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Different furrow management techniques for cotton production and water conservation in Harran Plain, Şanlıurfa

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Abstract: In this study, the water saving and conservation potential of various furrow irrigation management techniques for irrigated cotton were compared. Conventional every-furrow irrigation with open-end furrows (EFO) and blocked-end furrows (EFB), and alternate every-other-furrow management with open-end furrows (AFO) and blocked-end furrows (AFB), were considered. Considerable seasonal water savings were obtained with AFO and AFB flows, on average from 717 mm to 906 mm, respectively, when compared to EFO. Alternate furrows showed the ability to reduce tailwater runoff considerably. When compared with EFO, water use was reduced by 9063 m^3 ha^{-1} (60%) using AFB and 7167 m^3 ha^{-1} (48%) using AFO, with decreases in yield of 765 kg ha^{-1} (27%) and 492 kg ha^{-1} (17%), respectively. Similarly, average water use efficiencies were 0.36 kg m^{-3} for AFB and 0.31 kg m^{-3} for AFO, compared to 0.20 kg m^{-3} for EFO. Results showed the possibility of applying alternate-flow furrow management techniques for water conservation in cotton irrigation. Additionally, the alternate furrow method could also be considered as a deficit irrigation approach in the Harran Plain.

Key words: Alternate furrow, cotton, irrigation efficiencies, surface irrigation, Harran Plain

Şanlıurfa Harran Ovası'nda pamuk üretimi ve su artırımı için farklı karık işletim teknikleri

Özet: Bu çalışmada, pamuk tarımında, su artırımı ve korunumu ile ilişkili olarak, farklı karık işletim biçimleri karşılaştırılmıştır. Geleneksel sürekli karıklarla ardışık karıklar, serbest drenajlı (SKSD, AKSD) ve gölendirmeli (SKG, AKG) olarak, ele alınmıştır. Sürekli karık yöntemine göre, ardışık karıklardan ortalama 717-906 mm mevsimlik su artırımı sağlanmıştır. Ardışık karık sulama tekniklerinin, yüzey akış kayıplarını önemli ölçüde azalttığı saptanmıştır. Ucu açık karıkla (serbest drenajlı) karşılaştırıldığında, su kullanımı, sırasıyla, AKG tekniğinde 9063 m^3 ha^{-1} (% 60), AKSD'de ise 7167 m^3 ha^{-1} (% 48); verim, anılan tekniklerde sırasıyla, 765 kg ha^{-1} (% 27) ve 492 kg ha^{-1} (% 17) azalmıştır. Aynı şekilde, su kullanım randımanı, AKG'de 0.36 kg m^{-3} ve AKSD'de 0.31 kg m^{-3}, SKSD'de ise 0.20 kg m^{-3} olarak elde edilmiştir. Sonuçlar, pamuk sulamasında su artırımı için ardışık karık yönteminin kullanılabileceğini göstermiştir. Ayrıca, ardışık karık yönteminin Harran Ovası'nda bir kısıntılı sulama yaklaşımı olarak kabul edilebileceği anlaşılmıştır.

Anahtar sözcükler: Ardışık karık, pamuk, sulama randımanları, yüzey sulama, Harran ovası

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Introduction

Furrow irrigation is the dominant practice for cotton production in the Harran Plain of Şanlıurfa (Tekinel et al. 2001; Gençoğlan et al. 2005). Moreover, the tendency of farmers in this area to overirrigate results in drainage and salinity problems (Kanber et al. 2001). Because of the rising water table, some parts of the Harran Plain have serious problems such as salinization, alkalization, and nitrate pollution of shallow ground water (Çullu et al. 2000; Özer and Demirel 2004). At the same time, inconvenient irrigation management causes water shortages due to increasing farm water losses, and productivity decreases (Kanber et al. 1996; Kanber et al. 2001). Improvement of the existing irrigation system and management techniques is necessary to ensure more efficient water use without significantly reducing cotton yield.

Alternate/fixed every-other-furrow irrigation can promote irrigation efficiency and prevent loss of water (Hodges et al. 1989; Sepaskhah and Kamgar-Haghighi 1997). Since a reduced amount of irrigation water applied does not consistently reduce yields, water use efficiency may be increased (Graterol et al. 1993). In addition, alternate furrow irrigation methods supply water in a manner that greatly reduces the amount of surface wetted, leading to less evaporation and less deep percolation.

Many scientific results have shown that alternate furrow irrigation techniques with a combination of narrow- and wide-spaced furrow irrigation are used with many row crops for the successful management of irrigation (Graterol et al. 1993; Sepaskhah and Kamgar-Haghighi 1997; Kang et al. 2000). However, the results obtained from some crops, such as sorghum (New 1971), dry bean (Samadi and Sepaskhah 1984), sugar beet (Sepaskhah and Kamgar-Haghighi 1997), and maize (Mintesinot et al. 2004), revealed some yield reductions in alternate furrow irrigation when compared to every-furrow irrigation. Stone and Nofziger (1993) stated that wide-spaced furrow irrigation can often produce acceptable cotton yields with less water than every-furrow irrigation. Similar results were found by Yavuz (1993) in the Seyhan Plain in Adana. Goldhamer and Peterson (1984) compared a linear-move sprinkler machine and a 380 m-long alternate furrow irrigation system on a sandy loam soil. They found slightly lower cotton yields for the alternate furrow system; however, similar amounts of infiltrated water occurred in both systems.

The purposes of this work were to present and discuss improvements to furrow irrigation systems that will result in lower irrigation water use and higher irrigation performance, but that do not require heavy investment and may be easily adopted.

Materials and methods

This study was conducted in a cotton field at the Koruklu Research Center located in the Harran Plain in Şanlıurfa province (36°42′N, 38°58′E; altitude: 410 m) during the 1993-1995 growing seasons. A semiarid climate prevails in this area, with warm winters and hot and dry summers. The average temperature is 18.1 °C and the average annual rainfall is 330 mm. Relative humidity is about 70% in the winter months and decreases to 27% during the summer.

The experimental soil was from the Harran soil series (*Luvic Calcirol* from Dinç et al. 1991; *Vertic Xerochreph* from USDA-SCS 1998), which is widespread in the Harran Plain. The field was 160 m long, with furrows spaced at 0.7 m with an average 0.13% slope. The soil bulk density (γ_d, g cm^{-3}) was determined by the methodology suggested by Walker (1989). Some soil properties for irrigation were determined using the standard laboratory methods (Tüzüner 1980). Experimental soil has high soil water-holding capacity, and it is very appropriate for surface irrigation using high application depths and low irrigation frequency (Table 1).

In this study, 4 irrigation treatments were analyzed. First, every-furrow irrigation (EFO), in which water is always applied to every furrow, uses open-end furrows and is known as the conventional continuous furrow application. Second, every-furrow irrigation with blocked furrows (EFB) does not allow runoff losses. Third, alternate every-other-furrow irrigation with open-end furrows (AFO) applies water to the furrow that was dry in the previous irrigation cycle. Fourth, alternate every-other-furrow irrigation with blocked-end furrows (AFB) is similar to AFO, but runoff losses are not allowed due to the blocked-end furrows.

Table 1. Soil characteristics of the experimental field.

	Soil depth (m)			
	0-0.3	0.3-0.6	0.6-0.9	0.9-1.2
Organic matter (%)	1.7	1.3	-	-
Mineral matter (%)	98.3	98.7	100.0	100.0
Sand (%)	8.9	8.5	8.7	8.7
Silt (%)	29.5	25.4	24.3	23.2
Clay (%)	61.6	66.1	67.0	68.1
Soil texture	Clay	Clay	Clay	Clay
EC (dS m^{-1})	0.253	0.149	0.201	0.185
pH (in paste)	7.45	7.46	7.40	7.40
Bulk density (g cm^{-3})	1.32	1.37	1.31	1.45
Field capacity, FC (m^3 m^{-3})	0.461	0.475	0.464	0.519
Wilting point, PWP (m^3 m^{-3})	0.284	0.290	0.282	0.312
Available water, AWC (mm)	53.1	55.5	54.6	62.1

An inflow rate of 0.072 m^3 min^{-1}, which was predetermined according to the technique suggested by Merriam et al. (1980), was used in all treatments. This amount is about 25% of the amount estimated by the above method. This selection of inflow rate was very appropriate for these soils, which have a high intake rate and very low slopes. Figure 1 shows that the plots, which were randomly distributed, were placed side by side with 2 replications.

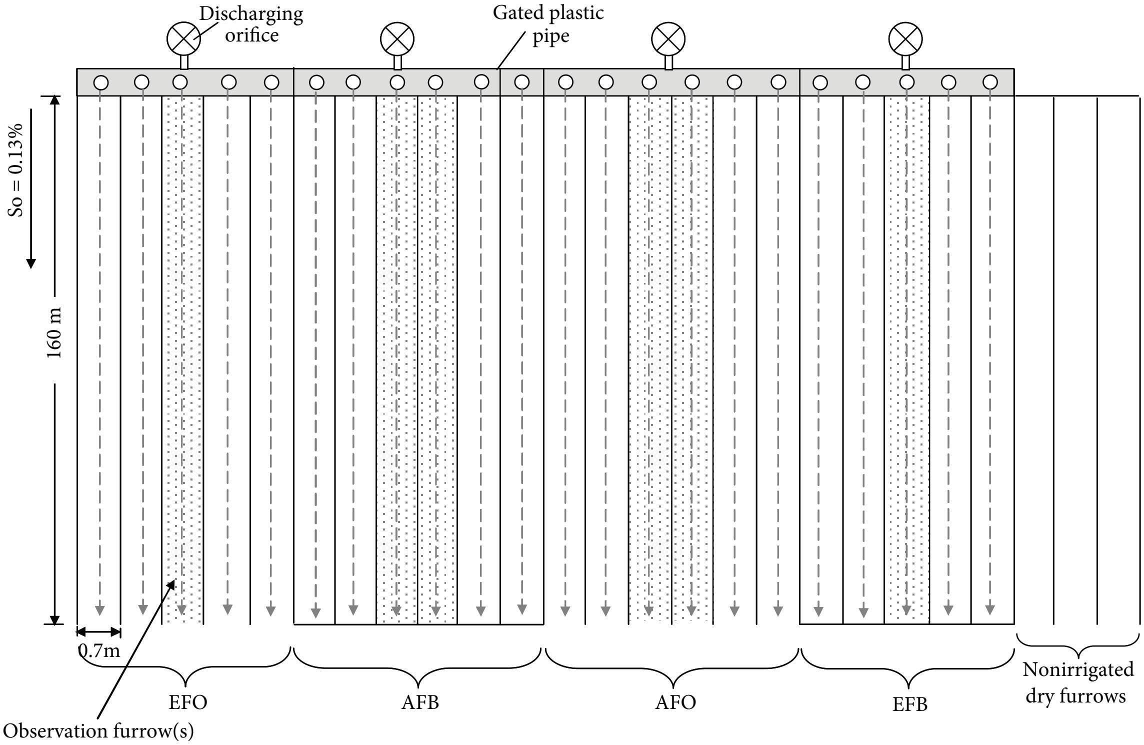

Figure 1. Schematic diagram of the plots in the first replication of the experiment. The average slope in the furrow flow direction was S_{fd} = 0.001302 m m^{-1}, ranging from 0.00125 to 0.001438 m m^{-1}. The standard deviation of the slopes was STDEV = 0.0002202 m m^{-1} and the coefficient of variation was CV = 0.10. The average slope across the field was S_{across} = 0.00048 m m^{-1}, with a standard deviation of STDEV = 0.000021 m m^{-1} and coefficient of variation of CV = 0.06.

Water was applied through a gated plastic pipe connected to barrels, in which a constant hydraulic head was created. For obtaining the constant flow rate, the holes of the pipes were adjusted by a gate plug. This system was installed on the upper side of every plot. The flow rates were checked by volumetric methods during the tests (Kanber et al. 2001).

Irrigation water taken from a deep well has an average sodium adsorption ratio (SAR) of 1.15 and electrical conductivity (EC) of 0.294 dS m^{-1}, which has no restrictions since it is much lower than the threshold salinity (5.1 dS m^{-1}) of cotton (Ayers and Westcot 1989). As for the water quality impacts on soil permeability, the combination of SAR and EC posed little or no restrictions on use (Grattan 2002).

Irrigations were applied at intervals of approximately 10 to 14 days based on treatment. The available soil water content at a root depth of 1.2 m was depleted to between 60% and 85% according to treatments at the beginning of the applications. Çetin (1992) and Kanber et al. (2001) indicated that the available water depletion level could be larger than 0.68. This is probably because a cotton crop likes and even requires some stress in order to produce a high yield.

Soil water content was determined by the neutron scattering method 1-2 days before and 2-3 days after irrigation, sowing, and harvest times at the head, middle, and end of the furrows at 0.3 m increments and at a depth of 1.2 m. Soil water data were used to estimate the irrigation depth required (Z_{req}).

For the EFO and AFO treatments, the inflow was stopped when the total outflow period equaled the intake opportunity time, which was estimated by using soil moisture deficit in infiltration functions for each application (Walker 1989). Total irrigation time or cut-off time (t_{co}) for these treatments was estimated as in Eq. (1):

$$t_{co} = T_a + T_i \qquad (1)$$

where t_{co} is the cut-off time (min), T_a, is the advance time (min), and T_i, is the intake opportunity time for the soil moisture deficit at the lower end of the furrow (min).

In the EFB and AFB treatments, total irrigation time was determined using soil moisture deficit, furrow area, and constant water flow. The water flow to the furrows was stopped when the total irrigation time was finished. Total irrigation time was calculated by Eq. (2)

$$t_{co} = \frac{SMD \times L \times s}{q_{in}} \qquad (2)$$

where *SMD* is the soil moisture deficit (m), q_{in} is the inflow rate (m^3 min^{-1}) during an irrigation event, and *L* and *s* are the length and spacing (m) of a furrow, respectively.

The methodology for the evaluation of alternate and continuous furrows was taken from the works of Walker and Skogerboe (1987), Walker (1989), and the ASAE (2003). The Kostiakov-Lewis infiltration equation was used for obtaining infiltration parameters of soil with the 2-point methodology given by Walker and Skogerboe (1987):

$$Z = k\,\tau_a + f_o\tau \qquad (3)$$

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

The initial values for the infiltration parameters f_o, *k*, and *a* were determined from flow advance and recession in the test furrows using the stations located at 20 m intervals along the furrows. In addition, furrow cross-sectional profiles at 3 locations (upper end, middle, and lower end along the furrows) and outflow losses were measured.

The roughness parameter of the Manning *n* was obtained from direct observations. For calculation of *n*, furrow cross-sectional area, furrow slope, flow water depths, and water surface width were used (Walker and Skogerboe 1987; Horst et al. 2005, 2007).

Performance indicators such as application efficiency (E_a), distribution uniformity (*DU*), water requirement efficiency (E_r), infiltration efficiency (*IE*), tailwater runoff (*TW*), and deep percolation (*DP*) were calculated using the approaches given by Walker and Skogerboe (1987). All performance parameters were calculated by Eqs. (4-8) (Walker and Skogerboe 1987).

$$E_r = 100 \times \frac{Z_{ave}}{Z_{req}} \tag{4}$$

$$IE = 100 \times \frac{Z_{ave}}{Z_D} \tag{5}$$

The average depth of water applied (D, mm) for the EFO and AFO treatments was computed from the following equations.

$$D = \frac{q_{in} \times 60 \times T_{co}}{L \times s} \tag{6}$$

$$Ea = \begin{cases} \dfrac{Z_{req}}{D} & Z_{lq} \geq Z_{req} \\ \dfrac{Z_{ui}}{D} & Z_{lq} \leq Z_{req} \end{cases} \tag{7a}$$

$$Z_{ui} = \frac{(SMD \times L_{xd}) + Z_{zi}(L - L_{xd})}{L} \tag{7b}$$

$$DU = 100 \times \frac{\overline{Z}_{lq}}{Z_{ave}} \tag{8}$$

Here, Z_{req} is the average depth required to refill the root zone in the quarter of the field with a higher water deficit (mm); L_{xd} is the length of a furrow that is fully irrigated (m); Z_{zi} is the average depth of infiltrated water in the underirrigated furrow length (mm); Z_{ui} is the average infiltrated water depth, with the exception of deep percolation losses, along the furrow length (mm); Z_{ave} is the average depth of infiltrated water along the furrow (mm); and $\overline{Z}_{lq}$ is the low quarter average depth of infiltrated water (mm).

The depth of infiltrated water (Z_i) during intake opportunity time for each station (i) along the furrows was calculated using the Kostiakov-Lewis equation:

$$Z_i = k\,[T_r - (T_a)_i]^a + f_0\,[T_r - (T_a)_i] \tag{9}$$

where T_r and T_a are recession and advance times (min) at the station (i), respectively. A similar procedure was applied to estimate the average Z_{lq}.

Deep percolation (DP) for each station (i) was estimated from the difference between Z_i and Z_{req} (Walker 1989). Runoff loss data for the EFO and AFO treatments, measured by Parshall flumes at the end of the furrows, were used to create tailwater hydrographs with respect to time. Total runoff losses (RF) were evaluated by using a perpendicular trapezoidal approach on the tailwater hydrographs (Walker and Skogerboe 1987). Actual evapotranspiration values (ET, mm) for all treatments were calculated as in Eq. (10):

$$ETa = P + D + S_g - DP - RF \pm \Delta W \tag{10}$$

where P is rainfall received during the growing period (mm), ΔW is the change of soil water content (final minus initial; mm), and S_g is the capillary contribution from the ground water table (mm). Since the water table was lower than 15 m, S_g is nearly 0.

Irrigation water use efficiency (WUE_{IR}) was estimated by Eq. (11) using the model given by Howell et al. (1990), which is yield produced per cubic meter of irrigation water:

$$WUE_{IR} = \frac{Ya}{D} \tag{11}$$

The water-consumed fraction at field level for the growing season (WCF_{field}) was estimated by Eq. (12) (Pereira et al. 2002):

$$WCF_{field} = \frac{ETa}{D + P} \tag{12}$$

where ETa is the actual water consumption (mm) and Ya is cotton yield (kg ha^{-1}).

Considering that a leaching fraction (LF) is required for the Harran soils, a beneficial water use fraction ($BWUF_{field}$) was calculated by Eq. (13) (Pereira et al. 2002):

$$BWUF_{field} = \frac{ETa\left(1 + \frac{LF}{100}\right)}{D + P} \tag{13}$$

Here, LF corresponds to about 7.3% for the Harran soils (Berekatoğlu and Bahçeci 2005).

Results

The fixed inflow rate was found to be erosive in the EFO furrow applications, particularly for the first irrigation (Figure 2). Alternate flow subjects the furrow bottom to less erosion and ensures better conditions to preserve soil fertility. The amount of sediment transported out of the field was higher in the EFO treatment (average of 0.53 g L^{-1} for all seasons) than in AFO (average of 0.13 g L^{-1}).

Some main irrigation parameters (Table 2), inflow-outflow hydrographs (Figure 3), and average water advance times (Figure 4) were different among the treatments.

The average advance velocities in both the AFO and AFB treatments were 24% and 58%, respectively, lower than that of the EFO treatment (Figure 4). Thus, the highest amount of water in the EFB treatment, with 64% of the total applied water, was used for advance. In the EFO treatment, this amount was only 48% of the total applied water.

Typical advance and recession behavior was different from one treatment to another (Figure 5, Table 2). Advance and recession rates varied depending on furrow management techniques. In the beginning of the irrigation season, when soil was highly permeable, advance rates were rather slow; they were faster mid-season. However, advance rates were slow at the end of the season, due to low soil moisture content in the profile (Table 2).

The observed average hydraulic roughness coefficient (*n*) was 0.0463 $m^{-1/3}$ s with a standard deviation of 0.00156. A certain variation in the *n* coefficients from the first to the last irrigation event was determined. They varied by 0.0356-0.0555 $m^{-1/3}$ s from the first to the seventh irrigation event for all furrows (Table 3).

There were seasonal variations in the final infiltration rate and infiltration parameters for the treatments (Table 4 and Figure 6). Both coefficients *k* and *a* and the final infiltration (*fo*) values varied from irrigation to irrigation and from year to year. The *fo* rate was quite similar when all open-end furrow treatments are considered ($P \geq 0.01$; $t_{cal} = 1.68$). The average *fo* was about 0.000215 $m^3\ m^{-1}\ min^{-1}$ with considerable variation (CV = 0.47). The *k* values in the first irrigation events for open-end furrows were 2-3 times higher than those for block-end furrow treatments (averaging 0.0162 for open-end and 0.0055 $m^3\ m^{-1}\ min^{-1}$ for block-end). The average *k* parameter of block-end furrows for the whole season was 17% less than that of open-end furrows. Values of *a* for block-end furrows were 2.5 times higher on average than those of open-end furrows. However, values of *a* reached the maximum level at the first irrigation and then decreased toward the end of the irrigation season with some minor exceptions.

The average infiltrated water and soil moisture deficiency values at every station along the furrow show the type of the irrigation level (Figure 7). For infiltrated water, generally, the EFO, EFB, and AFO treatments resulted in overirrigation and full irrigations. However, infiltrated water depth along the furrow in the AFB treatment was less than required. In this treatment, irrigation water was not sufficient to irrigate the entire furrow length due to slow water advance.

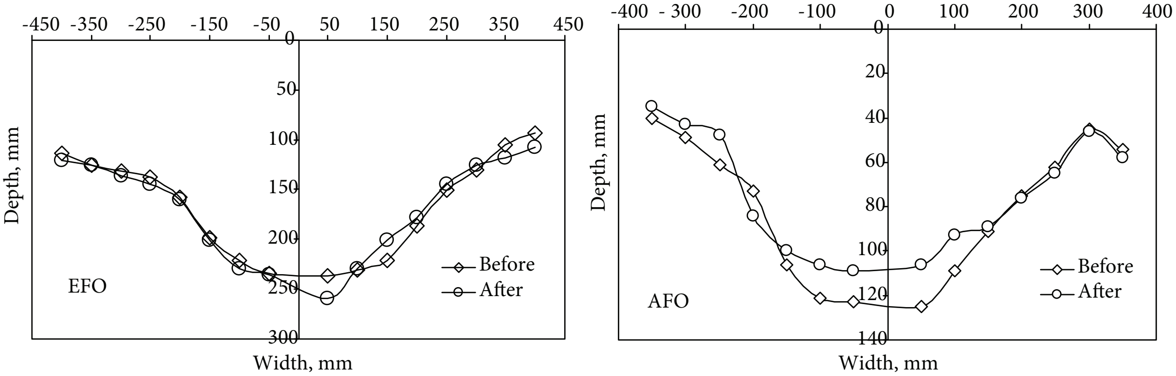

Figure 2. Typical furrow cross profiles before and after irrigation for open-end furrows irrigation (1993, third irrigation for EFO and fourth irrigation for AFO).

Table 2. Main measured irrigation parameters for treatments.

Year	Irrigation components		EFO		AFO		EFB		AFB	
1993	General	Irr. events	1st	7th	1st	7th	1st	7th	1st	7th
		$q_{\text{in (project)}}$	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
		$q_{\text{in (average)}}$	1.21	1.27	1.21	1.21	1.2	1.2	1.22	1.27
		$p_{\text{(before irr)}}$	0.68	0.77	0. 73	0.84	0.67	0.75	0.68	0.89
		t_{co}	275	315	305	400	238	264	238	297
	Wetting	$t_{\text{in-flow}}$	120	135	135	169	51	67	7	9
		$q_{\text{in-flow}}$	1.21	1.27	1.21	1.21	1.2	1.2	1.22	1.27
		t_{adv}	155	180	170	231	187	197	245	306
		L_{adv}	160	160	160	160	160	160	160	160
	Out flow	$t_{\text{out-flow}}$	152	200	160	209	-	-	-	-
		$q_{\text{out-flow}}$	0.41	0.26	0.20	0.29	-	-	-	-
1994	General	Irr. events	1st	7th	1st	7th	1st	7th	1st	7th
		$q_{\text{in (project)}}$	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
		$q_{\text{in (average)}}$	1.21	1.26	1.2	1.25	1.21	1.28	1.27	1.28
		$p_{\text{(before irr)}}$	0.73	0.82	0.75	0.85	0.72	0.80	0.73	0.88
		t_{co}	417	388	442	441	254	265	246	292
	Wetting	$t_{\text{in-flow}}$	240	181	232	175	86	82	49	62
		$q_{\text{in-flow}}$	1.21	1.26	1.2	1.25	1.21	1.28	1.27	1.28
		t_{adv}	177	207	210	266	168	183	197	232
		L_{adv}	160	160	160	160	160	160	160	160
	Out flow	$t_{\text{out-flow}}$	257	216	278	220	-	-	-	-
		$q_{\text{out-flow}}$	0.46	0.48	0.32	0.46	-	-	-	-
1995	General	Irr. events	1st	7th	1st	7th	1st	7th	1st	7th
		$q_{\text{in (project)}}$	1.2	1.2	1.2	1.20	1.2	1.2	1.2	1.2
		$q_{\text{in (average)}}$	1.2	1.27	1.2	1.17	1.23	1.17	1.2	1.27
		$p_{\text{(before irr)}}$	0.54	0.61	0.56	0.88	0.53	0.58	0.54	0.87
		t_{co}	215	338	254	371	192	210	186	293
	Wetting	$t_{\text{in-flow}}$	60	165	76	165	62	85	0.0	0.0
		$q_{\text{in-flow}}$	1.2	1.27	1.2	1.17	1.23	1.17	1.2	1.27
		t_{adv}	155	173	178	205	130	125	180	293
		L_{adv}	160	160	160	160	160	160	160	140
	Out flow	$t_{\text{out-flow}}$	120	330	136	299	-	-	-	-
		$q_{\text{out-flow}}$	0.45	0.27	0.17	0.22	-	-	-	-

$q_{\text{in (project)},}$ design inflow, L s^{-1}
$q_{\text{in (average)},}$ average actual inflow rate, L s^{-1}
$p_{\text{(before irr)},}$ actual depletion fraction of total available soil water in the 120-cm depth before irrigation
t_{co}, cut-off time, min
t_{adv}, advance time, min
$q_{\text{in-flow}}$, actual inflow to furrow, L s^{-1}
L_{adv}, distance of advance, m
$t_{\text{in-flow},}$ wetting time, min (time duration after advance to cut-off time)
$t_{\text{out-flow},}$ duration of outflow, min
$q_{\text{out-flow},}$ actual outflow rate, L s^{-1} (average outflow)

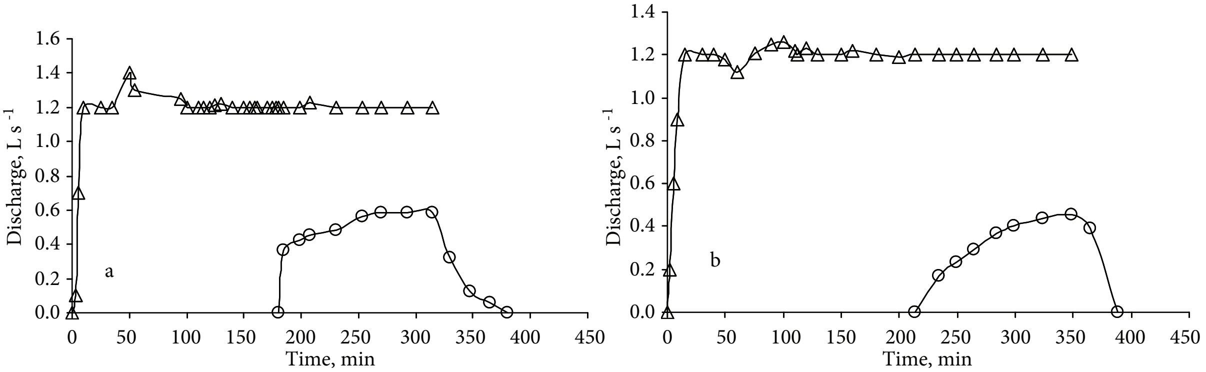

Figure 3. Typical inflow (Δ) and outflow (o) hydrographs for EFO third event (a) and AFO second event (b) in 1993.

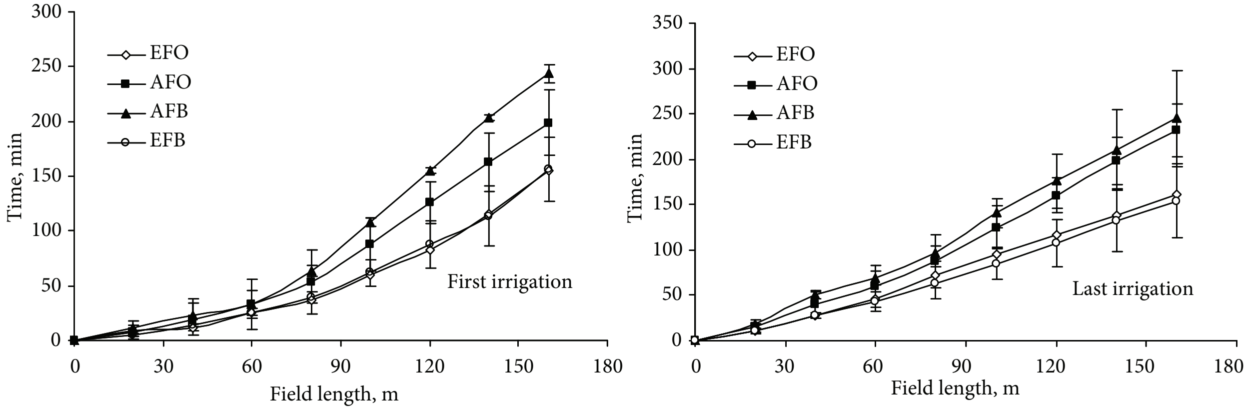

Figure 4. Comparison of the average advance curves for steady-flow and alternate-flow with open-end furrows and blocked-end furrows (each point on treatment curves shows the average value of 3 irrigation events).

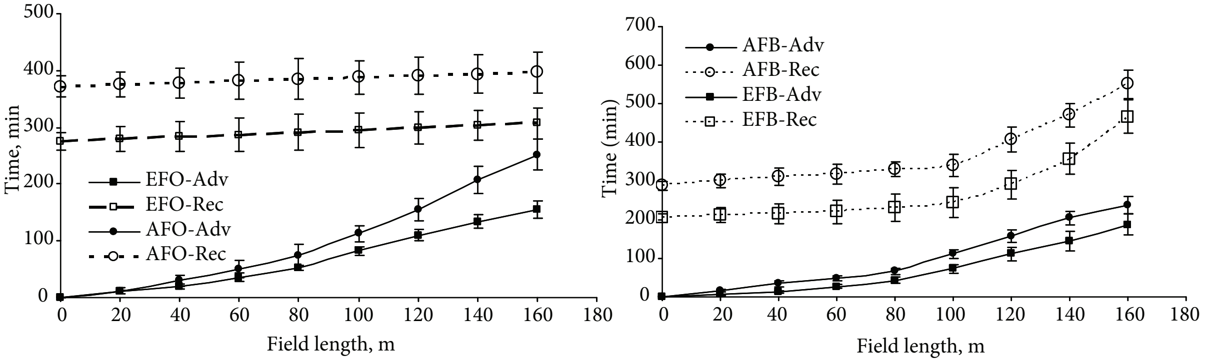

Figure 5. Typical advance-recession curves for open-end furrows and blocked-end furrows used with continuous flow and alternate flow (each point on treatment curves shows the average value of all 21 irrigation events).

The highest water storage values were recorded in the EFO and EFB treatments, at 1139 and 1333 mm; in the AFB and AFO treatments, the values were 540 and 469 mm (Figure 8).

The data for the last irrigation (Table 5) show similar performances and problems. Quite high tailwater runoff was also calculated in the EFO treatment. Runoff losses decreased from an average

Table 3. Estimated Manning's hydraulic roughness coefficient *n* from flow observations.

	Manning's coefficient, *n* ($m^{-1/3}$ s)	
All furrows and all irrigation applications	Average	0.0463
	Standard deviation	0.00156
First irrigation, all furrows	Average	0.0356
	Standard deviation	0.00126
Second irrigation, all furrows	Average	0.0397
	Standard deviation	0.00131
Third irrigation, all furrows	Average	0.0460
	Standard deviation	0.00160
Fourth irrigation, all furrows	Average	0.0555
	Standard deviation	0.00133
Fifth irrigation, all furrows	Average	0.0476
	Standard deviation	0.00216
Sixth irrigation, all furrows	Average	0.0516
	Standard deviation	0.00183
Seventh irrigation, all furrows	Average	0.0548
	Standard deviation	0.00381

of 21.1% in EFO to 11.0% in AFO. The runoff in EFO was almost 2 times larger (Figure 9). In the latter, runoff losses increased with the decrease in infiltration rate after the first irrigation. Thus, the runoff losses in all treatments increased toward the end of the irrigation season.

In the AFB treatment, deep percolation losses occurred at the head of the furrow, whereas in EFB, they occurred at the end of the furrow. The maximum deep percolation was obtained in alternate furrows and exceeded 20% for AFB; it reached almost 20% for AFO in the first events (Figure 10). On the other hand, deep percolation in the last irrigations for AFO and AFB was very high, as in the first irrigation, but about 10% for the EFO treatment.

All irrigation performance components varied depending on treatments and year (Table 5). Z_{req} in the first event was small, from 144.6 mm (EFB) to 153.7 mm (AFO) on average. The last irrigation was performed with a relatively high Z_{req}, between 160.5 mm (EFB) and 198.9 mm (AFB); actual depletion of *p* varied from 0.71 (EFB) to 0.88 (AFB). Higher soil water depletion occurred in the alternate furrows toward the end of the growing season.

The average uniformity (*DU*) in the first irrigation was high for all treatments, ranging from 71.1% (AFB) to 85.7% (EFO). On the other hand, the average *Ea* in the EFO and AFB treatments was generally low. Using a long cut-off time, slowing the water advance, and causing high runoff losses decreased *Ea* in the EFO treatment. The maximum *Ea* was measured in the EFB treatment (91.0%). For open-end furrow practices (EFO and AFO), *D* values were 39% and 46% higher than for blocked-end furrow treatments, respectively.

Table 4. Estimated infiltration parameters for treatments.

			f_o (m^3 m^{-1} min^{-1})	k (m^3 m^{-1} min^{-1})	a
All open-end furrows and all irrigations		Average value	0.000215	0.0293	0.172
		Standard deviation	0.0000833	0.023528	0.130142
		CV	0.47	0.044	0.022
EFO furrows	All irrigations	Average value	0.000199	0.030	0.1597
		Standard deviation	0.0000832	0.02749	0.105795
		CV	0.044	0.059	0.049
	All first irrigations	Average value	0.000257	0.0156	0.208
		Standard deviation	0.0000459	0.00794	0.0999
		CV	0.004	0.0699	0.095
	All third irrigations	Average value	0.00026	0.02177	0.19822
		Standard deviation	0.00008	0.01420	0.10504
		CV	0.300716	0.06512	0.045873
	All fifth irrigations	Average value	0.00018	0.03415	0.16048
		Standard deviation	0.00006	0.01890	0.04288
		CV	0.3204	0.05536	0.02672
	All last irrigations	Average value	0.000171	0.0339	0.08
		Standard deviation	0.00006846	0.0171	0.0546
		CV	0.005	0.0203	0.0114
AFO furrows	All irrigations	Average value	0.000232	0.028625	0.184094
		Standard deviation	0.0000825	0.019296	0.154186
		CV	0.15	0.42	0.55
	All first irrigations	Average value	0.000293	0.016793	0.3133
		Standard deviation	0.0000551	0.01458	0.2401
		CV	0.004	0.0356	0.053
	All third irrigations	Average value	0.00028	0.02278	0.17844
		Standard deviation	0.00016	0.01195	0.11436
		CV	0.059196	0.052476	0.082902
	All fifth irrigations	Average value	0.00016	0.0361	0.13934
		Standard deviation	0.00008	0.02281	0.09137
		CV	0.4803	0.049526	0.065577
	All last irrigations	Average value	0.000186	0.038567	0.167
		Standard deviation	0.000127659	0.01893	0.089034
		CV	0.005	0.034	0.028
All block-end furrows and all irrigations		Average value		0.0243	0.436
		Standard deviation	0.025	0.22	
		CV	0.883	0.382	
EFB furrows	All irrigations	Average value		0.0251	0.466
		Standard deviation		0.0263	0.266
		CV		0.582	0.351
	All first irrigations	Average value		0.00713	0.615
		Standard deviation		0.00691	0.129
		CV		0.0498	0.0045
	All third irrigations	Average value		0.0189	0.281
		Standard deviation		0.02359	0.1366
		CV		0.07264	0.064842
	All fifth irrigations	Average value		0.0463	0.211
		Standard deviation		0.00986	0.10667
		CV		0.03115	0.051084
	All last irrigations	Average value		0.0186	0.255
		Standard deviation		0.0163	0.356
		CV		0.0293	0.0742
AFB furrows	All irrigations	Average value		0.023399	0.404188
		Standard deviation		0.024584	0.164753
		CV		0.858	0.24
	All first irrigations	Average value		0.00386	0.564
		Standard deviation		0.00194	0.0459
		CV		0.012	0.024
	All third irrigations	Average value		0.015592	0.33437
		Standard deviation		0.00395	0.09397
		CV		0.02482	0.0232774
	All fifth irrigations	Average value		0.04511	0.24601
		Standard deviation		0.02171	0.05660
		CV		0.061845	0.0206574
	All last irrigations	Average value		0.356	0.218
		Standard deviation		0.0353	0.127
		CV		0.145	0.0483

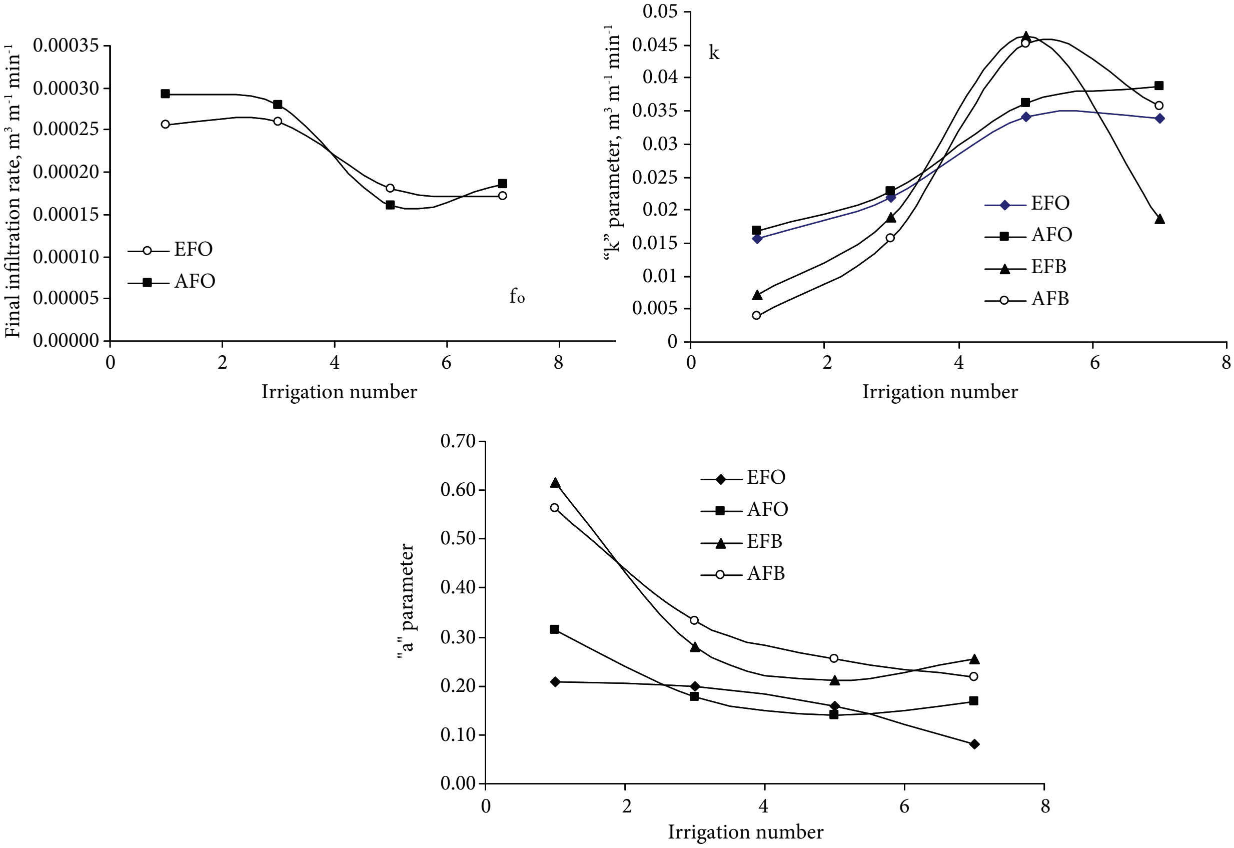

Figure 6. Seasonal variation of infiltration parameters in the different furrow management techniques.

During the trial years, 7 irrigations were applied to all treatments, from mid-June or the first week of July to late August. Total irrigation season lengths varied between 58 and 76 days (Table 6).

The average highest water use efficiency (*WUE*, 0.36 kg m^{-3}) was achieved with the AFB treatment, which also used less water and gave a low cotton yield. AFB used, on average, 5839 m^3 ha^{-1} (61%) less water than the EFO treatment; however, yield decreased by nearly 765 kg ha^{-1} (27%). The every-furrow flow treatments with both open- and blocked-ends used the maximum water and gave high yields; thus, they had low water use efficiencies, at 0.20 kg m^{-3} and 0.28 kg m^{-3}, respectively.

Estimates of WCF_{field} and $BWUF_{field}$ for all treatments are shown in the Table 7. Table 7 also includes the ET_a/ET_{max} ratio and Y_a and Y_{max} values.

The highest fractions of water consumed and beneficial water use were for AFB (0.98 and 1.05, respectively). However, these numbers were associated with 29% relative *ET* and 42% yield deficits. The next best results, relative to EFB, were similar fractions, but with a higher relative *ET* excess of 28% and a relative yield reduction of 15%. Meanwhile, AFO had quite low *VCF* and *BWUF* values (0.67 and 0.71, respectively) and a 39% *ET* deficit and 34% yield reduction.

Discussion

Erosive behavior of the fixed inflow rate in EFO applications has been explained by the loose condition of the soil surface from primary tillage in irrigated sugar beet fields (Sepaskhah and Kamgar-Haghighi 1997). Inflow rates (Figure 3) were similar among the present treatments, with coefficients of variation ranging from 0.048 to 0.045. In all treatments and applications, similar typical inflow-outflow hydrographs were taken, and they were

Table 5. Performance characteristics of the first and last irrigation events.[a]

	Treatments		EFO		AFO[b]		EFB		AFB[b]	
Year	Irr. no.		1st	7th	1st	7th	1st	7th	1st	7th
	Flow condition		Continuous-free		Alternate-free		Continuous-blocked		Alternate-blocked	
1993	Date		9-Jul	5-Sept	9-Jul	5-Sept	9-Jul	5-Sept	9-Jul	5-Sept
	q_{in} (average, L s^{-1})		1.21	1.27	1.21	1.21	1.2	1.2	1.22	1.27
	t_{co} (min)		275	315	305	400	238	264	238	297
	D (mm)		178.2	214.3	197.7	259.3	153	169.7	155.4	202
	Z_{req} (mm)		153.7	174.2	165	189.8	151.4	169.5	153.7	201.1
	Zui (mm)		136.8		148.6	169.6	138.2	154.3	129.0	167.7
	Z_{ave} (mm)		144.9	186	180.7	227.3	153	169.7	155.4	202
	Z_{lq} (mm)		118.0	175.1	145.7	145.3	131.1	149.7	122.0	156.7
	TWR	mm	33.3	28.3	17.0	32.0	0.0	0.0	0.0	0.0
		%	18.7	13.2	8.6	12.3	0.0	0.0	0.0	0.0
	DPR	mm	8.1	11.8	32.1	57.7	14.8	15.4	26.4	34.3
		%	4.5	5.5	16.2	22.3	9.7	9.1	17.0	17.0
	IE (%)		81.3	86.8	91.4	87.7	100	100	100	100
	Er (%)		94.3	100	100	100	100	100	100	100
	Ea (%)		76.8	81.3	75.2	65.4	90.3	90.9	83.0	83.0
	DU (%)		81.4	94.1	80.6	63.9	85.7	88.2	78.5	77.6
1994	Date		22-Jun	6-Sept	22-Jun	6-Sept	22-Jun	6-Sept	22-June	6-Sept
	q_{in} (average, L s^{-1})		1.21	1.26	1.2	1.25	1.21	1.28	1.27	1.28
	t_{co} (min)		417	388	442	441	254	265	246	292
	D (mm)		270.3	261.9	284.1	295.3	164.6	181.7	167.4	200.2
	Z_{req} (mm)		165	185.3	169.5	192.1	162.7	180.8	165	198.9
	Zui (mm)						149.3	163	128.7	152.3
	Z_{ave} (mm)		206.6	205.8	236	241.3	164.6	181.7	167.4	200.2
	Z_{lq} (mm)		178.5	187.2	178.8	197.6	136.9	152.7	124.4	147.8
	TWR	mm	63.7	56.1	48.1	54	0.0	0.0	0.0	0.0
		%	23.6	21.4	16.9	18.3	0.0	0.0	0.0	0.0
	DPR	mm	41.6	20.5	66.5	49.2	15.3	18.7	38.7	47.9
		%	15.4	7.8	23.4	16.7	9.3	10.3	23.1	23.9
	IE (%)		76.4	78.6	83.1	81.7	100	100	100	100
	Er (%)		100	100	100	100	100	100	100	100
	Ea (%)		61.0	70.8	59.7	65.1	90.7	89.7	76.9	76.1
	DU (%)		86.4	91.0	75.8	81.9	83.2	84.0	74.3	73.8
1995	Date		16-Jun	21-Aug	16-Jun	21-Aug	16-Jun	21-Aug	16-Jun	21-Aug
	q_{in} (average, L s^{-1})		1.2	1.27	1.2	1.17	1.23	1.17	1.2	1.27
	t_{co} (min)		215	338	254	371	192	210	186	293
	D (mm)		138.2	220	163.3	232.5	126.5	131.6	119.6	199.3
	Z_{req} (mm)		122	137.9	126.6	198.9	119.8	131.1	122	196.6
	Zui (mm)		96.8			153.8	116.2	116.8	82.5	156.4
	Z_{ave} (mm)		109.1	171.6	151.2	197.9	126.5	131.6	119.6	227.8[c]
	Z_{lq} (mm)		97.3	148	131.3	143.2	107.4	111.2	72.3	134.5
	TWR	mm	29.1	48.4	12.1	34.6	0.0	0.0	0.0	0.0
		%	21.1	22.0	7.4	14.9	0.0	0.0	0.0	0.0
	DPR	mm	12.3	33.7	24.6	44.1	10.3	14.8	37.1	71.4
		%	8.9	15.3	15.1	19.0	8.1	11.2	31.0	31.4
	IE (%)		78.9	78.0	92.6	85.1	100	100	100	100
	Er (%)		89.4	100	100	99.5	100	100	98.0	100
	Ea (%)		70.0	62.7	77.5	66.2	91.9	88.8	69.0	69.0
	DU (%)		89.2	86.2	86.8	72.4	84.9	84.5	60.5	59.0

[a] DU was used to evaluate infiltrated water distribution along the furrow (James 1988; Walker 1989). Ea is the management indicator (Pereira 1999; Pereira and Trout 1999; Pereira et al. 2002).

[b] Applied water (D) for the variable-furrow treatments was calculated for irrigated furrows only.

[c] For a 140 m furrow length.

similar to those observed before by researchers such as Rodriguez (1987), El-Dine and Hosny (2000), and Horst et al. (2005 and 2007). Small variations in the inflow rates and different furrow management techniques have influenced outflows. This example also shows that the outflow volume may be a significant fraction of the total inflow.

Comparison of the advance curves indicates that the advances are faster in every furrow management (Figure 4). The alternate furrow approaches caused a decrease in the advance velocity and the wet front in the AFB treatment, and could not reach the end of the furrow due to high horizontal percolations to neighbor furrows in later applications. At the beginning of the growing season, advance problems were not encountered because soil moisture content was relatively high.

The recession curves in the AFO and EFO treatments were about linear, with relatively small differences between the upstream and the downstream sections (Figure 5). In block-end furrows, recession curves are very long because water ponds at the end of the furrows; they show similar shapes and large differences between upstream and downstream. This produces relatively important differences in the infiltration opportunity time between upstream and downstream, which become larger when the cut-off time is shorter. This may cause farmers to adopt larger t_{co} and, therefore, to overirrigate.

The hydraulic roughness parameters of *n* increased from the first to the last irrigation events due to the crusted soil surface resulting from different furrow management techniques (Table 3). Moreover, they were affected by a lack of tillage during the season. However, some results from recent years show that the roughness coefficient *n* either decreased toward the end of the irrigation season or remained similar during the irrigation season (Horst et al. 2005, 2007).

The highest variations in the average f_o values (Table 5, Figure 6) may be caused by excessive side lateral percolation in the alternate irrigated furrows. On the other hand, f_o in the open-end furrows gradually decreased toward the last irrigation, from 0.000275 to 0.000179 $m^3\ m^{-1}\ min^{-1}$. This may result from the rearrangement of the soil particles due to transport and deposition inside the furrows, as shown in Figure 2.

Coefficients *k* were grouped into 2 categories (Figure 6), depending on furrow end conditions. These values reached their maximum levels at the fifth irrigation and remained constant in open-end furrows. On the other hand, these same values declined toward the end of the season in blocked-end furrows. The lower average *k* parameter for block-end furrows for the entire season may be due to the lower wetted surface area, and the lateral movement of water exceeds the downward movement, as stated by Stone et al. (1979, 1982) and Graterol et al. (1993). These results show that the *k* parameter was more affected by the furrow end conditions than the inflow management.

The coefficients of *a* were grouped into 2 categories (Figure 6) depending on the furrow end condition. The highest *a* values obtained can be explained by the specific characteristics of the ponded flow furrow irrigation. The parameters *k* and *a* did not show certain trends, but a trend existed for *k*, which increased from the first to the fifth event, and inversely for *a*, which decreased. Finally, it can be said that variations among the infiltration parameters may be caused by properties of soil surface conditions, which change during irrigations due to the formation of crusts (surface sealing layer) and the development of a root system in the growing crop.

Overirrigation with the EFB treatment (Figure 7) can occur when irrigation water ponds near the end of the furrow. However, deficit irrigation results in the AFB treatment may be due to the lower infiltration rate caused by insufficient water applied, as explained by Stone et al. (1979).

Water storage showed similarities in every irrigated furrow or variable irrigated furrow. The differences in the water intake results were statistically significant at 0.01 level (average STDEV = 6.99, LSD = 28.45). Reductions in the cumulative water storage were about 59% for AFO and 53% for AFB, compared to EFO and EFB. The alternate furrow approaches reduced water intake (Figure 8). This may be caused by lower infiltration due to a reduction in the wet soil surface and high lateral percolation (Stone et al. 1979; Graterol et al. 1993; Rice et al. 2001).

Similar results for runoff (Figure 9) were reported by Rice et al. (2001) and Kanber et al. (2001). Reduction of tailwater runoff with the AFO treatment may have been due to higher side percolation.

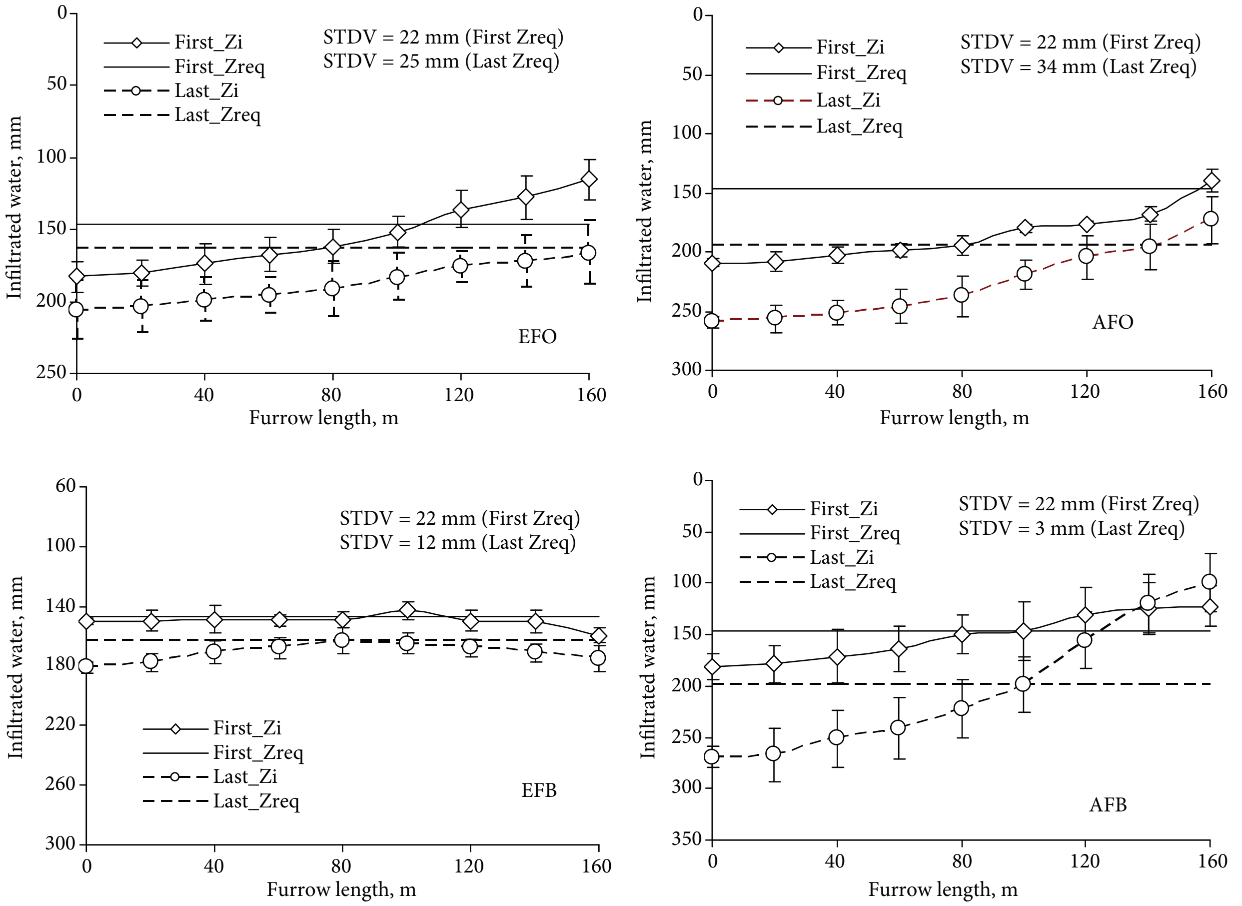

Figure 7. Average infiltrated water depth (Z_i) and soil water deficit (SMD) profiles for the first and last irrigation events in all treatments.

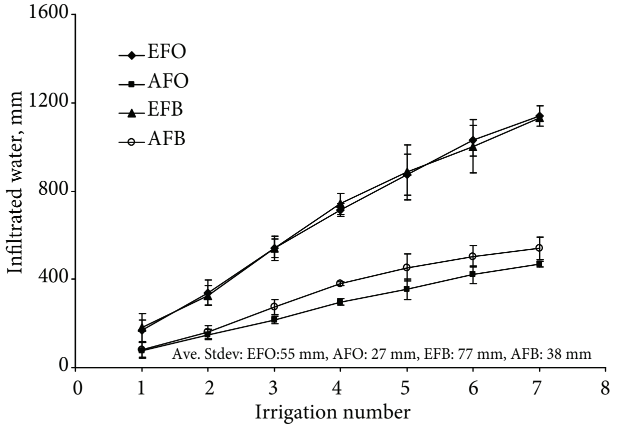

Figure 8. Average cumulative water storage in different furrow management practices. Water storage shows similarities with respect to every-irrigated furrow or variable-irrigated furrow approaches.

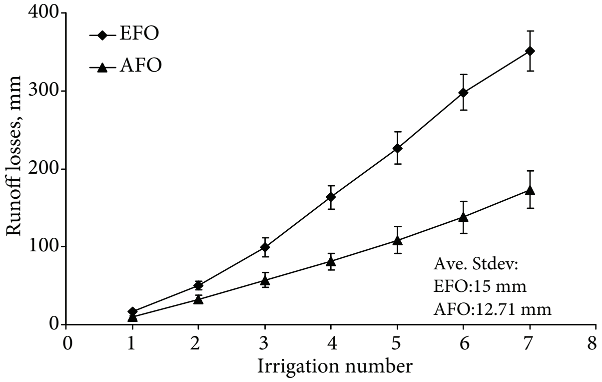

Figure 9. The cumulative average runoff losses for open-end furrow treatments.

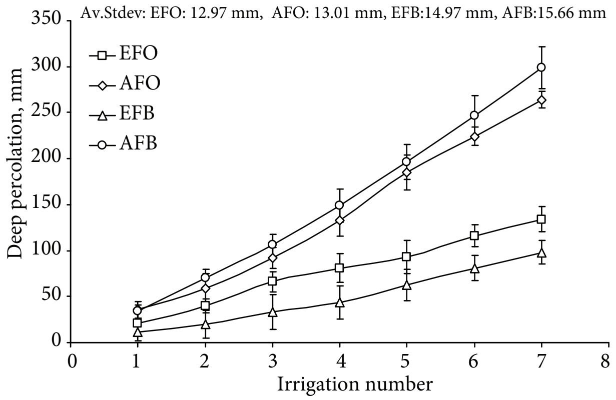

Figure 10. Cumulative average deep percolation losses measured according to different furrow management techniques (deep percolation losses in variable furrow flow treatments are calculated for entire plot area).

Most of the deep percolation losses (Figure 10) in the alternate furrow practices may be the consequence of side percolation to a nonirrigated neighboring furrow, which remains at root depth. This demonstrates that deep percolation losses below root depth might not occur, as found by Sepaskhah and Kamgar-Haghighi (1997). However, Rice et al. (2001) reported that average deep percolation increased with the alternate furrow practice. In general, in open-end furrow treatments, the entire field received Z_{req} at the expense of some deep percolation.

DU was relatively higher (*DU* > 85%) for both of the every-furrow treatments than in the alternate-furrow treatments (*DU* ≈ 70%). Due to advance problems caused by surface conditions, results showed that the high inflow rate should be used in the advance phase for this particular soil with alternate-furrow practices.

Application efficiency (*Ea*) is generally low in mainly open-end furrow treatments due to excessive cutoff times that may be caused by irrigation depths much higher than Z_{req}. As mentioned before, this demonstrates poor irrigation scheduling and is due to the fact that the longer wetting phase was used, and the cutoff time was longer for the open-end furrow treatments.

Cotton yields were the same or slightly lower than those in previous experiments using surface and pressurized irrigation methods in the Harran Plain (Çetin and Bilgel 2002; Kanber et al. 1996, 2001). On the other hand, similar results on cotton yield and suitable irrigation methods or irrigation programs were obtained by numerous scientists (Vanjura et al. 2002; Aujla et al. 2005; Horst et al. 2005, 2007).

Table 6. Irrigation water depth (*D*), actual seed cotton yields (*Ya*), and irrigation water use efficiency (WUE_{IR}) for different furrow irrigation management techniques.

Years	Treatments	Irrigation water[a], *D* (m^3 ha^{-1})	Changes in irrigation water relative to average (%)	Actual yield, *Ya* (kg ha^{-1})	Yield changes relative to average (%)	WUE_{IR} (kg m^{-3})	Changes in WUE_{IR} relative to average (%)
1993	AFB	5491	−36	2471	−7	0.45	36
	EFB	10,360	20	3393	28	0.33	−1
	AFO	6720	−22	2130	−20	0.32	−4
	EFO	11,832	38	2632	−1	0.22	−33
	Average	8601		2657		0.33	
1994	AFB	6143	−44	1850	−24	0.30	25
	EFB	12,620	14	2644	9	0.21	−13
	AFO	8371	−24	2282	−6	0.27	14
	EFO	17,091	55	2921	21	0.17	−29
	Average	11,056		2424		0.24	
1995	AFB	5882	−42	2028	−27	0.34	15
	EFB	10,581	5	3225	16	0.30	2
	AFO	8113	−20	2756	−1	0.34	13
	EFO	15,782	56	3090	11	0.20	−35
	Average	10,090		2775		0.30	

[a] Irrigation depths for alternate-furrow treatments show the half-amount of water applied to the irrigated furrow.

Table 7. Comparative water use effectiveness at field level for the different furrow irrigation management techniques.[a]

Years	Treatments	Total water use $(D + P)$[b] (mm)	ET_a (mm)	ET_a/ET_{max}	$Y_{a,}$ kg ha^{-1}	Y_a/Y_{max}	WCF_{field}	$BWUF_{field}$
1993	AFB	706	694	0.73	2471	0.68	0.98	1.05
	EFB	1193	1186	1.25	3393	0.93	0.99	1.06
	AFO	829	626	0.66	2130	0.59	0.76	0.81
	EFO	1340	862	0.91	2632	0.73	0.64	0.69
1994	AFB	719	707	0.74	1850	0.51	0.98	1.05
	EFB	1367	1360	1.43	2644	0.73	0.99	1.06
	AFO	942	551	0.58	2282	0.63	0.58	0.63
	EFO	1814	1480	1.56	2921	0.80	0.82	0.87
1995	AFB	632	620	0.65	2028	0.56	0.98	1.05
	EFB	1102	1095	1.15	3225	0.89	0.99	1.06
	AFO	855	562	0.59	2756	0.76	0.66	0.70
	EFO	1622	1117	1.18	3090	0.85	0.69	0.74

[a] ET_{max} is the cotton water consumption for maximum yield (ET_{max} = 950 mm according to Kanber et al. 1996; Bahçeci and Nacar 2007), Y_a is the actual cotton yield (kg ha^{-1}), and Y_{max} is the maximum cotton yield for Harran conditions [3630 kg ha^{-1} for surface irrigation method (Çetin and Bilgel 2002)].

[b] Rainfall received in all cotton growing seasons was 157 mm in 1993, 105 mm in 1994, and 44 mm in 1995.

On the point of irrigation performance (Table 5), results indicated that considerable water savings may be achieved with alternate-furrow flows. Horst et al. (2007) reported high water use efficiency (0.61 kg m^{-3}) for cotton irrigated using surge flow with an alternate-furrows approach. Similar and comparable results were found by Kanber et al. (2001), Çetin and Bilgel (2002), Tennakoon and Milroy (2003), and Aujla et al. (2005). Because water is the limiting factor for farmers in the Harran Plain, they should maximize water productivity. Therefore, water savings must be implemented, and then a policy of economic incentives has to be applied to cover the decrease in yields associated with alternate-furrow irrigation.

Results for water use performances show the clear advantage of alternate-furrow over every-furrow approaches, as well as the advantages of blocked-end furrow over open-end furrow flow. In spite of the improved water use performance associated with a large *ET* deficit, results indicate that alternate furrows are difficult to implement in practice. Additionally, it is important to remember that these results were obtained in a water-scarce region tending toward desertification, where the consequences of climatic change may be disastrous (Tonkaz and Çetin 2007; Tonkaz et al. 2007; MEF 2007).

Conclusions

When compared with every-furrow irrigations with open-end furrows, high water use savings with small yield reductions were obtained by alternate-furrow irrigation. Similarly, average water use efficiencies were 0.36 kg m^{-3} in AFB and 0.31 kg m^{-3} in AFO, compared with 0.20 kg m^{-3} in EFO. Moreover, the consumed fraction of water used was 0.98, compared with 0.72 for EFO. These results demonstrate the possibility of applying deficit irrigation in the Harran Plain.

Acknowledgements

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References

ASAE (2003) Evaluation of irrigation furrows. In: ASAE Standards: EP 419.1. St. Joseph, MI, USA, pp. 919-924.

Aujla MS, Thind HS, Buttar GS (2005) Cotton yield and water use efficiency at various levels of water and N through drip irrigation under two methods of planting. Agric Water Manag 71: 167-179.

Ayers RS, Westcot DW (1989) Water quality for agriculture. FAO Irrigation and Drainage Paper 29, Rev. 1, FAO, Rome, Italy.

Bahçeci İ, Nacar AS (2007) Estimation of root zone salinity, using SaltMod, in the arid region of Turkey. Irr Drain 56: 601-604.

Berekatoğlu K, Bahçeci İ (2005) Possibilities of using drainage canal water for irrigation purposes in the Harran Plain. Harran Üniversitesi Ziraat Fakültesi Dergisi 9: 43-52 (in Turkish).

Çetin, Ö (1992) Comparison of Different Irrigation Methods (Furrow, Trickle, LEPA, and Sprinkler) for Cotton under Harran Plain Conditions. Final Report, Ministry of Rural Affairs, Şanlıurfa, p. 84.

Çetin Ö, Bilgel L (2002) Effects of different irrigation methods on shedding and yield of cotton. Agric Water Manag 54: 1-15.

Çullu MA, Atmaca A, Öztürkmen AR, Ağca N, İnce F, Derici MR (2000) Determination of the Probability of Salinity Problems in the Harran Plain. Southeast Anatolia Project Authority Publications, Ankara (in Turkish).

Dinç U, Senol S, Sayın M, Kapur S (1991) The physical, chemical and biological properties and classification mapping of soil of the Harran Plain. In: Soils of the Harran Plain (Eds. U Dinç, S Kapur). Pub of the Turkish Sci and Tech Res Council: 1-10.

El-Dine TG, Hosny MM (2000) Field evaluation of surge and continuous flows in furrow irrigation systems. Water Res Manag 14: 77-87.

Gençoğlan C, Gençoğlan S, Kırnak H, Akbay C, Boz İ (2005) Harran ovası koşullarında yetiştirilen pamuğun kısıntılı sulama analizi. GAP IV. Tarım Kongresi 21-23 Eylül. 2005, Şanlıurfa, Kongre Bildiri Kitabı 2: 1026-1031.

Goldhamer DA, Peterson CM (1984) A Comparison of Linear Move Sprinkler and Furrow Irrigation on Cotton: A Case Study. Final Technical Report, California Department of Water Resources, Sacramento, CA, USA.

Graterol YE, Eisenhauer DE, Elmore RW (1993) Alternate-furrow irrigation for soybean production. Agric Water Manag 24: 133-145.

Grattan SR (2002) Irrigation Water Salinity and Crop Production. Water Quality Fact Sheet. Division of Agriculture and Natural Resources, University of California, UC DANR Electronic Publication Number 8066, Oakland, CA, USA.

Hodges ME, Stone JF, Garton JE, Weeks DL (1989) Variance of water advance in wide-spaced furrow irrigation. Agric Water Manag 16: 5-13.

Horst MG, Shamutalov SS, Gonçalves JM, Pereira LS (2007) Assessing impacts of surge-flow irrigation on water saving and productivity of cotton. Agric Water Manag 87: 115-127.

Horst MG, Shamutalov SS, Pereira LS, Gonçalves JM (2005) Field assessment of the water saving potential with furrow irrigation in Fergana, Aral Sea basin. Agric Water Manag 77: 210-231.

Howell TA, Cuenca RH, Solomon KH (1990) Crop yield response. In: Management of Farm Irrigation Systems (Ed. GJ Hoffman). ASAE Monog., Chap 4, St. Joseph, MI, USA, pp. 93-116.

James LG 1988 Principles of Farm Irrigation System Design. John Wiley and Sons Inc., New York.

Kanber R, Köksal H, Önder S, Kapur S, Şahan S (2001) Comparison of surge and continuous furrow irrigation methods for cotton. Agric Water Manag 47: 119-135.

Kanber R, Önder S, Ünlü M, Köksal H, Özekici B, Sezen SM, Yazar A, Koç K (1996) Optimization of Surface Irrigation Methods for Cotton and Comparison with Sprinkler Irrigation. Research Report No: 18, GAP Research Projects, Univ. of Çukurova Agricultural Faculty, Research, and Development Project No: 155, Adana, Turkey.

Kang SZ, Shi P, Pan YH, Liang ZS, Hu XT, Zhang Z (2000) Soil water distribution, uniformity and water use efficiency under alternate furrow irrigation in arid areas. Irr Sci 19: 181-190.

MEF (2007) First national communication on climate change. In: Republic of Turkey. Under the United Nations Framework Convention on Climate Change. Ministry of Environment and Forestry, Ankara, pp. 161-196.

Merriam JL, Shearer MN, Burt CM (1980) Evaluating irrigation system and practices. In: Design and Operation of Farm Irrigation Systems (Ed. ME Jensen). ASAE Monog., 3, St. Joseph, MI, USA, pp. 721-760.

Mintesinot B, Verplancke H, Van Ranst E, Mitiku H (2004) Examining traditional irrigation methods, irrigation scheduling and alternate furrows irrigation on vertisols in northern Ethiopia. Agric Water Manag 64: 17-27.

New L (1971) Influence of alternate furrow irrigation and time of application on grain sorghum production. Tex Agric Exp Prog Rep 2953: 26-32.

Özer N, Demirel AF (2004) Problems of water table and salinity in Şanlıurfa and Harran Plains. Symposium on Salinity Management in the Irrigated Areas, Ankara: 157-162.

Pereira LS (1999) Higher performance through combined improvements in irrigation methods and scheduling: a discussion. Agric Water Manag 40: 153-169.

Pereira LS, Oweis T, Zairi A (2002) Irrigation management under water scarcity. Agric Water Manag 57: 175-206.

Pereira LS, Trout TJ (1999) Irrigation methods. In: CIGR Handbook of Agricultural Engineering, Vol 1: Land and Water Engineering (Eds. HN van Lier, LS Pereira, FR Steiner FR). ASAE, St. Joseph, MI, USA, pp. 297-379.

Rice RC, Hunsaker DJ, Adamsen FJ, Clemmens AJ (2001) Irrigation and nitrate movement evaluation in conventional and alternate furrow irrigated cotton. Trans of the ASAE 44: 555-568.

Rodriguez CMM (1989) Pulsed furrow irrigation evaluation. MSc Thesis, Crandfield Institute of Technology, Silsoe College, Bedford, p. 58.

Samadi A, Sepaskhah AR (1984) Effects of alternate furrow irrigation on yield and water use efficiency of dry beans. Iran Agric Res 3: 95-115.

Sepaskhah AR, Kamgar-Haghighi AA (1997) Water use and yields of sugar beet grown under every-other-furrow irrigation with different irrigation intervals. Agric Water Manag 34: 71-79.

Stone JF, Garton JE, Webb BB, Reeves HE Keflemariam J (1979) Irrigation water conservation using wide-spaced furrows. Soil Sci Soc Am J 43: 407-411.

Stone JF, Nofziger DL (1993) Water use and yield of cotton grown under wide-spaced furrow irrigation. Agric Water Manag 24: 27-38.

Stone JF, Reeves HE, Garton JE (1982) Irrigation water conservation by using wide-spaced furrows. Agric Water Manag 5: 309-317.

Tekinel O, Kanber R, Yazar Y, Ünlü M, Topaloğlu F, Çullu MA, Önder S (2001) Pollution of Soil and Water Resources in Southeast Anatolia Region: Their Dimensions, Reasons and Solution Proposals. Final Report of UNDP Project Number 17, Southeast Anatolia Project Authority, Ankara.

Tennakoon SB, Milroy SP (2003) Crop water use and water use efficiency on irrigated cotton farms in Australia. Agric Water Manag 61: 179-194.

Tonkaz T, Çetin M (2007) Effects of urbanization and land-use type on monthly extreme temperatures in a developing semi-arid region, Turkey. J Arid Environ 68: 143-158.

Tonkaz T, Çetin M, Tülücü K (2007) The impact of water resources development projects on water vapor pressure trends in a semi-arid region, Turkey. Climatic Change 82: 195-209.

Tüzüner A (1980) Toprak ve Su Analiz Laboratuvarları El Kitabı. Tarım Orman ve Köy İşleri Bakanlığı Köy Hizmetleri Genel Müdürlüğü Yayınları, Ankara (in Turkish).

USDA-SCS (1998) Keys to Soil Taxonomy, 8th ed. USDA Nat Res Conservation Service, Washington, DC, USA.

Vanjura DF, Upchurch DR, Mahan JR, Burke JJ (2002) Cotton yield and applied water relationships under drip irrigation. Agric Water Manag 55: 217-237.

Walker WR (1989) Guidelines for Designing and Evaluating Surface Irrigation Systems. FAO Irrigation and Drain Paper No: 45, Rome.

Walker WR, Skogerboe GV (1987) Surface Irrigation: Theory and Practices. Prentice Hall Inc., Englewood Cliffs, NJ, USA.

Yavuz MY (1993) Effects of different irrigation methods on the cotton yield and water use efficiency. PhD Thesis. Çukurova University, Institute of Basic and Applied Science, Irrigation and Drainage Department, Adana, p. 196.