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The Effect of Layered Soil with Two Textures on Wetting Pattern of Two Adjacent Trickle Sources

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ABSTRACT

Drip irrigation is important in rationing the use of irrigation water, especially in arid and semi-arid regions that suffer from a severe shortage of water resources. To estimate the volume of the wetted soil under drip irrigation, twelve laboratory experiments were conducted to track the advancement of the wetting front during certain times for the wetting phase and the moisture redistribution phase as a result of adding water from two linear drip sources. Three spacings between the emitters (30, 40, 50) cm were considered for a layered soil consisting of two soil textures: one with clay over sandy loam, and the other with sandy loam over clay. Two rates of discharge (0.956 and 1.515 cm^3/min/cm) were considered. The data were represented by empirical relationships to estimate the wetting pattern in the horizontal and vertical directions and in the middle of the spacing between the two emitters, with a determination coefficient of 0.96, 0.98, and 0.97, respectively. It was observed that the wetting pattern increases with a decrease in the interval between the drippers, and that this increase is regular along the wet perimeter, and this increase is greater in the vertical direction than in the horizontal direction, and for both soil profiles. In addition, an increase in water application let to increase the vertical progression, as it is greater in the case of soil profile (sandy loam over clay), while the horizontal progression is clear for the soil profile (clay over sandy loam).

Keywords:
Drip irrigation, overlapping wetting pattern, emitters spacing, Layered soil.

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1. INTRODUCTION

To design the most optimal drip irrigation system, the dimensions of the wetting distribution pattern must be studied well [1]. The drip irrigation system relies on giving frequent low water application comparing with traditional irrigation methods. The advancement of water from the emitter causes a saturated zone around the supplying point near the emitter. The saturated zone usually surrounded by unsaturated zone ended by advancement front phase [2, 3]. The advancement of wetting front is influenced by many factors: physical soil characteristics, water application rate, method of water application from emitter (continuous or intermittent), the initial moisture of the soil, and the heat of both water and soil [4, 5]. The movement of water within the soil continues in all directions as a result of capillary rise forces and gravitational forces during the phase of moisture and moisture redistribution [6]. In layered soils, the movement of water in the surface layer is similar to homogeneous soils and upon arrival to the separation limit in the case of coarse soils above fine soils, the horizontal movement above the transition zone of the water connectedness of soils is higher than the soils. [8] The size of the wet soil represents the amount of water stored in the root zone area, as the vertical dimension applies to the depth of the root zone area, while the occasional dimension defines the separation between the drops and the drip lines [3]. Increasing the volume of the applied water increases the horizontal and vertical advancements of the wetting front, and the increase in vertical direction is greater than that of horizontal direction and this is more evident in coarse soils [9]. It is important to study a situation applying soil because most soils are either ploughed into two layers, the excited surface and the undisturbed substrate [10], or have a surface crust on the soil as a result of the impact of a large water drops on the soil surface [11]. This usually lead to create two layers with different characteristics. Water holding capacity of the clay soil is greater than the sandy and loamy soils [12,13]. The distance between two adjacent emitters is an important factor affecting the distribution of moisture within the soil in drip irrigation. When the distance is relatively small, the wetting front zone is somewhat of a single drip source, by increasing the distance, the width of the wetting area will increase, in addition to increasing the depth of saturation below the supplying point. With time, the horizontal advancing of wetting front will exceeds the vertical one [14, 15]. The progress of the wetting front increases as the distance between the emitters decrease, [16] and has shown that the distribution of moisture is better when using a 30 cm instead of using 50 cm as a distance between two emitters [17]. It also appears that the displacement between the center of wetting pattern from the emitter increases as the soil surface elevation declines and is more pronounced with the fine soils; this is also true when increasing the application rate of water from emitters with same volume of added water [18]. The subsurface pattern is also a result of the wetting and redistribution phase [19]. The main objective of the study is to develop empirical relationships to represent horizontal and vertical advancement of wetting front under two linear drip sources for a layered soil.

2. EXPERIMENTAL SETUP AND METHODS

Laboratory tests included 12 tests to study the advancement of the wetting front during the development of moisture redistribution by adding water from two drip sources with (30, 40 and 50 cm) as a distance between two drips applied to a layered soil consisting of two soil textures: one with clay over sandy loam, and the other with sandy loam over clay. Samples from both soils were brought to the laboratory to identify the physical soil properties. The grain size analysis was conducted to determine the percentile of each grain. Further, the soil moisture was balanced based on the laboratory environment. The results of soil classification are shown in table 1.

Table 1: Soil Properties and Classification

Soil texture	Region	Soil classification%			Bulk density g/cm^3	Initial water content %
		sand	silt	clay		
Clay	Sagittarius	14	38	48	1.37	10
Sandy loam	Forests	57	25	18	1.48	4.7

One of the soil samples was brought from the forest area at Mosul city and the other from the arcs, which were cleaned and sifted with a sieve (2 * 2) mm and then brushed and air dried in the yard of the Hydraulic Laboratory of the Department of Dam Engineering and Water Resource/University of Mosul. The, the samples were packed with tight plastic bags for access to homogeneous moisture content. Two water application rates 0.956 and 1.515 cm ^{3}/min/cm were selected based on the recommendation of previous studies. Further, two water application duration (380, 240) minutes were used as shown in table 2. An iron container with dimensions (5.5cm * 70cm * 140cm) was used to conduct the experiment. One side of the container consists of transparent plate to follow the advancement of the wetting front. The container was filled gradually with soil layers of thickness of each (5) cm considering the soil bulk density in term of the primary moisture of the soil and required size of soil for each layer. The 8 layers of mixed sand soil are stacked: 5 layers of clay soil and thus complete the dictating of the device with a 65-centimeter-thick topping that reflects the condition of a soil grain (clay above sandy loam). The water is processed through the fixed proportion tank, which is fed from a seeded upper tank with variable water level over time to determine the amount of water entering the soil during the experiment and connected to the drip sources by an extension tube. Figure 1 shows the soil container and water supplying system.

Table 2: Summary of Laboratory Experiments

Interval distance/cm	Discharge CM^3/Min/CM	type of soil
30,40,50	**0.956**	**Upper layer clay and lower mix sandy**
30,40,50	**1.515**	
30,40,50	**0.956**	**The upper layer is a sand mix and the lower is mud**
30,40,50	**1.515**	

Figure 1: Soil container and water processing system

After preparing the soil layers, water was applied to the soil surface through the two drip sources after determining the amount of water application rates from the emitters. During the experiments, advancement of the wetting front on the front of the transparent container side is marked at selected times, and water continues to be added until the volume of water added reaches 4 liters at which time the surface of the soil is covered to reduce evaporation from the surface of the soil. The progress of the wetting frontline will continue to be observed after the cutoff of water supply to monitor the redistribution of moisture for 48 hours from the beginning of the experiment

3. RESULTS AND ANALYSIS

Coordinates (X, Y, Z) are respectively representing surface horizontal advancement, vertical advancement under the emitter (cm) and vertical advancement at the mid-interval between the drops (cm) of the wet pattern at measurement times during laboratory tests (4, 8, 15, 30, 60, 90,....) minutes considering the source of the drip is the point of origin where relationships have been found to predict the wetting pattern produced by two linear drip sources during the phase of moisture and the phase of moisture redistribution in terms of the time of water application (Ti) min, water application rate (q cm^3/min/cm) and basic infiltration rate (Ib cm/min), distance between the two linear drip (S cm) during the redistribution phase. The following relationships have been derived to predict X, Y and Z:

$$X = 0.991714 * Ti^{0.48848} * q^{0.534582} * S^{-0.00824} * Ib^{-0.1256} ,,,, R^2 = 0.977 \ldots..(1)$$

$$Y = 6.769944 * Ti^{0.540273} * q^{0.42872} * S^{-0.22546} * Ib^{-0.199525} \ldots\ldots R^2 = 0.989 \ldots\ldots(2)$$

$$Z = 5.8138622 * Ti^{1.0098} * q^{1.020241} * S^{-1.07775} * Ib^{0.117723} \ldots\ldots R^2 = 0.96 \ldots\ldots(3)$$

In the redistribution phase, the non-dimensional relationships were as follows:

$$\frac{X}{S} = 1.533103 * [\frac{Ts}{Tr}]^{-0.44611} * [\frac{q * Ts}{S^2}]^{0.553457} * \left[\frac{Ib^2 * Ts}{q}\right]^{-0.05962} ,,,,.R^2 = 0.96 \ldots.(4)$$

$$\frac{Y}{S} = 1.862691 * [\frac{Ts}{Tr}]^{-0.53095} * [\frac{q * Ts}{S^2}]^{0.593877} * \left[\frac{Ib^2 * Ts}{q}\right]^{0.001808} ,,,,.R^2 = 0.98 \ldots..(5)$$

$$\frac{Z}{S} = 2.009839 * [\frac{Ts}{Tr}]^{-0.59085} * \left[\frac{q * Ts}{S^2}\right]^{0.666673} * [\frac{Ib^2 * Ts}{q}]^{0.012105} \ldots\ldots R^2 = 0.98 \ldots..(6)$$

Ts :Moisture redistribution time (min)
Tr: Water application time (min)

Figures (2-5) also illustrate the relationship between the measured and predicted values from the equations derived above.

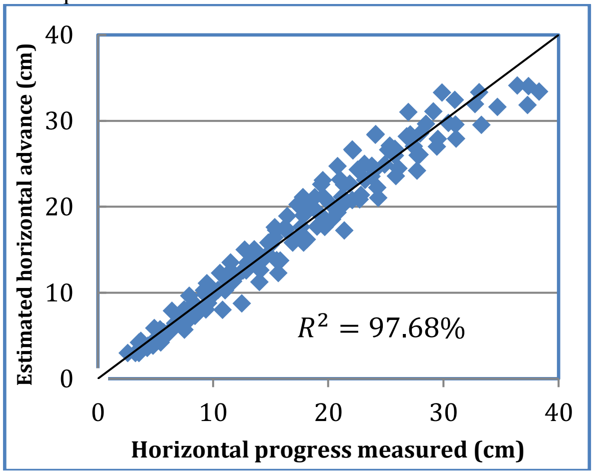

Figure 2: Measured and predicted horizontal advancement during the wetting phase

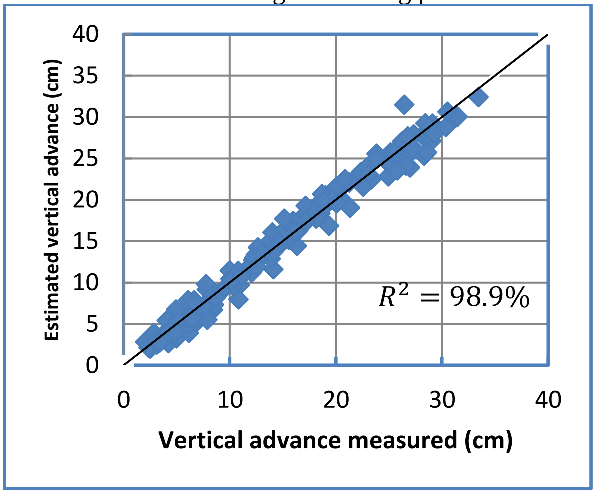

Figure 3: Measured and predicted vertical advancement during the wetting phase

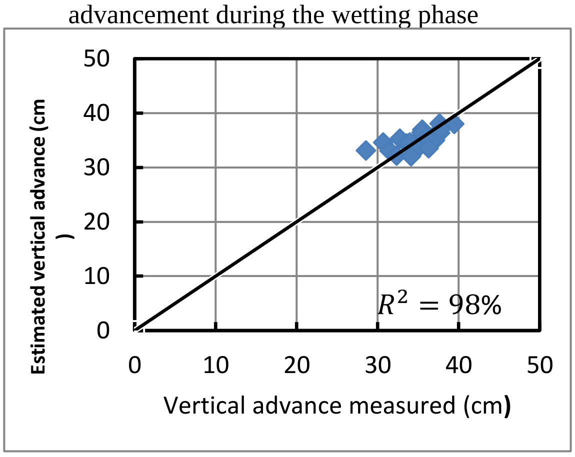

Figure 4: Measured and predicted vertical advancement during the moisture redistribution phase

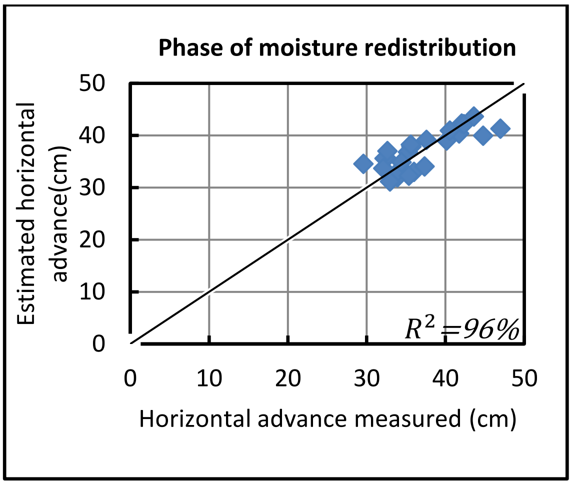

Figure 5: Measured and predicted horizontal advancement during the moisture redistribution phase

Figures (6-9) show the wetting front pattern for different cases of soil type and water application rates for two adjacent linear drip sources at a specified interval.

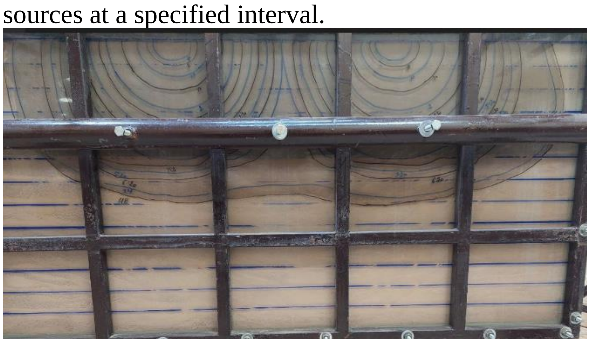

Figure 6: Wetting pattern in a layered soil (sandy loam in the upper layer and clay in the lower layer) with application rate 0.956 cm^3/min/cm and 50 cm distance between two drips

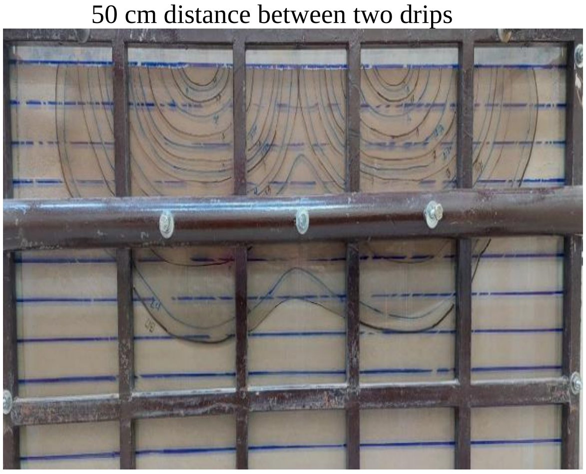

Figure 7: Wetting pattern in a stratified soil (clay over sandy mixture) with application rate 0.956 cm^3/min/cm and 50 cm distance between two drips

Figure 8: Wetting pattern for a layered soil (sandy loam over clay) with application rate 1.515 cm^3/min/cm and 30 cm distance between two drips

Figure 9: Wetting pattern in layered soil (clay in the upper layer and sandy loam in the lower layer) with application rate 1.515 cm^3/min/cm and 30 cm distance between two drips

4. DISCUSSION

The empirical equations that were derived were used to study the effect of various factors affecting the wetting front patterns.

a. Effect of water application rate on the wetting front advancement

It is clear from Figures (10), (11), (12) and (13) that increasing the water application rate increases the wetting front advancement of the horizontal and vertical directions for both cases of soils. Further, the figures show the relationship between the horizontal advancement from Equation (1) and the vertical advancement from Equation (2) of the wetting front over time and for different water application rates (0.8, 1.2, and 1.6) cm^3/cm/min. It can be concluded that the wetting front advancement in the vertical direction is greater than the horizontal advancement of the wetting front of sandy loam soils. As for clayey soils, the horizontal advancement of the wetting front is greater because capillary rise forces are more dominated in the fine texture soils. Thus, fine texture soils with relatively small pore sizes (clay) are more affected by capillary rise forces than course soils (sandy mixture) with relatively large pores that are more affected by the gravity force, and this is consistent with what was found by [20, 21, 22, 23,24].

b- Impact of the distance between two adjacent emitters on the wetting front advancement

Figures (14) and (15) show that the horizontal advancement of wetting front is not affecting by the distance between emitters during the moisture distribution pattern phase while the soil texture effect speed of wetting front advancement. In the case of clay soil in the upper layer, the advancement of wetting front is faster than in the case of sandy mixture soil in the upper layer. As for Figure (16). (17) shows that there is an effect of the distance between the emitters on the vertical progress under the emitter in the wetting stage, where the progress increases with the decrease of the distance between the emitters, and this is consistent with what was found [3, 10].

c- The effect of soil stratification on the wetting front advancement

Figure (18) shows the vertical advancement of the wetting front with time. We conclude that the speed of the vertical advancement is greater when the upper soil is a sandy mixture because it contains pores with large diameters and is therefore more affected by downward gravitational forces. It is also noted that the speed of wetting front advancement decreases when it reaches the dividing line between the two layers and begins moving through the fine clay layer, due to the weak conductivity of the fine soil. While the speed of wetting front advancement is slower when the clay soil is in the upper layer until it reaches the dividing line between the two layers, then the speed increases when it moves within the coarse soil layer. Figure (19) shows the advancement of the wetting front in the horizontal direction for the first two cases of water application rates when the sandy mixture soil is in the upper layer. It is clear that the speed of advancement is slower than when the clay soil is in the upper layer due to the low conductivity of the fine soil, so it forms a hydraulic barrier obstructing the direction of water infiltration. Then, horizontal advancement of wetting front becomes more dominated.

d-The vertical advance of the wetting front at the midpoint between the two drip sources

Figure (20) shows that the vertical advancement of the wetting front under the emitter roughly coincides with the wetting front advancement at the middle distance between two emitters. Figures (21) and (22) show that the vertical advancement of wetting front under the emitter is larger than the vertical advancement at the middle of the point as the distance between the emitters at a certain time and water application rate. This is due to the period required for the two wetting pattern fronts to overlap between the two emitters which increases with the increase in the distance between the emitters, meaning that the overlap between the two wetting spots is delayed, and thus the volume of soil between the two spots increases as the interval between the emitters increases .

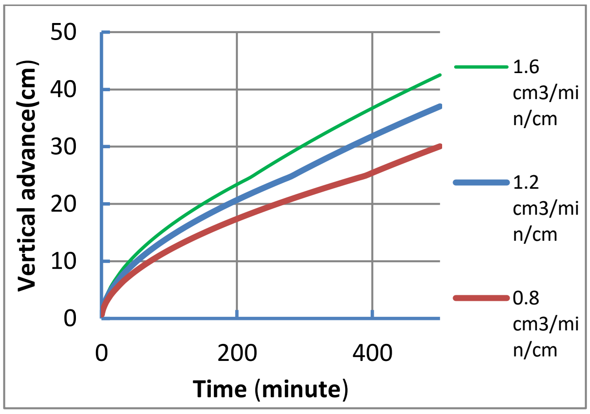

Figure 10: Change in the vertical advancement of the wetting front with time for a layered soil (clay over sandy loam) for distance of 30 cm between emitters.

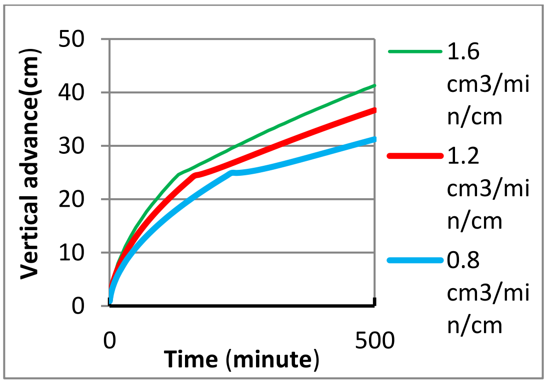

Figure 11: Change of vertical advancement of the wetting front with time for a layered soil (sandy mixture over clay) with distance of 30 cm between emitters.

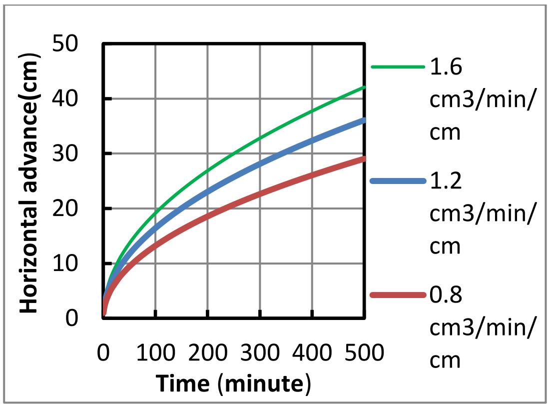

Figure 12: Change in horizontal advancement of the wetting front with time for a stratified soil (clay over sandy mixture) for distance of 30 cm between emitters.

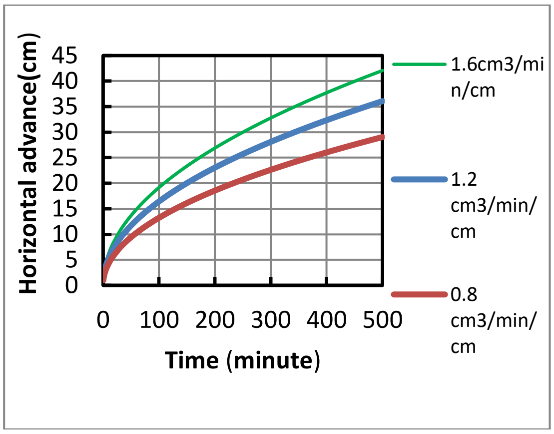

Figure 13: Change in horizontal advancement of the wetting front below emitter with time for a stratified soil (sandy mixture in the upper layer and clay in the lower layer) for a distance of 30 cm between emitters

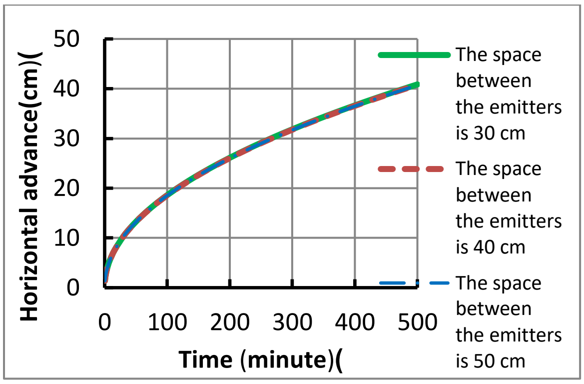

Figure 14: Variation of the horizontal advancement of the wetting below the emitter with time for stratified soil (clay over sandy loam) and for distance of 30 cm, 40 cm, and 50 cm between emitters and water application rate is 1.515 cm^3/min/cm.

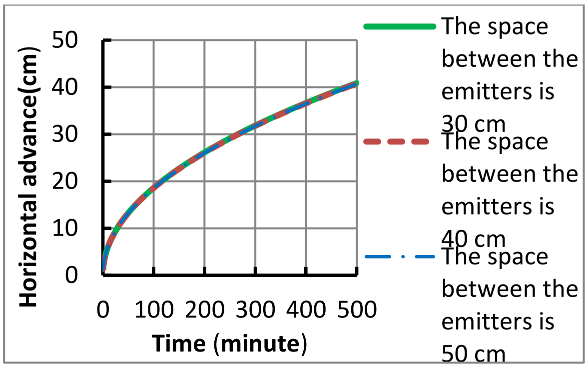

Figure 15: Change in horizontal advancement of the wetting front with time for a stratified soil (sandy mixture over clay) with distance of 30 cm, 40 cm, 50 cm between emitters and a water application rate of 1.515 cm^3/min/cm

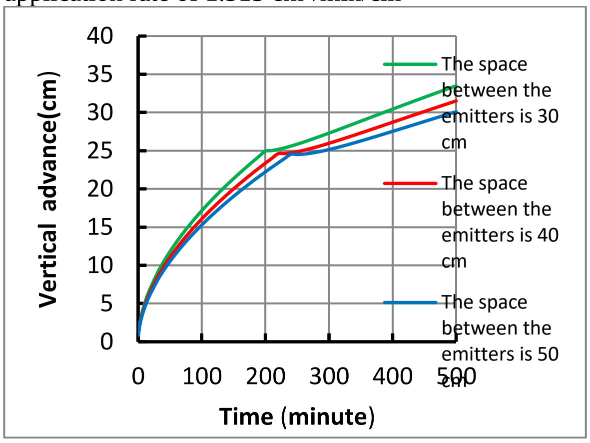

Figure 16: Change in vertical advancement of the wetting front with time for a layered soil (sandy mixture over clay) with distance of 30 cm, 40 cm, 50 cm between emitters and water application rate of 0.956 cm^3/min/cm.

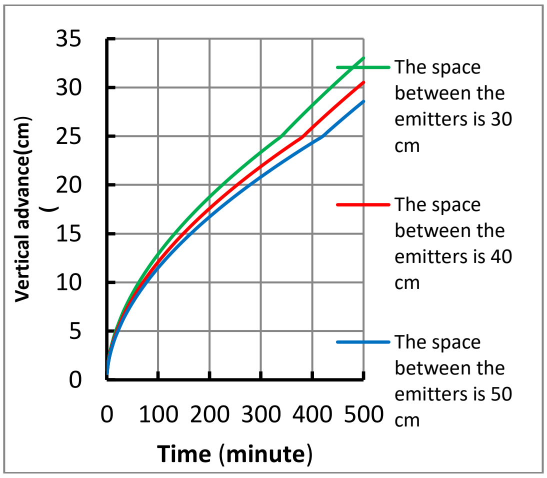

Figure 17: Change in vertical advancement of the wetting front with time for a layered soil (clay over sandy loam) for distance of 30 cm, 40 cm, and 50 cm between emitters and water application rate of 0.956 cm^3/min/cm

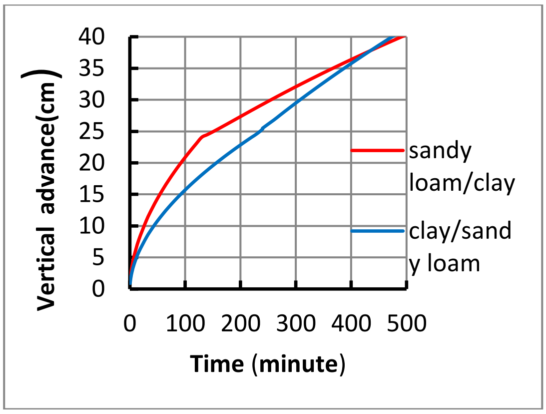

Figure 18: Change in vertical advancement of the wetting front with time for two stratified soils (sandy mixture over clay) and (clay over sandy mixture), at distance of 30 cm between emitters and water application rate of 1.515 cm^3/min/cm

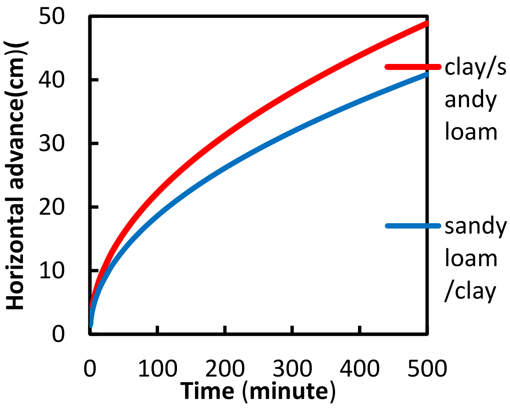

Figure 19: Variation of horizontal advancement of the wetting front with time for two layered soils (sandy loam over clay) and (clay over sandy loam), at distance of 30 cm between emitters and an addition rate of 1,515 cm^3/min/cm

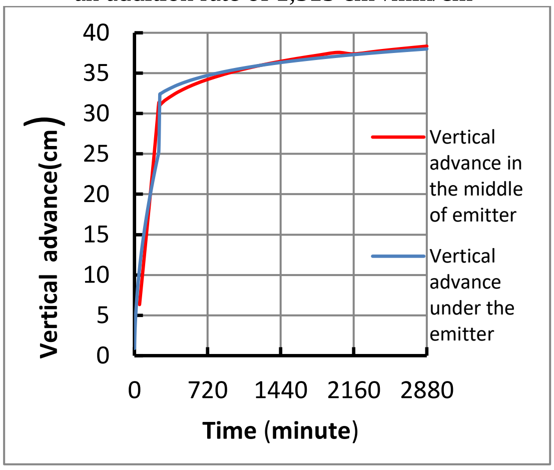

Figure 20: Change in the vertical advancement of the wetting front below the emitter and at the middle of the distance between the two emitters with time for a water application rate of 1.515 cm^3/min/cm for an distance of 30 cm between emitters.

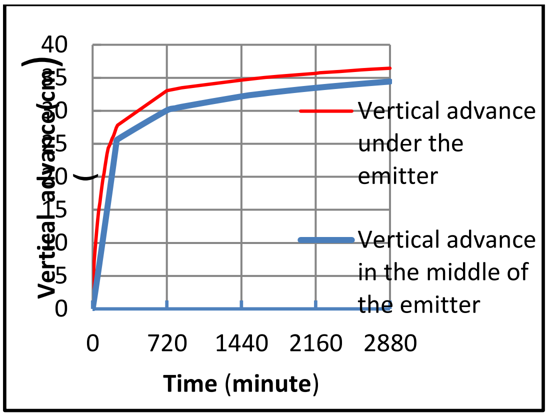

Figure 21: Change in the vertical advancement of the wetting front below the emitter and at the middle of the distance between the two emitters with time for a water application rate of 1.515 cm^3/min/cm for an distance of 40 cm between emitters.

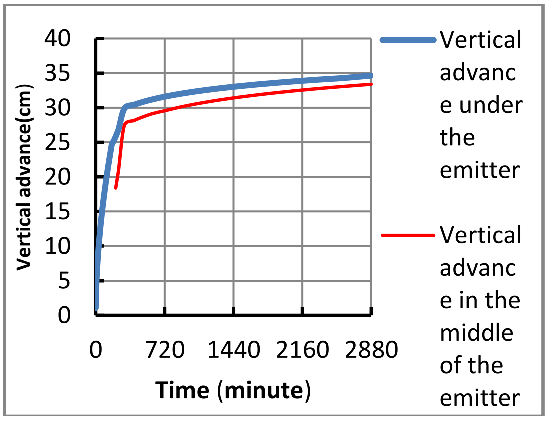

Figure 22: Change in the vertical advancement of the wetting front below the emitter and at the middle of the distance between the two emitters with time for a water application rate of 1.515 cm^3/min/cm for a distance of 50 cm between emitters.

5. CONCLUSION

a) An imperial relationship was derived to show the behavior of the wetting front advancement under the drip, in the middle of the interval, and in the horizontal direction resulting from the two drip sources during the wetting phase as a function of the duration water application, water application rate, distance between the two drip sources, and the basic infiltration rate of the soil. It appears from the equations that there is a good agreement between the measured and estimated values.

b) An imperial relationship was derived to show the advancement behavior of the wetting front during the moisture and redistribution phases as a function of the duration of water application, the redistribution time, the water application rate, the distance between the two drip sources, and the basic infiltration rate.

c) The study proved that the vertical and horizontal wetting front advancement increases with increasing water application rate.

d) As the distance between the two drip sources increases, the width of the wetting pattern increases, and the vertical advancement under the emitter is greater than the vertical advancement at the middle interval between the two drip sources.

e) In the case of sandy mixture soil in the upper layer and clay soil in the lower layer, the vertical advancement wetting front is greater than in the case of clay soil in the upper layer.

f) The horizontal advancement is greater if the clay soil is above the sandy mixture.

g) The distance between the two drip sources is an important factor that affects the distribution of moisture within the soil in drip irrigation, as it turns out that the advance of the wetting front increases with the decrease in the interval under the same conditions, because the overlap time between the two horizontal wetting pattern between the two drip sources is less.

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تأثير التربة الطباقية بنسجتين على نمط الابتلال لمصدري تنقيط متجاورين

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الملخص

للري بالتنقيط أهمية في التقنين من استخدام مياه الري لاسيما في المناطق الجافة وشبة الجافة التي تعاني نقصاً حادا في الموارد المائية. لتخمين حجم التربة المبتلة تحت الري بالتنقيط، تم اجراء 12 فحص مختبري لتتبع تقدم جبهة الابتلال خلال ازمنة معينة لطوري الترطيب وطور اعادة توزيع الرطوبة نتيجة اضافة الماء من مصدري تنقيط خطيين وبثلاث فواصل بين المنقطات (30،40،50) سم لمقد تربة طباقي متكون من تربتين ذات نسجتين مختلفتين أحدهما (تربة طينية فوق مزيجية رملية) والأخر (تربة مزيجية رملية فوق طينية) ومعدلين للتصريف (0.956 و1.515 سم^3/دقيقة/سم). تم تمثيل البيانات بعلاقات تجريبية لتخمين نمط الابتلال بالاتجاه الافقي والعمودي وفي منتصف الفاصلة بين المنقطين وبمعامل تحديد 0.96، 0.98، 0.97 على التوالي. لوحظ ان نمط الابتلال يزداد بنقصان الفاصلة بين المنقطات وان هذه الزيادة منتظمة على امتداد المحيط المبتل وهذه الزيادة تكون أكبر في الاتجاه العمودي منه بالاتجاه الافقي ولكلا مقدي التربة وأن بزيادة معدل إضافة الماء يزداد التقدم العمودي حيث يكون أكبر في حالة مقد التربة (المزيجية الرملية فوق الطينية) أما التقدم الافقي فيكون واضح لمقد التربة (الطينية فوق المزيجية الرملية).

الكلمات الدالة:

الري بالتنقيط، التداخل بين بصلتي الابتلال، الفاصلة بين المنقطات