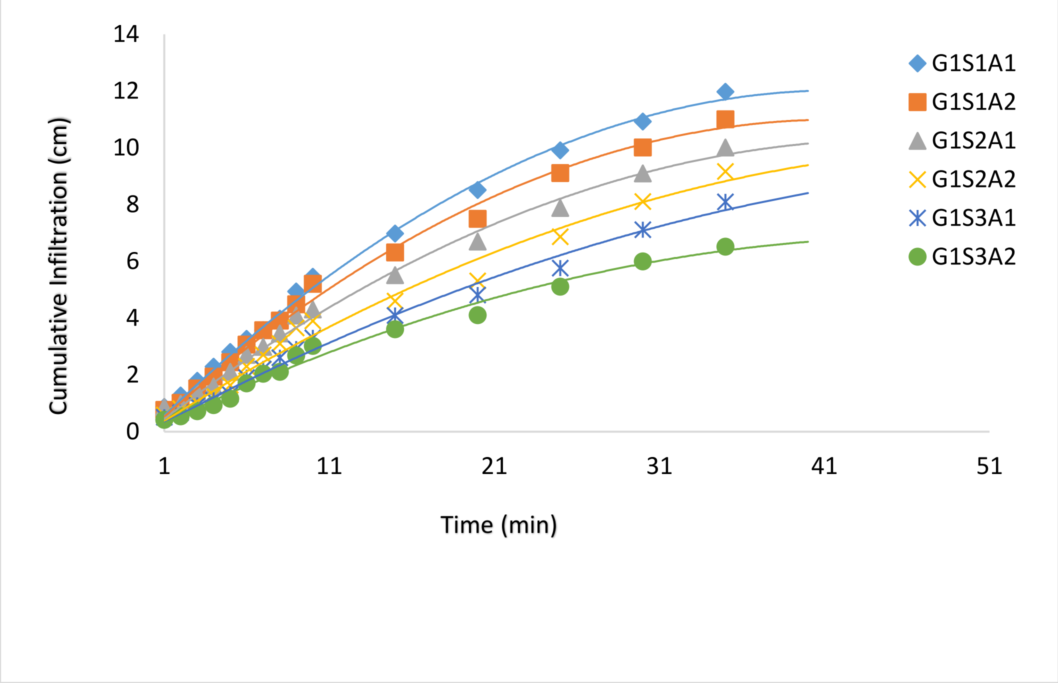

Fig. 3: Effect of water salinity levels and the addition technique on the cumulative infiltration values in soil with a gypsum content of 90 g kg^{-1}.

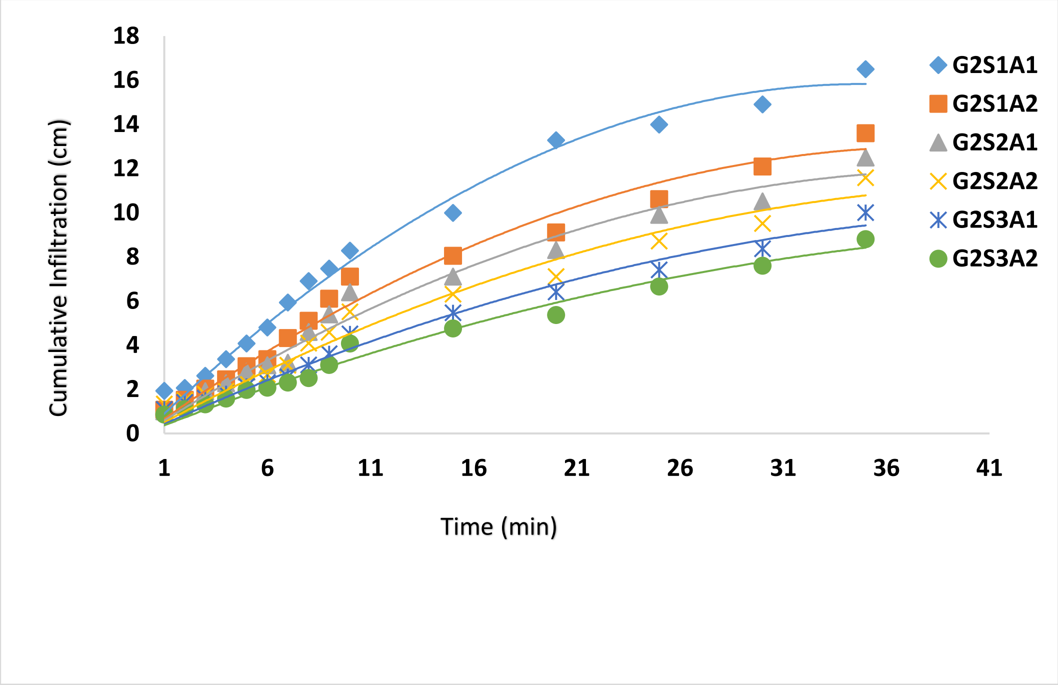

Fig. 4: Effect of water salinity levels and the addition technique on the cumulative infiltration values in soil with a gypsum content of 197 g kg^{-1}.

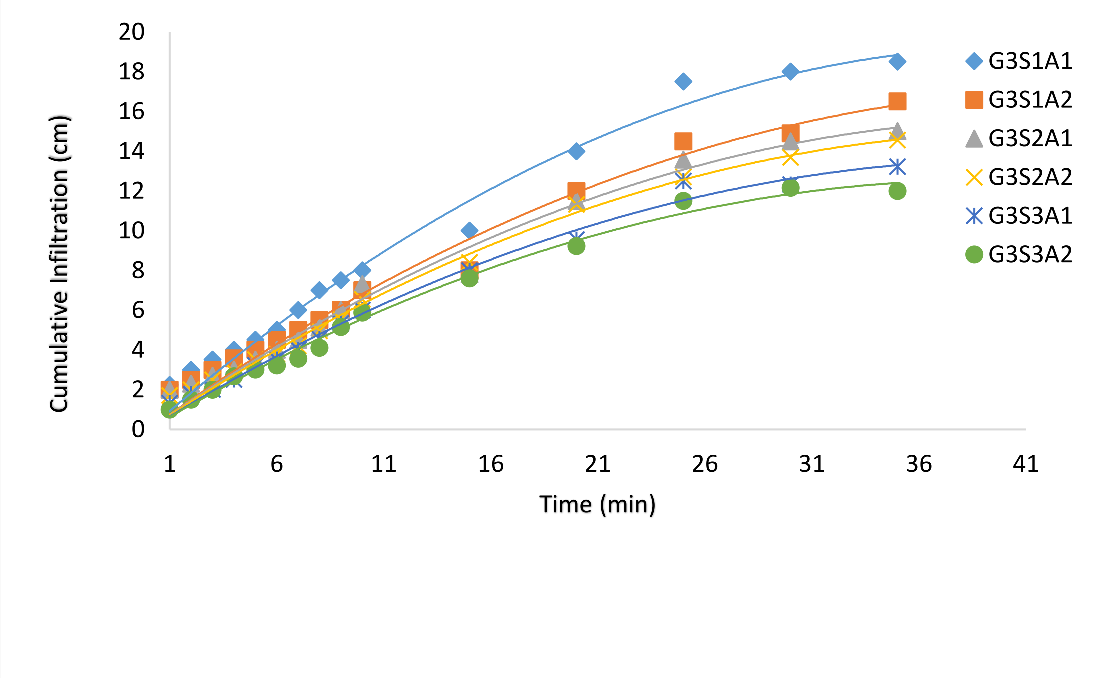

Fig. 5: Effect of water salinity levels and addition technique on the cumulative infiltration values in soil with a gypsum content of 463 g kg^{-1}.

Conclusions

1. The results indicate that cumulative infiltration values rise with increasing soil gypsum content.
2. Cumulative infiltration values decrease with higher water salinity for all study parameters.
3. Cumulative infiltration values increase with the continuous addition technique compared to the intermittent addition technique.

Supplementary Materials:

No Supplementary Materials.

Author Contributions:

The first author contributed to the writing and preparation of the original draft, the second contributed to the review, editing, and methodology, and the third contributed to the review, editing, and development of the methodology.

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Data available upon request.

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The authors declare no conflict of interest.

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