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Determination of Irrigation Lengths in Vertisol Soils Using the Two-Point Infiltration Method and Kostiakov-Lewis Equation

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ABSTRACT

Vertisol soils, which cover large lands in irrigated areas in Turkey and the world, swell when wet and form deep cracks when dry. These properties of Vertisol soils cause a significant decrease in irrigation efficiency when irrigating with surface irrigation methods, thus causing water insufficiency and drainage problems. If appropriate irrigation time, flow rate and furrow-border lengths are used, water application efficiency can be increased in these soils. For this purpose, two-point infiltration tests were carried out using 120 m long, 0.5-0.6% slopping furrows. A constant water level orifice was used to keep the flow rate unchanged during the tests. Water advanced and recession times were observed and recorded at stations created at 20 m intervals. Before and after the test, the cross-sectional area of the furrow was measured with a rill-meter. By evaluating the obtained data, the Kostiakov-Lewis infiltration equation, which is expressed as Z = 0.00822 τ 0.27695 + 0.00048 τ equation, was obtained. With the determined equation, the optimal irrigation length was estimated to be approximately 85 m for 90% water application efficiency and 115 m for 80% water application efficiency, using the advance and recession curves.

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İki Nokta İnfiltrayon Yöntemi ve Kostiakov-Lewis Denklemi Kullanılarak Vertisol Topraklarda Sulama Uzunluklarının Belirlenmesi

ÖZET

Türkiye ve Dünya'da sulanan alanlarda geniş arazileri kaplayan vertisol topraklar, ıslakken şişer ve kuruduğunda derin çatlaklar oluştururlar. Vertisol toprakların bu özellikleri, yüzey sulama ile sulanırken sulama randımanının önemli ölçüde düşmesine, dolayısıyla su yetersizliğine ve drenaj sorunlarına neden olur. Uygun sulama süresi, debi ve karık-border uzunlukları kullanılırsa, bu topraklarda su uygulama randımanları artabilir. Bu amaçla 120 m uzunluğunda, %0.5-0.6 eğimli karıklar kullanılarak iki nokta yöntemi ile infiltrasyon testleri yapılmıştır. Test süresince akış debisinin değişmemesi için sabit su seviyeli orifis kullanılmıştır. Su ilerleme ve çekilme süreleri 20 m aralıklarla oluşturulan istayonlarda gözlenerek kaydedilmiştir. Test öncesinde ve sonrasında rillmetre ile karık kesit alanı ölçülmüştür. Elde edilen verilerin değerlendirilmesiyle, $Z = 0.00822\,\tau^{0.27695} + 0.00048\,\tau$ eşitliği ile ifade edilen Kostiakov-Lewis infiltrasyon eşitliği elde edilmiştir. Belirlenen eşitlik ile, ilerleme ve çekilme eğrileri kullanılarak, %90 su uygulama randımanı için en uygun sulama uzunluğu yaklaşık 85 m ve %80 su uygulama randımanı için 115 m olarak tahmin edilmiştir.

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INTRODUCTION

Infiltration is one of the basic components of the hydrological cycle and is a highly complex process affected by many factors. The rate of infiltration, advanced and recession, which determine important aspects such as surface flow and deeper infiltration in-furrow and border methods. Advance and recession time in clogged border methods; a very important criteria that affects the maximum permissible application rate in rain and drop methods (Kanber, 1997).

Infiltration rate measurement methods could be listed as cylinder infiltrometer, sprinkler, ponding, blocked furrow, input-output flow measurement, and two-point method.

Numerous equations have been developed to explain the phenomenon of infiltration. These equations can be divided into three groups: physically-based equations, semi-empirical models, and empirical models (Turner 2006). Physically based equations are based on mass conservation and Darcy's laws. These approaches use data obtained from soil water properties and do not require measuring the infiltration. Green-Ampt Model, Philip Model, Smith and Parlange Model (Skaggs and Khalel 1982; Rawls et al. 1993). While the semi-empirical models were obtained to explain the experimental results. They are based on simple forms of the continuity equation and simple hypotheses that give a coherent infiltration rate. Horton, Holtan, Overton and Singh and Yu models are considered within the infiltration group (Rawls et al 1993). Empirical models have been derived from data obtained from field or laboratory experiments. Empirical models have a tendency to be less affected by assumptions about soil surface and profile properties, but are more restrictive if calibrated, so calibration parameters are determined based on real field measurements (Skaggs and Khaleel 1982, Hillel 1998). The mentioned models are the most used equations in the world. Kostiakov Models, modified by Huggins and Monke Models, are widely used in irrigation engineering (Kanber 1997).

As the swollen clayey soils dry, there are large cracks with significant effect on the infiltration. The frequency and intensity of drying of the soil profile and the increase in the number of wetting / drying cycles help to form cracks (Hulugalle et al. 2001). Vertisol soils are dominated by smectite clay minerals, which swell while wetting, shrinking and forming deep cracks (Probert et al 1987). The formation of large cracks and slits during the irrigation season in Vertisol soil causes considerable water losses, irrigation efficiency is falling and various problems arise. Depending on the formation of cracks, the infiltration parameters also have been changing with time.

After the estimation and calibration of infiltration parameters in furrow irrigation, a large number of studies have been carried out in order to optimize the irrigation criteria.

Application efficiency in undeveloped surface irrigation systems varies between 45 and 60%. With careful management and water control, reuse of tailwater, this value can be increased up to 70-85% (Ley 1978). It is stated that the efficiency of water application in a good irrigation network should not be less than 50-60% (Güngör et al. 1996; Bautista and Wallender 1993; Kanber 1997). Esfandiari and Maheshwari (1996) showed that furrow irrigation in Australia caused excessive water accumulation, surface flow losses, and salinity problems due to poor planning and management. For optimum water management in surface irrigation, detailed infiltration characteristics of the field to be planned should be known. Evaluation of field-based infiltration is very difficult due to terrestrial and temporal changes in soil physical properties, initial moisture content and management differences (Bautista and Wallender 1993). The two-point method is a simple, compact and relatively accurate inverse function widely used to estimate the parameters of the Kostiakov-Lewis function. However, the applicability of the method is limited to inclined free-draining furrows (Zerihun et al. 2004). The performance of the Kostiakov, Philip, and Horton (exponential equation) models showed that when compared with the Kostiakov-Lewis model results, the Kostiakov-Lewis model gave the best correlation between cumulative infiltration and time (Zhang et al. 2012).

Increasing irrigation efficiencies in vertisol soils covering large areas in our country depends on well-made infiltration tests at a significantly level. The reliability of the results obtained from spatially small footprint infiltration tests is quite low. If the test sites are vertisols and have deep cracks and crevices, their reliability is much reduced. However, it is difficult to repeat infiltration tests covering large areas. In addition, as the test area expands, soils variation increases and the uniformity disappears.

Taking into account the above explanations, and using infiltration data obtained at the end of the test study, we estimated the optimal irrigation lengths in vertisol soils irrigated by surface irrigation methods, in order to reduce the percolation losses and increase the irrigation efficiency in Harran plain.

MATERIAL and METHODS

The tests were carried out on the Harran Seri soil, which is widespread in the Southeastern Anatolian Region. For this purpose, the GAP Agricultural Research Institute land located on the 34th km of

Şanlıurfa-Akçakale road was used as a test site (Figure 1).

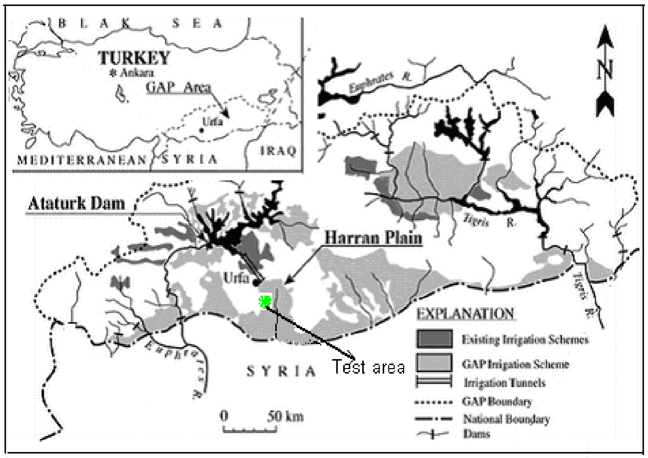

Figure 1. Geographic location of test area
Şekil 1. Test alanının coğrafi konumu

Climate Characteristics

The Harran Plain is under the influence of the Mediterranean and the continental climate characteristics of the South Eastern Anatolia Region. The summers are hot and dry, the winters are cold and rainy. The temperature difference between night and day is high.

The Soil Properties of Test Site

The study was carried out on the Harran series soil showing vertisol characteristics. The study area has alluvial material, flat and deep soils. The soils are generally heavily textured the studied area has a fairly flat topography and the average slope (s) is 0.65% (USDA-SCS, 1998). There is chlorite, illite, kaolinite, and quartz minerals in the Harran series soils along with smectite and palygorskite, the dominant clay minerals (Çakmaklı 2008). Some physical and chemical properties of the working-site soils are shown in Table 1.

Table 1. Some physical and chemical properties of the test site soil
Çizelge 1. Test sahası toprağının bazı fiziksel ve kimyasal özellikleri

Depth cm	pH	ECe dS m^{-1}	Texture				BD g cm^{-3}	FC %	PWP %	AW mm	RAW mm	Lime (%)	Organic matter (%)
			Sand%	Clay%	Silty%								
0 - 30	7.72	0.969	23.2	53.8	23.0	C	1.25	33.44	21.64	4.43	2.66	31.10	1.54
30 - 60	7.77	0.874	25.2	53. 8	21.0	C	1.30	32.34	21.99	4.04	2.42	25.40	1.32
60 - 90	7.74	0.961	25. 1	52. 8	22.0	C	1.35	34.38	22.75	4.71	2.83	24.30	
0-90										13.17	7.90		

pH, soil reaction; FC, Field capacity; PWP, permanent wilting point; AW, available water; BD bulk density; RAW readily available water

Two Point Infiltration Method

The methodology for the evaluation of alternate and continuous furrows was taken from the works of Walker and Skogerboe (1987), Walker (1989). The Kostiakov-Lewis infiltration equation has been used for obtaining infiltration parameters of soil with the Two-point methodology given by Walker and Skogerboe (1987).

$$Z = a\,\tau^{b} + f_0\,\tau \qquad (1)$$

where Z is the cumulative infiltration per unit length of the furrow (m^3 m^{-1}), τ is the intake opportunity time (min), k and a are empirical parameters, and f_0 is the empirical base of the infiltration rate (m^3 m^{-1} min^{-1}).

The method developed for the planning of surface irrigation; the method is also known as the volume balance approach. The method relies on the existence of an exponential relationship between the rate of progression of water and time over the furrow (Kanber 1997).

In the infiltration test with the two-point method, the progress of the water along the furrow (the advanced phase, the time to reach the waterfronts) and the recession phase to measure the total infiltration were measured (Walker and Skogerboe 1987). From the moment the test was brought to end, and after the water was cut, recession times were determined by measuring the time at which was reached these stations

It is assumed that the infiltration function is in the form of Kostiakov-Lewis form (Kanber 2010). For this purpose, the following equations were used.

$$X = pt^{r} \qquad (2)$$

$$r = \frac{\ln 2}{T_a - \ln T_{0.5a}} \qquad (3)$$

in equations; X, water is the distance of advanced, m; t, time since the beginning of the advanced, min; T_a total advanced time, minutes; $T_{0.5a}$ the time taken for water to travel halfway through the water in half of the furrow, or the half-way distance, in minutes; r and p are the empirical coefficients.

The coefficients for the Kostiakov-Lewis equation are obtained by using the progress data. For this purpose, the volume-balance equation for any time period is written as follows.

$$Q_0\,t = \sigma_y.A_o.X + \sigma_2.a.t_a.X + \left(\frac{f_o.t.X}{1+r}\right) \quad (4)$$

Where; A_0 is the flow cross-sectional area at the inlet of the furrow, m^2; Q_0, applied flow rate, $m^3\ min^{-1}$; t, the time elapsed since the beginning of the run, min; t_a, flow time, min; σ_y, surface storage shape factor, (0.70-0.809); σ_2, subsurface shape factor. Equivalent items are estimated by means of the equations given below.

$$\sigma_z = \frac{b + r(1-b) + 1}{(1+b)(1+r)} \quad (5)$$

$$A = \sigma_1 y^{\sigma_2} \quad (6)$$

$$WP = \gamma_1 y^{\gamma 2} \quad (7)$$

In equation; y, depth, m; WP, wet perimeter, m. The coefficients and exponents are empirical. The current cross-sectional area at the entrance of the furrow;

$$A_0 = C_1\left(\frac{Q_0 n}{60\sqrt{S_0}}\right)^{C_2} \quad (8)$$

The following equations are used for the calculation of the coefficients.

$$C_2 = \frac{3\sigma_2}{5\sigma_2 - 2\lambda_2} \quad (9)$$

$$C_1 = \sigma_1\left(\frac{\gamma_1^{0,67}}{\sigma_1^{1,67}}\right)^{C_2} \quad (10)$$

The infiltration coefficients such as a, b and f_0 at the end of the test carried out by the two-point method are estimated by the following equations (Walker and Skogerboe 1987).

In equation, Z, cumulative infiltration depth, cm; t, irrigation time, hour; f_o, basic infiltration rate, cm h^{-1}; a and b are the infiltration coefficients.

While the infiltration of water along the furrow was examined, the volume-equilibrium approach in the furrow end and the middle was determined by the following equations.

$$Q_0\left(T_{0,5a}\right) = \frac{\sigma_y A_o L}{2} + \frac{\sigma_2 a\left(T_{0,5a}\right)^b L}{2} + \left(\frac{f_o\left(T_{0,5a}\right)L}{2(1+r)}\right) \quad (11)$$

and for the field end,

$$Q_0\left(T_a\right) = \sigma_y A_o L + \sigma_2 a\left(T_{0,5a}\right)^b L + \left(\frac{f_o\left(T_a\right)L}{(1+r)}\right) \quad (12)$$

Here, $T_{0.5a}$, the time taken for water to travel half way through the neck, min; T_a, time to advance of water to the end of the furrow, min; L, lateral size, m; a and b infiltration coefficients; r, achievement equalization superiority.

$$b = \frac{\ln\left(V_a / V_{0,5a}\right)}{\ln\left(T_a / T_{0,5a}\right)} \quad (13)$$

$$V_a = \frac{QT_a}{L} - 0,77A_0 - \frac{f_0 T_a}{(r+1)} \quad (14)$$

$$V_{0,5a} = \frac{2QT_a}{L} - 0,77A_0 - \frac{f_0 T_{0,5a}}{(r+1)} \quad (15)$$

$$a = \frac{V_a}{\sigma_2 T a_a^b} \quad (16)$$

The value of f_0 in the infiltration equation is calculated by the following equation.

$$f_0 = \frac{Q_{in} - Q_{out}}{L} \quad (17)$$

The Q_{in} and Q_{out} values in the equation are the flow quantities entering and outgoing, $m^3\ min^{-1}$.

In making the tests and evaluating the results, was benefited from the principles given by Walker and Skorgerboe (1987); Mitchell and van Genuchten (1993); Waller and Wallender (1991); Kanber (1997; 2010).

Stream Size and Fixed Flow

A fixed head orifice was used to obtain constant flow during the tests (Figure 2). On the base of the orifice, there are drain pipes and on the upper side, there are discharge pipes to provide a constant head on both sides. The exit nipples on the orifice side were extended to the entrance of the test furrows with hoses. According to the diameters of the hoses, approximate the flow rates were calculated with orifice equality. Later, volumetric flow control was performed before starting the tests and the hoses outlet width were adjusted in the water outlet to obtain the appropriate flow rate.

Measurement of Furrow Geometries

At the beginning and end of each infiltration test, the geometry of the furrow was determined. For this purpose, the rill-meter was placed in the chosen places at the beginning, in the middle, and at the end of the furrow. Using the furrow and flow cross-sectional areas were determined (Kanber et al 1996).

Rillmeter is formed on a horizontal bar with 5 cm spacing and 16 pieces of 50 cm bar (Figure 3). To determine the furrow cross-section profile, the upper beam of the rillmeter was placed on the furrow parallel to the ground using a spirit level.

This beam was used as the reference plane in the measurements. After the vertical bars were placed parallel to each other and perpendicular to the reference plane, the sections from the top of the bars to the borders were measured to obtain the furrow cross-section profile.

This process was repeated three times throughout the ridge before and after irrigation to obtain an average value. Values, such as the depth of the furrow, the cross-section area, and the wet perimeters were determined with the obtained data.

Figure 2. Orifice used to provide a constant water head
Şekil 2. Sabit su yükü sağlamak için kullanılan orifis

Figure 3. Rillmeter used in measuring the flow cross-sectional areas
Şekil 3. Akış kesit alanlarının ölçülmesinde kullanılan rillmeter

This process was repeated three times throughout the ridge before and after irrigation to obtain an average value. Values, such as the depth of the furrow, the cross-section area, and the wet perimeters were determined with the obtained data.

Tests for Determining the Properties Furrow

The results obtained from the infiltration tests are discussed in detail in the following sections. In the test, 120 m length and 80 cm width furrows were used.

Before the test the average of the measurements was taken and plotted, and the furrow cross-sectional profile was determined (Table 2). The procedure was repeated after the test to determine the changes in the cross-section of the cross.

In order to determine the furrow depth and cross-sectional area values were used the obtained values from Figure 4, which these values are the average values of the rillmeter measurements before and after the test.

Table 2. Mean cross-section values obtained before and after the test
Çizelge 2. Test öncesi ve sonrası elde edilen ortalama kesit değerleri

Before	Average values, cm															
	23.9	25.0	24.1	21.4	18.2	15.5	12.7	10.7	11.3	13.6	15.6	18.4	21.7	24.2	25.7	25.3
After	25.5	26.8	25.4	22.9	20.1	18.0	15.7	14.2	14.3	15.5	17.5	20.8	23.3	25.9	26.5	25.2

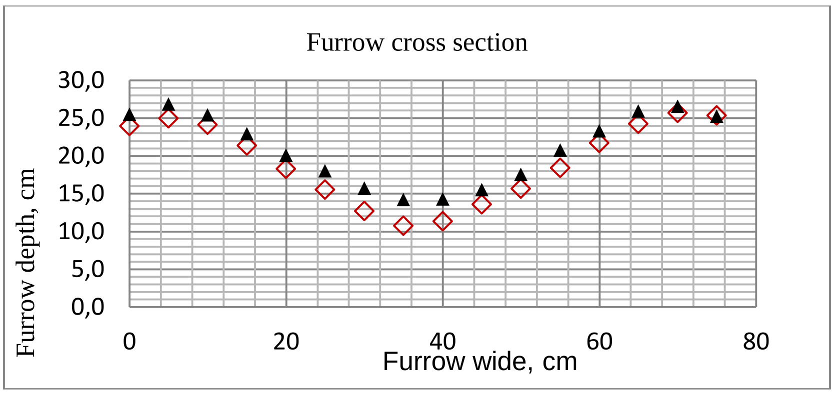

Figure 4. The cross-sectional profile, before and after the test
Şekil 4. Test öncesi ve sonrası kesit profili

The rillmeter measurements of the depth and width of the test furrow are given in Table 3.

Using Figure 4, the cross-sectional area per 1 cm height was calculated from the furrow bottom. In this process, as shown in the graph, the minimum point of the furrow bottom is 14.2 cm. This point was assumed to be 0. In this case, when the ordinate value is Y_1 = 15, the height from the bottom of the trough is found Y_1-Y_0 = 0.15-0.142 = 0.008 m (Table 4).

Continuing process, for each cm height, was found abscissa values of the furrow width, and at Table 4 were processed. Furrow width for each depth was determined by the difference X_2-X_1. When the depth of the furrow was 0.08 m, the furrow width was 0.12 m, and the furrow depth was 0.118 m, the furrow width was determined as 0.568 m.

By using the obtained values, the cross-section areas of the furrows were calculated for different depths of the furrows. Other properties related to the test furrows are given in Table 5.

Table 3. The relationship between the depth of the furrow and the width of the furrow
Çizelge 3. Karık derinliği ile karık genişliği arasındaki ilişki, m

	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Furrow depth, m	0.00	0.005	0.015	0.025	0.035	0.045	0.055	0.065	0.075	0.085	0.095
Furrrow wide, m	0.00	0.140	0.185	0.230	0.260	0.285	0.315	0.355	0.405	0.445	0.520

Table 4. Relationship between furrow depth and wide
Çizelge 4. Karık derinliği ile genişliği arasındaki ilişki

Ordinate	Y	**0.142**	**0.15**	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25	0.26
Height	H	0	**0.008**	0.018	0.028	0.038	0.048	0.058	0.068	0.078	0.088	0.098	0.108	**0.118**
Absis	X_1		31.5	28.8	27.2	25	22.5	20.4	18.2	16.5	14.9	13.2	11	8.5
Absis	X_2		43.5	46.5	49	50.9	52.4	53.8	55.4	57.3	59.5	61.3	63.1	65.3
Wide furrow	m	0	**0.12**	0.177	0.218	0.259	0.299	0.334	0.372	0.408	0.446	0.481	0.521	**0.568**

Table 5. Some properties of tested furrows
Çizelge 5 Test karığının bazı özellikleri

L	S_o	W	SMD	Q_{in}	Q_{runoff}	n1	n2	n3
m	m m^{-1}	m	cm	m^3 min^{-1}	m^3 min^{-1}			
120	0.0065	0.8	14.218	0.1125	0.05434	0.04	0.02	0.015

L; furrow length, SMD; soil moisture deficit; Q_{in} input flow; $Q_{runoff;}$ ouput flow; n1 for newly plowed soil; n2; Irrigated, smooth surface soils; n3 for dense vegetation covered soil that prevents water movement

RESULTS and DISCUSSION

Advanced and Recession Times

The length of furrows used in tests are 120 m, and the slope 0.65%, width of furrows 0.8 m and soil moisture deficit 0.14 m, and flow stream used q = 1.875 l s^{-1}. During the test period, the water was observed at stations at a distant of 20 meters and the time to reach the end of the furrow and the recession times also observed, after the water was cut off (Table 6).

The advanced and recession curves plotted from the obtained data are given in Figure 5. The water reached the middle of the furrow in 15 minutes, and to the end of the furrow in 45 minutes.

The recession time from the entrance of the furrow was measured as 248 minutes. At the beginning of the furrow, the rate of water advanced was high, towards the end of the furrow, as expected, decreased (Table 6). Calculated parameters for the tested furrow are given in Table 7.

At the end of the test, the cross-sectional area was measured and the mean values of the results obtained are given in Table 8.

At the end of the field tests, the furrow parameters calculated by evaluating the data obtained and the coefficients of the Kostiakov-Lewis infiltration equation are given in Table 9, and 10.

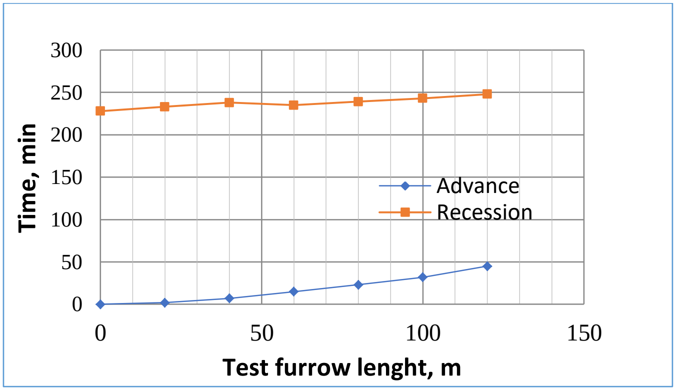

Figure 5. Advanced and recession curves
Şekil 5. İlerleme ve çekilme eğrileri

Table 6. Advanced-recession and net irrigation times

Çizelge 6 İlerleme ve çekilme eğrileri ile net sulama süreleri

Distance m	0	20	40	60	80	100	120	120	60
Advance time, min	0	2	7	15	23	32	45	45	15
Recession time, min	228	233	235	238	239	243	248	248	235
T_{net}	228	231	231	220	216	211	203		

Table 7. Parameters of tested furrow

Çizelge 7. Test karığına ilişkin parametreler

T. m	y. m	a_2	a_1	σ_1	σ_2
0.52	0.095	0.804775216	3.457053094	1.9155	1.80478
0.285	**0.045**				

Table 8. Parameters related to the furrow profile

Çizelge 8. Karık profiline ilişkin parametreler

Width (T), m	Depth (y), m	$(0,5*(T_i-T_{i-1}))^2$	$(Y_i-Y_{i-1})^2$	$2*((Y_i-(Y_{i-1}))^2+(Ti-(Ti-1))^2)^{0.5}$	$WP_{0.12}$	$WP_{0.06}$
0	0	0.00490	0.000025	0.14036	0.14036	0.14036
0.14	0.005	0.00051	0.0001	0.04924	0.04924	0.04924
0.185	0.015	0.00051	0.0001	0.04924	0.04924	0.04924
0.23	0.025	0.00023	0.0001	0.03606	0.03606	0.03606
0.26	0.035	0.00016	0.0001	0.03202	0.03202	0.03202
0.285	0.045	0.00023	0.0001	0.03606	0.03606	0.03606
0.315	0.055	0.00040	0.0001	0.04472	0.04472	**0.34297**
0.355	0.065	0.00063	0.0001	0.05385	0.05385	
0.405	0.075	0.00040	0.0001	0.04472	0.04472	
0.445	0.085	0.00141	0.0001	0.07762	0.07762	
0.52	0.095	0.06760	0.009025	0.55362	0.55362	
					1.11751	

Table 9. Parameters related to the furrow profile (Kanber, 2010)

Çizelge 9. Karık profiline ilişkin parametreler

$WP_{0.12}$	$WP_{0.06}$	y_{end}	$y_{initial}$	γ_2	γ_1	C_2	C_1	A_o
1.11751	0.34297	0.095	0.045	1.581	46.163	0.924	7.530	0.0119

r	f_o	V_L	$V_{0.5L}$	b	σ_z	a
0.631	0.00048	0.0196	0.0145	0.2770	0.83219	0.00822

Table 10. Parameters calculated from the data obtained at the end of the test

Çizelge 10. Test sonunda elde edilen verilerden hesaplanan parametreler

Ao	r	f_o	V_L	$V_{0.5L}$	b	σ_z	a
0.01194	0.63093	**0.00048**	0.01962	0.01447	**0.27695**	0.83219	0.00822

a_2	a_1	s_1	s_2	$WP_{0.12}$	$WP_{0.06}$	γ_2	γ_1	C_2	C_1
0.80478	3.45705	1.9155	1.80478	1.11751	0.34297	1.58083	46.1627	0.9236	7.52952

Kostiakov-Lewis infiltration equation in the test was found as follows;

$$Z = 0.00822\ \tau^{0.27695} + 0.00048\ \tau \qquad (18)$$

in equation; τ is the intake opportunity time, min and Z the cumulative infiltration per unit length of furrow, $m^3\ m^{-1}$.

By using this infiltration equation with the advanced and recession curves obtained by the tests, furrow, and border lengths could be calculated as follows in Harran plain vertisol soils.

The soil moisture content in the test period is close to the moisture content before irrigations in Harran Plain. This season can be accepted as the most appropriate time for the infiltration test in terms of soil water content. Because, when the soil is very dry, the test results cannot be reflecting exactly the soil moisture conditions during the irrigation season. Therefore, the infiltration coefficients could be more different than expected.

To meet this objective the quarter-time rule says that the stream size should be large enough for the water to reach the end of the field (furrow irrigation) the contact time is the time needed to infiltrate the required amount of water (FAO 1989).

Considering the soil properties, it can be easily calculated that the available water is about 13.17 cm at a depth of 90 cm. For the 1.2 m effective root zone of cotton, the required water for each irrigation considering that irrigation is made when 60% of the available capacity for field crops is consumed,

diw=13.17x1.2/0.9 x0.60 = 105 mm as is calculated.

In this case, if it is made a graphical solution, from Figure 6, or the Kostiakov-Lewis equation it is found that the infiltration time of 105 mm of water is 104 minutes. Clemmens et al. (1998) used criteria such as water advanced and infiltration furrow irrigation planning. Kanber et al. (1996), Walker, and Skogerboe (1987), Walker (1989), Renault and Wallender (1996). Temizel and Apan (2010), and FAO (1990) reported that; to achieve 90% water application efficiency, the water-front must reach the end of the furrow in 1/4 of the net infiltration time.

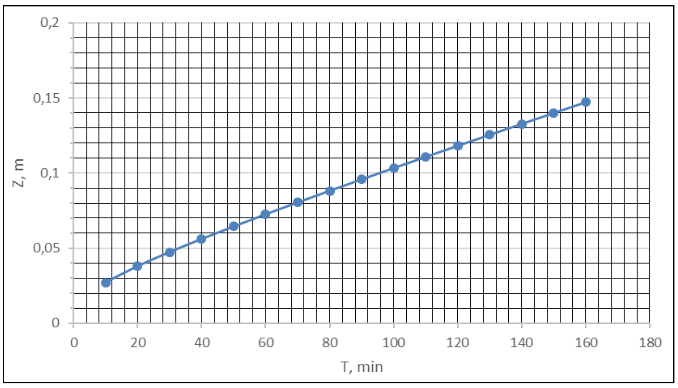

Figure 6. Cumulative infiltration and time relation
Şekil 6. Eklenik infiltrsyon ve zaman ilişkisi

Taking into account that here the advanced time is calculated as;

$t_a=T_n/4=150/4=37.5$ minutes.

In the advanced curve for the test area from Figure 7, the maximum length of the furrow may estimate to be approximately 85 m. Likewise, assuming that 80% of the irrigation efficiency is sufficient, it will be sufficient for the water front to reach the end of the furrow, in 40% of the net infiltration time. In this case, the advanced time will be 104 minutes x 0.40 = 41.6 minutes.

From here, the irrigation length, i.e. furrow length, is found approximately 115 m, using the advanced curve of Figure 7. Of course, the furrow length also will change depending on the flow rate, and the rate of advance increases. Increasing the length of the furrow reduces requirement efficiency (RE), requirement distribution efficiency (RDE), total distribution efficiency (TDE) values (Holzapfel et al. 2010).

CONCLUSIONS

The main objective of furrow irrigation is the appropriate selection of planning and managerial variables. These variables are the furrow length, flow rate to the furrow, and cutoff time. These variables are computed through optimization based on minimizing the total irrigation cost and maximizing the application efficiency of irrigation. As the water advanced rate rapidly decreases with increasing furrow length, systems can be designed to provide the opportunity time required to achieve the desired water application at less than the full length, for example, about 80 percent of the total length from the top end (USDA-NRCS, 2012).

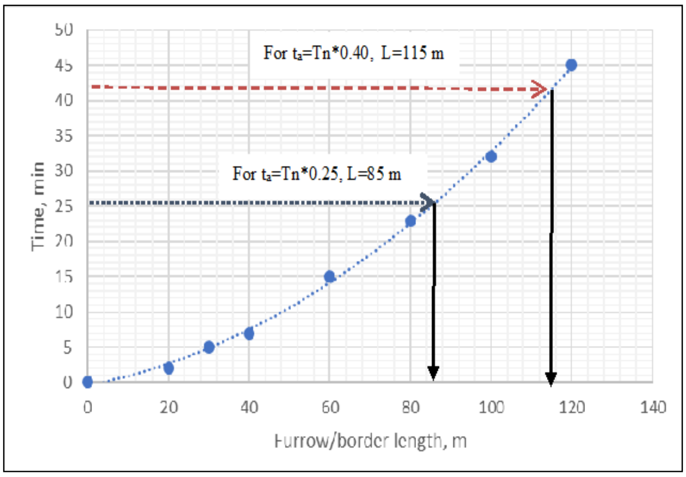

Figure 7. Estimating irrigation length using the water advanced curve

Şekil 7. İlerleme eğrisi kullanılarak sulama uzunluğunun kestirimi

Normally stream sizes up to 0.5 L s^{-1} will provide adequate irrigation provided the furrows are not too long. When larger stream sizes are available, water will move rapidly down the furrows and so generally furrows can be longer. The maximum stream size that will not cause erosion will depend on the furrow slope; in any case, it is advised not to use stream sizes larger than 3.0 l s^{-1} (FAO 1990). The flow stream size used in this study was 1.875 l s^{-1} and will not lead to erosion according to this soil structure.

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Contribution of the Authors as Summary

Author declares the contribution of the authors is 100%.

Statement of Conflict of Interest

Author has declared no conflict of interest.

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