Assessing the performance of an innovative on- farm Gated pipe technique: preliminary results of an experimental test

Summary:

An experiment was conducted in CIHEAM-Bari's experimental field (Bari, Italy) to assess the performance (Water advance, Water Application Efficiency and Distribution Uniformity) of surface irrigation systems under two different furrow techniques, 1) innovative self-compensating gated pipes and 2) traditional furrow irrigation. The results showed that self-compensating gated pipes can improve the application efficiency of furrow system by 11%. The distribution uniformity for that case study was enhanced by 17%, while the time of irrigation was reduced by one third. The innovative system is expected to achieve even better performance with lower initial soil moisture content and longer irrigation events. The experiment also showed that the innovative technique is expected to reduce drainage. Further study had to be carried out to assess the environmental impact.

Introduction

1.1. Background

Distinguished with low capital cost, low energy consumption and traditional/cultural legacy, by far surface irrigation is the dominant irrigation technique on earth, representing 86% of the fully controlled irrigated areas especially in developing countries (FAO 2014). Surface irrigation includes a broad class of irrigation methods in which water is distributed over the field by gravity. A flow is introduced at a high point or along high edge of the field and allowed to cover the field by overland flow. The rate of coverage is dependent on the difference between the system volume and the accumulating infiltration. Secondary factors include field slope and roughness (Walker and Skogerboe 1987). The prevalence of each irrigation technology is displayed in (Figure 1). Where for each country color indicates the irrigation technology: green is surface irrigation, blue is sprinkler irrigation and red is localized irrigation (AQUASTAT 2015).

In Egypt the situation is not so different. In fact, out of 3.55 million ha of irrigated lands 2.7 million are irrigated with surface irrigation (mostly furrows and floods) accounting for 77% of the total irrigated area, mainly located in the Nile Delta. The country suffers from both water scarcity, poor water quality and lack of energy resources. According to the Ministry of Water Resources and Irrigation (MWRI 2014) in Egypt the quantity of water availability is imposing limits on its national economic development. As indication of scarcity in absolute terms, often the threshold value of 1000 m^3/p/year, is used. Egypt has passed that threshold already in the nineties. The population predictions and the ambitious agriculture projects which consumes more than 80% of the water resources - will bring Egypt down to 500 m^3/p/year by 2025. So, it becomes vital to improve water application efficiency without enhancing energy consumption.

In order to face water scarcity problem, from the eighties, policy makers in Egypt enhanced a program for reuse of drainage water. Such policy considerably improves water distribution efficiency at district level, but also creates problems on water quality of drainage canals.

Eventually, the country is undergoing a relevant modernization program to improve on-farm irrigation systems in 2.1 million ha - out of its 2.7 million - in the Nile Delta and Valley during the period 2011-2021. The aim will be to save water for reclaiming the targeted areas in the 2030 strategic plan. Therefore, the potentiality of addressing modernization of surface irrigation systems is crucial.

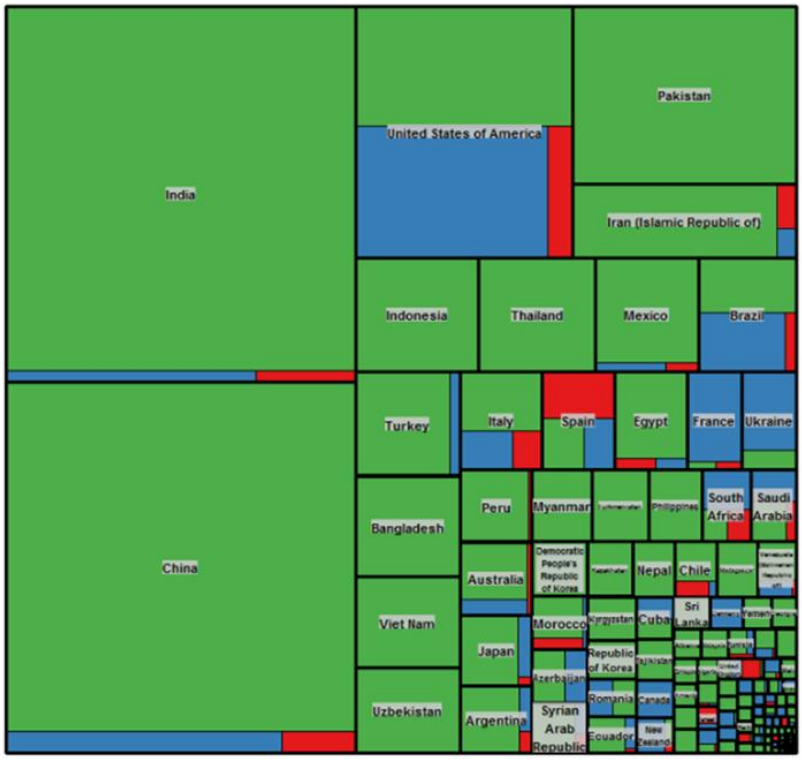


Figure 1 the prevalence of each irrigation technology around the world, green: surface, blue: sprinkler and red: localized

1.2. Furrow surface irrigation

Surface Furrow irrigation is characterized with its concavities combined (usually) with small canals along the longitudinal slopes, ending with a run off collective drain. For this study a free draining furrow was considered. In such case depletion and recession phases are very short compared to the advance and filling phases.

Hereafter the most important surface irrigation concepts and terms that will be used in the recent study are reported. Surface irrigation is divided in phases separating hydrological processes. These phases are useful to analyze water movement on the irrigated field. The phases are separated by characteristic times, in which certain singularities appear(Playán 2012). These times are:

- Starting time **(t_s)**, when water first flows into the border, basin or furrow.
- Time of advance **(t_a)**, when water completely covers the basin or border, or when water reaches the downstream end of a furrow.
- Time of cut off **(t_c)** when water stops flowing into the irrigated field.
- Time of depletion **(t_d)**, when a part of the basin, border or furrow becomes uncovered by water once the water has fully infiltrated or has moved to lower areas of the field.
- Time of recession **(t_r)**, when water can no longer be seen over the field.

These characteristic times determine the length of the irrigation phases (Figure 2 and Figure 3):

- **Advance phase**: between t_a and t_s. Water is covering the field.
- **Filling phase**: between t_c and t_a. Water is building up in the field.
- **Depletion phase**: between t_d and t_c. Water level decreases in the field.
- **Recession phase**: between t_r and t_d. Water uncovers the field surface.

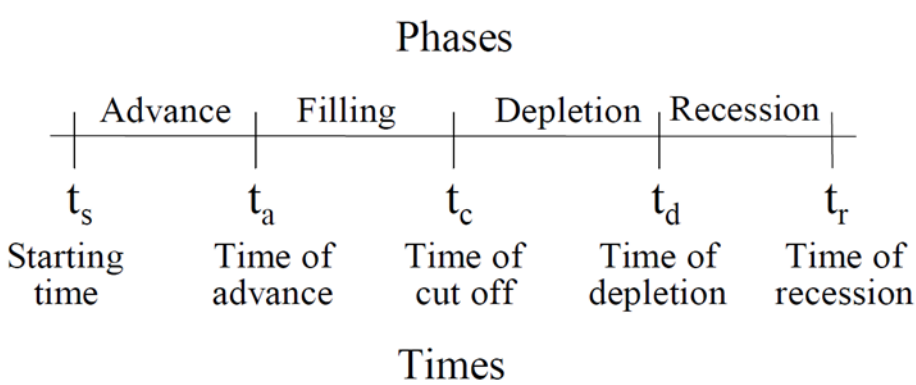


Figure 2 Surface irrigation Times & Phases

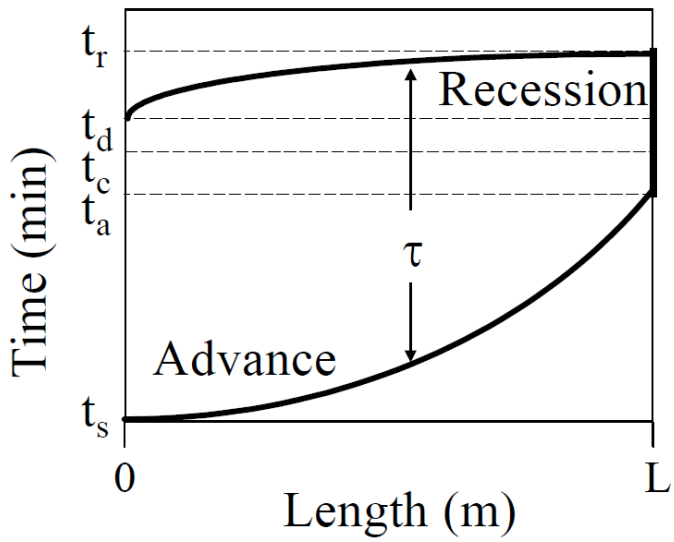


Figure 3 Advance - Recession Curve of a surface irrigation event

In the last decades a number of technical and managerial enhancements were developed to improve the performance of furrow irrigation. Using Gated pipes to attain higher distribution uniformity in shorter irrigation time is becoming more popular practice. Instead of an open ditch, a distribution pipe 100-250 mm made of plastic or aluminum is used, the pressure inside the pipe is usually lower than 1 bar.

A number of publications discussed the performance of furrow irrigation under gated pipes. By far the most of the papers are mainly following two approaches: either i) comparing gated pipes to conventional irrigation systems in terms of yield, water use efficiency (on-farm scale), advance time of irrigation; or ii) by modifying the gated pipe systems itself, either by technical improvement e.g. self-compensating outlets, or by exploiting the manageability of the system and evolve better practices (e.g. alternate irrigation, surge irrigation).

Any opening gate follows the relation:

$$Q = C_d \mathrm{A}\sqrt{2gh}$$

Where Q is the outlet discharge, C_d is the coefficient of discharge, A is the Orifice area, g the gravitational acceleration, and h is the water head. Under the same orifice diameter and assuming identical orifices, the discharge will be function of the operating pressure head which could vary along the pipe according to the length of the pipe, pipe diameter, spaces between the gates (number of gates), pipe material, slope, and upstream operating pressure. Such pressure reduction causes the variation of the discharge along the gated pipe and impacts the overall distribution uniformity.

1.3. Self-compensating gated pipe system

Self-compensating gated outlets minimizes each pressure and maintain constant outlet discharges within a certain operating range. Special rubber flow regulator was developed by a ROLLAND French company in the formwork of the EU project (MADFORWATER, 2020) and, it was tested in the present study. The rating curve (discharge vs pressure) for this type of orifice was tested in the hydraulic lab.

In this study self-compensating circular outlets were used. (Figure 4) reported rating curve of the outlet is, while (Figure 5) shows its shape and design. This outlet maintains a discharge between 0.8-1 L/sec in a pressure range of 0.2-0.5 bars (2-5 meters).

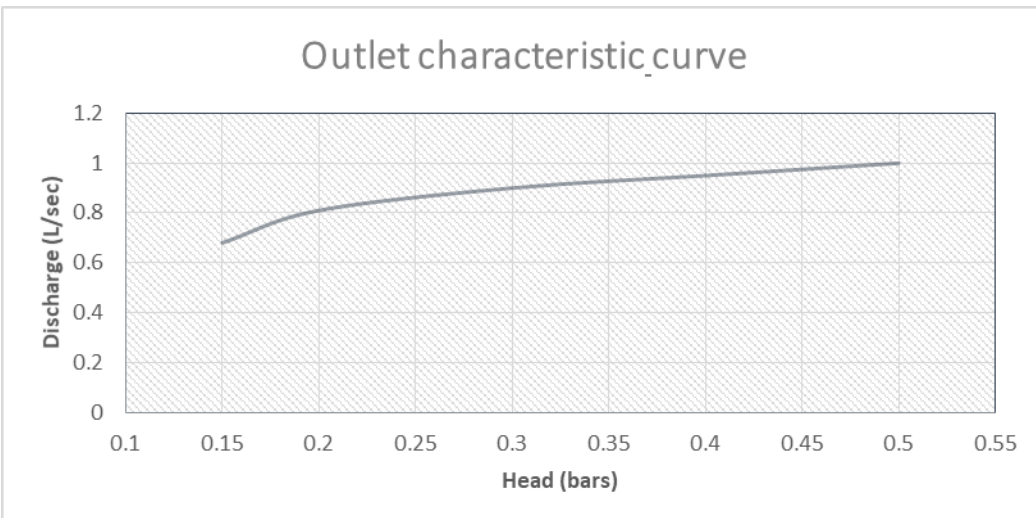


Figure 4 operating curve for one modified outlet (ROLLAND,2018)

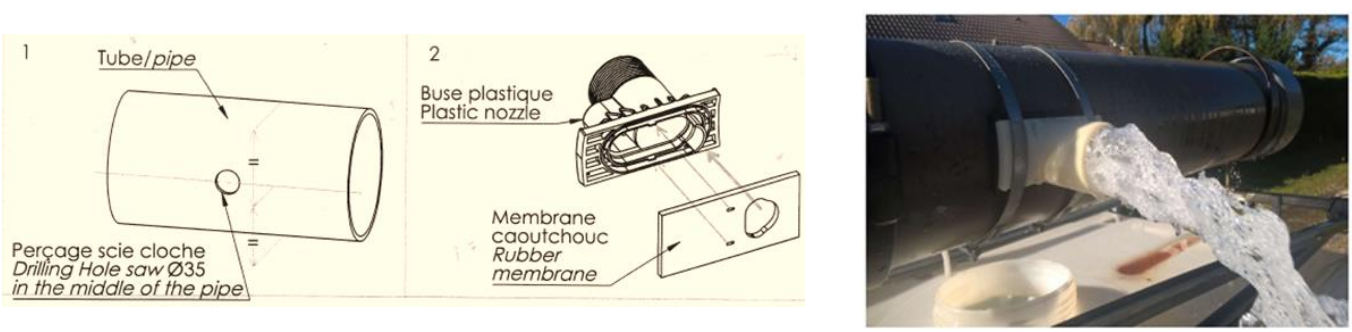


Figure 5 outlet detailed design (ROLLAND,2018)

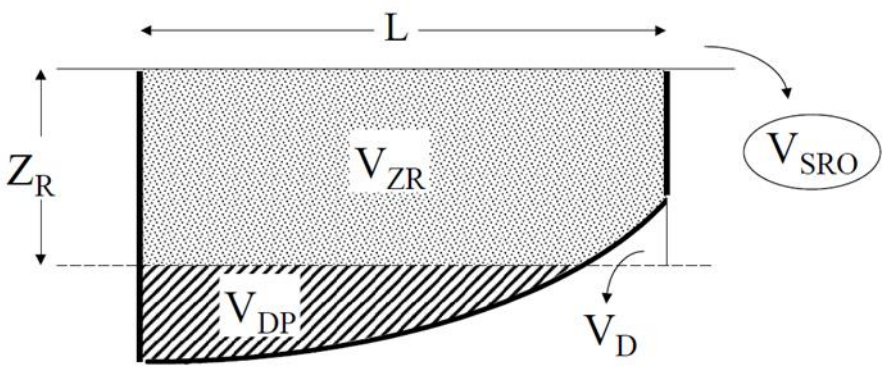
1.4. Surface irrigation performance

"Efficiency" and "Distribution Uniformity" had to be used together to describe the performance of a surface irrigation event. Although its simplicity, the word "efficiency" can mean different things to different authors, thus hereafter the definitions of indicators used to assess the performance in this study.

The term Application Efficiency (AE) refers to the amount of water volume infiltrated and retained in the soil in respect to the total amount of water applied. Hence, drainage is the only component considered as losses. Distribution uniformity (DU) is the average infiltrated depth in the end quarter of the field relative to the average infiltrated depth.

$$AE\ \% = \frac{Volume\ of\ water\ retained\ targeted\ depth(m^3)}{Volume\ of\ water\ applied\ (m^3)} * 100$$

$$DU\ \% = \frac{Average\ infiltrated\ depth\ in\ the\ end\ quarter\ \ (mm)}{Average\ infiltrated\ depth\ (mm)} * 100$$



L	Furrow length
Zr	Root zone
Vzr	Volume of water retained in the root zone
V_{DP}	Volume of water lost to deep percolation
V_D	volume of deficit
V_{SRO}	Volume of water lost to surface drainage

Figure 6 Components of water volume balance in a surface irrigation event

1.5. Surface irrigation modelling

(Valipour, Sefidkouhi et al. 2015) reviewed the literature and results of more than 100 published articles regarding simulation of surface irrigation, 53.4% of the simulations belonged to furrow irrigation out of which 54.5% were satisfactory valid. The most relevant irrigation method simulated by hydrodynamic (HD) and other models were border, basin, and furrow irrigation. Kinematic wave (KW) and volume balance (VB) models were used. Also zero inertia (ZI) model was used. The study concluded that kinematic wave approach is the most valid to simulate furrows irrigation system.

For this study WinSrfr version 3.4.1 (download on www.ars.usda.gov) was used. WinSRFR (Bautista, Clemmens et al. 2009) is an integrated software package developed for hydraulic analysis of surface irrigation systems. Users can analyze the performance irrigation events and estimate field-average infiltration parameters based on field-measured data, formulate design and operational alternatives, and conduct simulation studies using an unsteady one dimensional flow model.

The functionality and organization of WinSRFR were defined based on the analytical process typically followed in assessing and improving the hydraulic performance of surface irrigation systems. Program functionalities, referred to as WinSRFR Worlds, are Event Analysis, Operation Analysis, Physical Design, and Simulation.

In the present study the simulation function was used to design the irrigation event and to compare both systems within the optimal expected performance. It is worthy to mention that WinSRFR do not consider the water delay impact from the main ditch on the advance phase in the furrows, hence it considers one starting time for all the furrows and - as all models - assumes identical repetitive furrow or set of furrows. Thus it is not useful for comparing gated pipes to traditional furrows.

Also the Event Analysis function was used to validate the model by comparing the simulated scenario produced by the actual field results.

Test procedures

2.1. Experimental layout

The experiment was conducted at the CIHEAM's Experimental fields in Valenzano (Bari) Italy. The field layout is 20*49 m with 0.3% longitudinal slope, It was divided into 18 furrows out of which, half were used to test the modified self-compensating gated pipes, while the other were used to test the traditional furrows, eleven posts (stations) were installed along the furrow, each 5 meters, to record the irrigation advance and recession time. The layout and dimensions of the furrows are illustrated in figure 7. The irrigation runoff was collected via channel to calibrated reservoirs with a total volume of 2,500 liters. A submersible pump was installed in

the reservoirs to withdraw water drainage volumes. The gated pipe network consisted of PE pipe with a 90 mm diameter. The friction losses were calculated according to Hazen Williams's equation (all details are illustrated in Table 1). The pipes dimeter was chosen according to the maximum allowed flow velocity, v = 1.5 m/sec. The last outlet discharge is 0.8 l/sec. A pressure regulator was used to reduce and fix the pressure upstream of the gated pipe. Two manometers were installed to check the pressures upstream and downstream the flow regulator. A flow meter was installed to measure the water volume applied at each irrigation even.

Table 1 hydraulic calculation sheet the letters from A-L refers to the sections of the network as illustrated in figure 7

Hydraulic calculations sheet

HF=(1.131*10^9)*((Q/C)^1.852)*(D^-4.87)*(L)

HF	FRACTION LOSS	**m**
Q	FLOW	**m3/h**
C	FACTOR	**150**
D	DIAMETER	**mm**
L	LENGTH	**m**
V	VELOCITY	**m/s**

	Q	Dout	Din	L	V	hf
	FLOW	DIAMETER	DIAMETER	LENGTH	VELOCITY	FRACTION LOSS
	m3/h	mm	mm	m	m/s	m
PIPE AB	2.88	90	83	1	0.14785944	0.000337463
PIPE BC	5.76	90	83	1	0.29571887	0.001218242
PIPE CD	8.64	90	83	1	0.44357831	0.002581397
PIPE DE	11.52	90	83	1	0.59143775	0.004397859
PIPE EF	14.4	90	83	1	0.73929719	0.006648423
PIPE FG	17.28	90	83	1	0.88715662	0.009318849
PIPE GH	20.16	90	83	1	1.03501606	0.012397889
PIPE HI	23.04	90	83	1	1.1828755	0.015876283
PIPE IJ	25.92	90	83	1	1.33073494	0.019746189
PIPE JK	28.8	90	83	1	1.47859437	0.024000825
PIPE KL	28.8	90	83	66.7	1.47859437	1.600855029
H_{minor} (fittings)						0.160119249
TOTAL FRICTION LOSSES						1.857497696

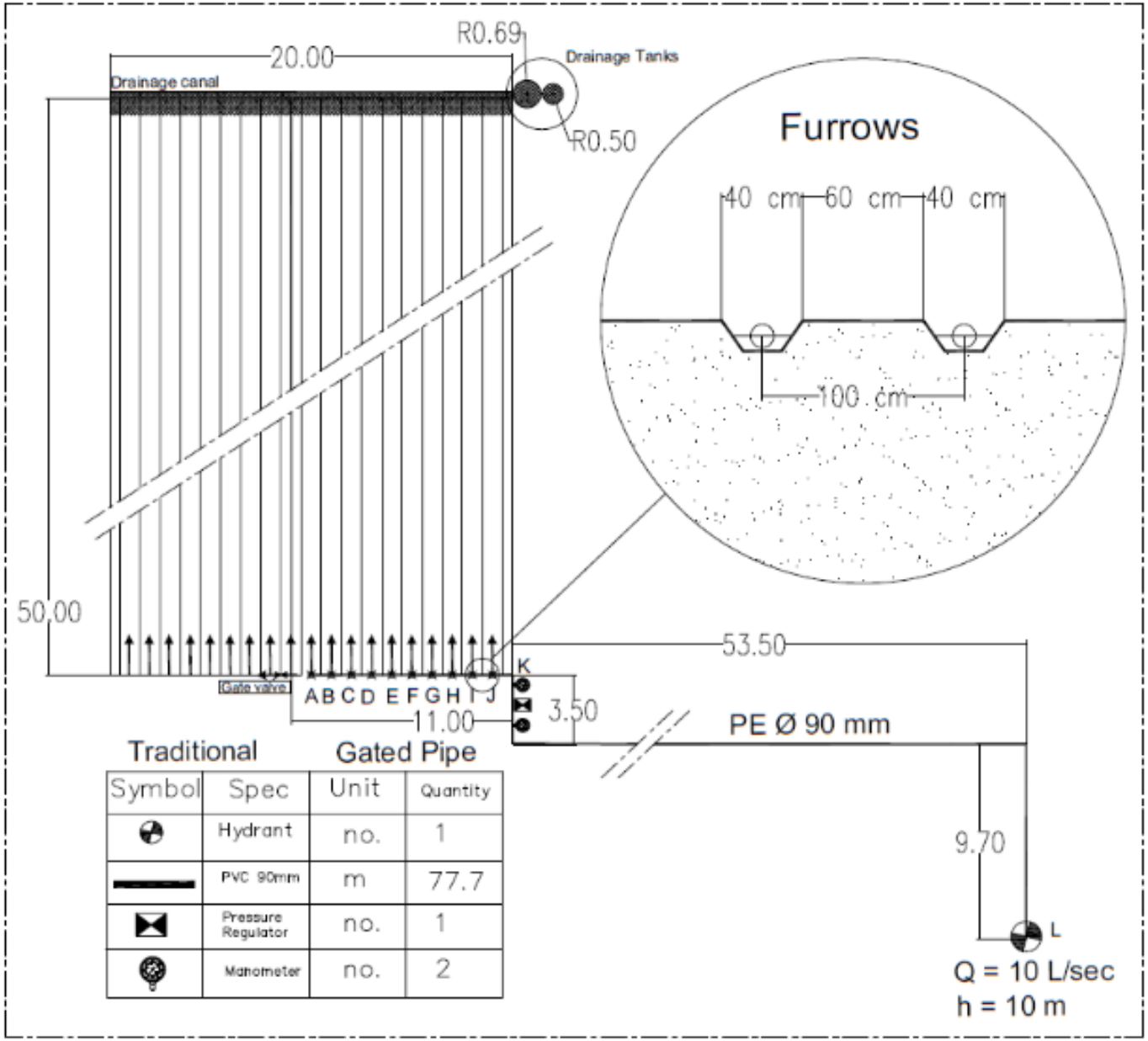


Figure 7 Experiment layout

Figure 8 Flow meter

Figure 9 Pressure regulator with upstream and downstream manometers

Figure 10 Self- compensating gated pipe closed- opened

Figure 12 Water advance by gated pipe system

Figure 11 Metal gates used for better controlling the opening section for traditional system

Figure 14 Water advance by traditional furrows system

Figure 13 Traditional furrow irrigation

Figure 15 Drainage Channel

Figure 16 Water advance through the furrows

Figure 17 Reservoirs for measuring drainage water

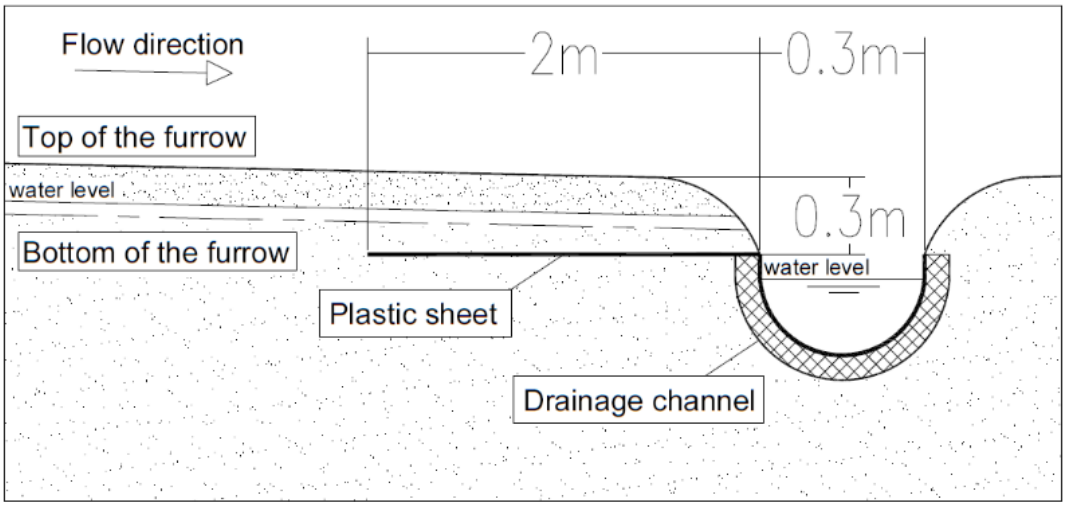


Figure 18 Cross sectional view for the drainage channel

2.2. Soil physical properties

A mechanical-physical analysis was done prior the experiment at two different interval depths (0-10 and 10-30cm). To identify the texture properties, soil physical data were averaged on 10 disturbed samples collected each 5 m along the furrow at two interval depths. in the same way, 10 undistributed soil samples more were collected in order to determine the initial soil water content by applying thermo-gravimetric method While, the available soil water content (ASW) was extrapolated from a soil hydraulic characterization done through a monitoring with a tension-infiltrometer (Ankeny, Ahmed et al. 1991). All data are listed in the Table 3.

Table 3 soil physical properties

soil depth (cm)	FC (%)	WP (%)	ASW (%)	ρ_b (gcm^{-3})	Particle size distribution (%)			Texture class	Stone mass percentage in soil (%)	Initial soil water content (%)
					sand	clay	loam			
0--10	14.9	5.6	9.3	1.11	46.3	14.5	39.2	loam	32	16.8
10--30	13.2	4.4	8.8	1.14	42.4	14.5	43.1	loam	20	20

Where FC: field capacity; WP: wilting point; ASW: available soil water content; BD: bulk density

2.4. Measuring soil infiltration

Soil infiltration is a complicated process that is a function of a number of factors, i.e. soil texture, soil structure, tillage operations, compaction, soil initial water content, air entrapment, soil salinity, water salinity and time. The last factor is the most relevant. Darcy's law approximates theoretically the infiltration process. However, theoretical analysis is rarely used to analyze surface irrigation due to intense data requirement and spatial variability. Therefore empirical equations are being used. The parameters of empirical infiltration equations are obtained by regression, and do not have any physical meaning. The main drawback of such equations is that the parameters are characteristic of the location and time of the experiment.

For this study Koskiatov – Lewis equation was used to generate the parameters of the empirical relation. It describes the relation between the soil infiltration rate (i) and time (t). In surface irrigation referred as the opportunity time (τ). The opportunity time is the interval during which water will infiltrate at a specified location. It begins when the water flow first reaches the point (advance) and ends when the water eventually drains from the point (recession).

In this study soil infiltration curve was conducted on site using a double ring infiltrometer (Brouwer, Prins et al. 1988).

Steps for the infiltration test by using double ring infiltrometer:

Step 1: the small ring (30cm diameter) was hammered for 15cm depth in the soil. A piece of wood was used to protect the ring from damage during hammering. The measuring rod was

planted on the vertical side of the ring were at least 15cm of the rod was above the ground. (Figure 19)

Step 2: the wider ring (60cm diameter) was hammered around the small ring were both rings had the same height above the ground.

Step 3: as fast as possible the water was poured in the small ring to 100mm height, and in between the rings as well.

Step 4: the clock time and the water level was recorded in the beginning of the test.

Step 5: After 1-2 minutes, the drop in water level was recorded. Then the water level was raised up to the original level and measured in time intervals, while the water level in between the rings was kept in constant level.

Step 6: The reading were taken frequently 1-2 minutes in the start and extended as the time goes to reach 20-30 min.

Two infiltration tests were carried out in two different locations along the furrow.

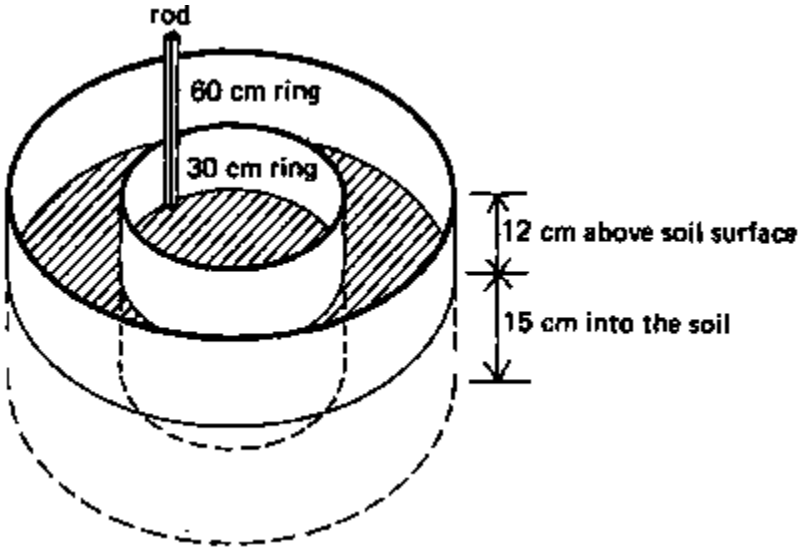


Figure 19 set up of double ring infiltrometer test source: FAO

From the infiltration test the relation between the infiltration rate and the accumulated infiltrated depth with time was plotted and the kotiakov prameters was extracted as the regriossin on the curve. (Figure 20)

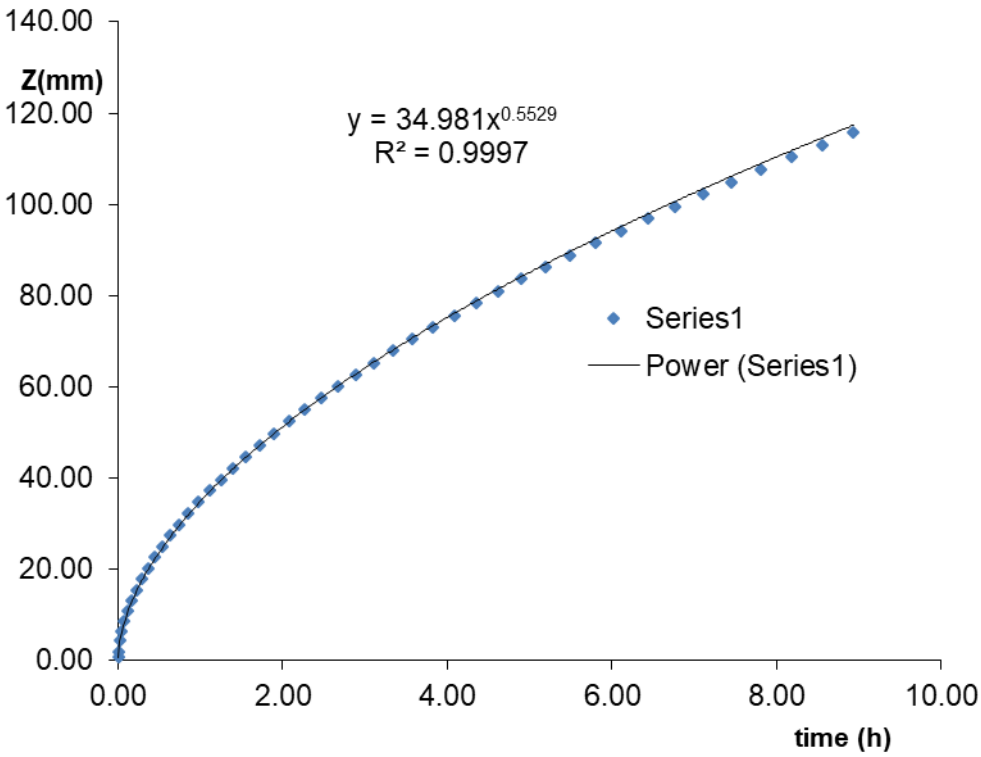


Figure 20 cumulative infiltration and Kostiakov parameters

The Kostiakov – Lewis equation is:

$$i = ka\tau^{a-1} + f_0$$

Where (i) is the infiltration rate (mm/hr), (τ) is the opportunity time (hr), (f_0) is the basic infiltration rate (mm/hr), (k and a) are empirical parameters.

The integration of the regression of the curve is representing the cumulative infiltrated depth:

$$\mathrm{Z} = \int_0^{\tau} i(\tau)d(\tau)$$

$$Z = k\tau^a + f_0\tau$$

Where Z is the cumulative infiltrated depth (mm). For this location and from the empirical relation in Figure 20:

$$Z = 34.981\ \tau^{0.553} +\ 1.76\tau$$

2.4. WinSRFR Event simulations

As mentioned Application efficiency (AE) and Distribution Uniformity (DU) are the main indicators to evaluate the overall performance of any surface irrigation event. Those indicators are dependent on a number of designing and operating factors, mainly:

- Upstream discharge (Q)
- Field slope (S)
- Field dimensions (L*W)
- Soil infiltration rate (i)
- Roughness (n)
- Furrow cross-sectional dimensions (V/H)
- Duration of the event (time of cutoff) (T_c)
- And targeted infiltrated depth (Z_r)

Except the last two (T_c and Z_r), all of the other mentioned factors are assumed to be hard to modify. Thus an expert user tends to raise the performance by selecting the best cutoff time for each irrigation event. That time ensures the best combination of the possible minimum drainage with the maximum possible retained water in the targeted soil depth.

Assuming the inflexibility of the all other factors is usually valid. However, a number of on farm practices could impact the mentioned factors and could be used to enhance the performance. For example, using gated pipe alternate irrigation, the odd and even furrows are irrigated separately, consequently doubles the available discharge per furrow. While surge irrigation exploits the crusting and consolidation phenomena to reduce the advance time. However in the present study such practices are not taken into consideration, as the main objective is comparing gated pipes to conventional furrow irrigation.

With this objective in mind, the event was simulated using WinSRFR. All of the data for the simulation are gathered from the field. The only assumption in the simulation process is the required infiltrated depth (cm) which depends on the expected root zone length, the deficit prior irrigation and the soil characteristics. As there are no crops cultivated, the required infiltrated depth was assumed to be 25mm.

The next step is to figure out the cut off time. Trial and error simulations were used. For each trial the same data were inserted in the model and the cut off time was changed by 10 min step. Then the AE and DU were reviewed. The results showed that 30 min is expected to achieve 79 % for AE with and 89% for DU

Farm: Farm 1, **Field**: Field 1
Folder: Folder 1, **Simulation**: Simulation 1

Input Parameters - **Solution Model**: Zero-Inertia

System Geometry - Trapezoid Furrow, No Drainback, Open End
Slope = 0.003 m/m
Furrow Length = 50 m — Bottom Width = 20 cm
Furrow Set Width = 8 m — Side Slope = 0.8 H/V
Furrow Spacing = 1 m — Maximum Depth = 12 cm
Furrows/Set = 8

Infiltration - Kostiakov Formula: Z = k*T^a
- Furrow Spacing (No WP Effect)
k = 34.37 mm/hr^a
a = 0.553

Roughness - Manning n
Manning N = 0.02

Furrow Set Inflow - Standard Hydrograph
Furrow Inflow Rate = 0.8 l/s — Furrow Set Inflow Rate = 6.4 l/s
Cutoff Time = 30 min

No Cutback — Required Depth = 2.5 cm
Unit Water Cost = 30.00 $/ML

Calculated Performance Indicators

Hydraulic Summary

Dapp	= 2.88 cm	Dmin	= 1.84 cm	Tco	= 30 min
Dinf	= 2.26 cm	Dlq	= 2.01 cm	TL	= 16.3 min
Ddp	= 0 cm	Ymax	= 2 cm	XR	= 1.84
Dro	= 0.62 cm	Verr%	= -0.01 %		

Efficiency & Uniformity Indicators

AE	= 78 %		
DUmin	= 0.81	DUlq	= 0.89
ADmin	= 0.74	ADlq	= 0.81

Costs

Total	= 8.64 $/ha		
DP	= 0.00 $/ha	DP%	= 0 %
RO	= 1.87 $/ha	RO%	= 22 %

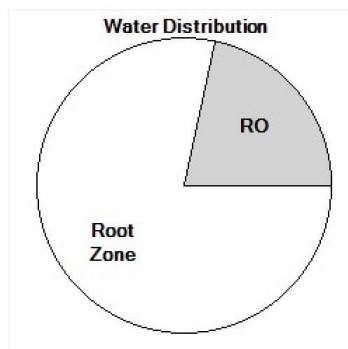


Figure 21). Compared to 20 and 40 min for cutoff, this combination was the most appropriate. Lower irrigation time will achieve higher AE and however the infiltrated depth will be much lower than the targeted infiltrated depth (25mm). While increasing the time to 40 min will decrease the AE to 65% which is not acceptable as a simulated result.

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No Cutback — Required Depth = 2.5 cm
Unit Water Cost = 30.00 $/ML

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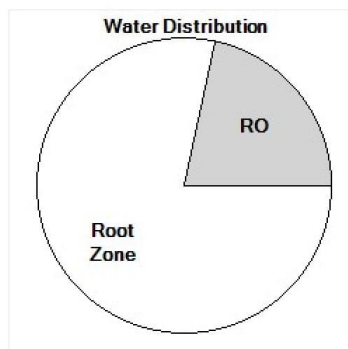

Figure 21 shows the field data inserted and the results for 30 min cut off time.

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DP	= 0.00 $/ha	DP%	= 0 %
RO	= 1.87 $/ha	RO%	= 22 %

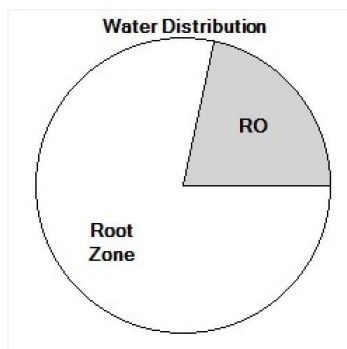

Figure 21 Data inserted and simulation results for 30 min irrigation event

2.5. Data collected from the field trials

The simulated event was applied in the field using both systems. For all furrows the advance and recession times and the amount of drainage were measured on field. The event was analyzed using the advance recession curves and Koskiatov – Lewis to calculate the infiltrated

depth in the eleven posts for each furrow (8*11 posts), Table 4 shows an example of the infiltrated depth calculations. While Figure 22 shows the Advance – Recession curves for one of the furrows under gated pipe irrigation. Finally, The DU was calculated according to the average infiltrated depth of the low quarter in the whole filed (the lowest 22 points) relative to the total average infiltrated depth.

$$Z = 34.981\,\tau^{0.553} + 1.76\tau$$

Table 4 Advance recession and infiltrated depth in the second furrow under Gated pipe irrigation

Post	Advance F2	Recession F2	Opportunity Time	Infiltrated depth (cm)
0	0:00:00	0:33:10	0:33:10	2.52
5	0:00:39	0:33:20	0:32:41	2.50
10	0:01:10	0:33:59	0:32:49	2.51
15	0:01:44	0:34:00	0:32:16	2.48
20	0:03:16	0:35:30	0:32:14	2.48
25	0:04:10	0:35:40	0:31:30	2.45
30	0:06:40	0:36:30	0:29:50	2.38
35	0:08:20	0:37:42	0:29:22	2.36
40	0:10:06	0:38:07	0:28:01	2.30
45	0:12:10	0:38:10	0:26:00	2.20
49	0:13:30	0:38:10	0:24:40	2.14

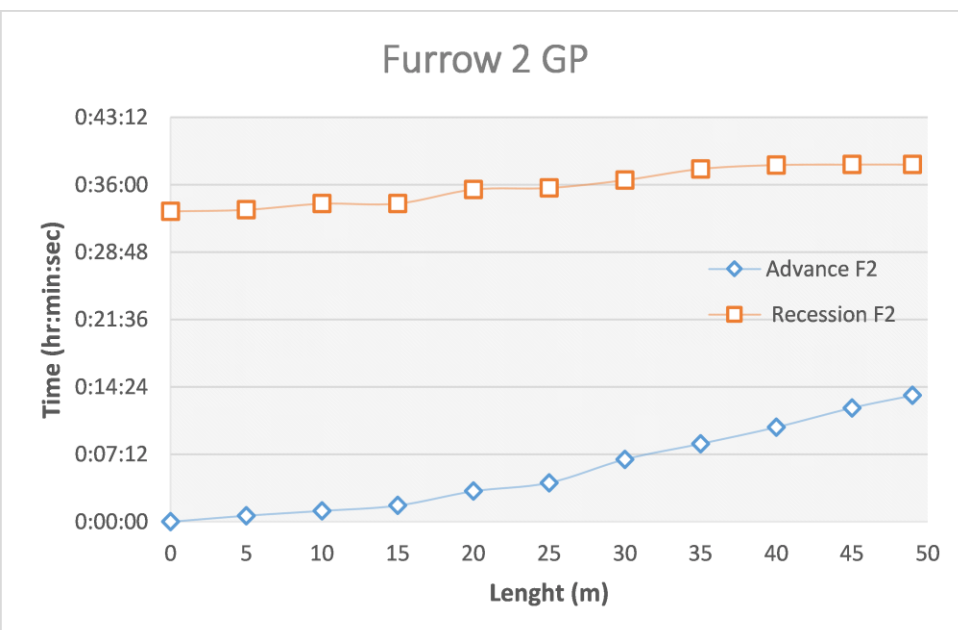

Figure 22 the advance recession curve of furrow (2) under the self compensated gated pipe system

$$DU\ \% = \frac{Average\ infiltrated\ depth\ in\ the\ end\ quarter\ \ (cm)}{Average\ infiltrated\ depth\ (cm)} * 100$$

Regarding the measurements of the Application Efficiency AE on field. The run off was collected by the drainage channel in to the calibrated reservoirs and measured after each event. While the amount of water applied was measured using the flow meter. As drainage was considered the only irrigation losses, the AE will be:

$$AE\ \% = \frac{(Vap - Vro)(m^3)}{Vap\ (m^3)} * 100$$

Where V_{ap} is the amount of water applied in m^3 and V_{ro} is the runoff in m^3 (drainage).

It is important to clarify the nexus between cutoff time, application efficiency and distribution uniformity in surface irrigation comparative assessments. Assuming water availability, distribution uniformity in the root zone will be the main factor impacting the yield. Thus, low performance surface irrigation events usually mean longer cut off time and lower AE rather than lower DU. farmers tend to irrigate more and for longer time attain higher DU. Thus, using the same irrigation time as a bench mark for comparison is valid as long as the final results for both systems show satisfactory DU (above 80%). The actual difference between two surface irrigation systems relays on comparing the irrigation time and AE to achieve high DU. As farmers (users) will tend to achieve the maximum possible DU.

Therefore, the comparison will be done by three steps: 1) Starting the trials by the self-compensated gated pipe system and calculating AE and DU using 30 min cutoff time as generated from the model 2) the second trial will be testing the traditional furrow system for the same cutoff time (30 min) and under the same conditions 3) in the same trial the DU will be evaluated in case of insufficient DU, the event will be extended to achieve higher DU (above 80%).

For the third step, to evaluate the DU on field the variation of the time of advance was used as an indicator for the good or bad DU. Because infiltration is assumed to be uniform over the field, the variation in intake opportunity time is an indication of the uniformity. However in free ending furrow irrigation the recession phase is very fast in all the field compared to advance. Thus the time of Advance is the main contributor to the DU.

The quarter time rule is widely used to obtain satisfactory irrigation event. The advance phase should finish in quarter of the time needed to fill the root zone with the required depth, that could be determined from the infiltration curve (Walker 1989).

The average opportunity time to infiltrate the required depth in any point is calculated from Koskiatov:

$$Z = 34.981\,\tau^{0.553} + 1.76\tau$$

If the required depth Z = 25mm, then τ = 22-23 min, and the advance phase should finish in around 7-8 min. In other words, the average allowed opportunity time in the low quarter should not get below 20 min. Thus, the following rule was used to evaluate DU in field: If the advance phase did not finish on time, the irrigation event will be extended till the average opportunity time in the low quarter of the field is around 19 -20 min.

2.6. Event analysis

Once the data were collected after the trials, the model was validated by comparing the simulated scenario and the measured parameters using the calibrated gated pipe system results. The recorded advance - recession times and kostiakov parameters were inserted into the model to generate the actual advance and recession curves. Figure 23 shows both actual and simulated curves.

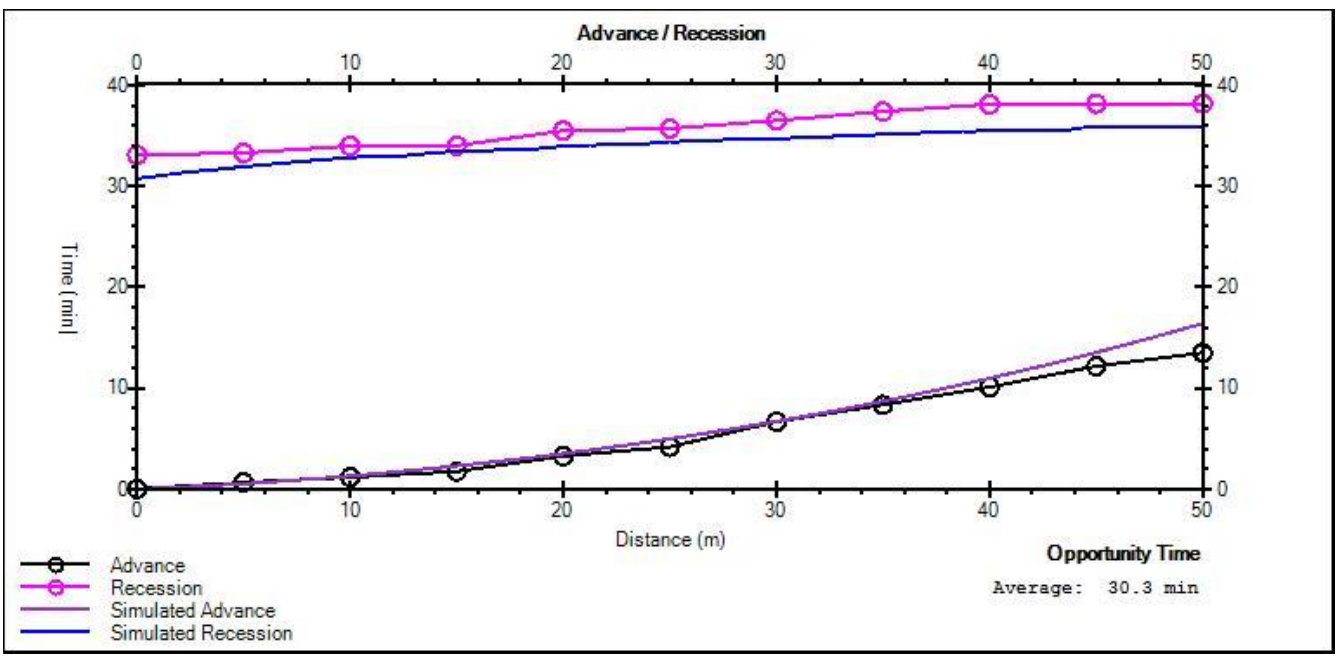

Figure 23 actual and simulated advance and recession curves

Results and discussion

The Application efficiency was quite high for both system. Using gated pipe systems, by applying 11.46 m^3 in 30 min the drainage measured in the reservoirs was 2.1 m^3 resulting an application efficiency of 82%. While by traditional surface irrigation system, for the same applied volume and duration (30 min) The amount of drainage was 2.5 m^3. Resulting a slightly lower efficiency of 78%. However, AE can't be used alone to evaluate a surface irrigation event.

The last 3 furrows under traditional surface irrigation failed to complete the advance phase in 30 min, thus the irrigation event was extended to 15min more to achieve a satisfactory distribution uniformity using the quarter time rule. Which is typically any farmer will do to irrigate his field. After 45min the AE decreased to 70.7 %. Where, out of 17.45 m^3 of water applied 5.1 m^3 was measured as drainage. While the DU reached 79 %.

The significant difference between the two systems lays in shorter advance times (7-10 min) and steady uniform discharges achieved by the self-compensated gated pipe system, Which resulted a decrement in the variation of opportunity times between the furrows and raised the DU to almost 96 % in 30 min with 82% AE.

While, in traditional furrow system the variation of the discharges among the furrows impacted the advance phase. The advance was very fast in the first furrows and deteriorated gradually to the last furrow, resulted a longer irrigation event. It is important to notice how the drainage water increased from 2.5 m^3 in the first 30 min to 5.1 m^3 in 45 min. As the advance phase is not uniform, and the infiltration rate decreases with time, the furrows which finish the advance early will contribute more to tail water in the added 15 min. The relation between the amounts of drainage from each furrow and the infiltration rates is controlled by the difference between advance and cutoff time for each furrow. It is worthy to mention that DU in this type of surface irrigation is subjected to the skills of the irrigator himself and how he can control the discharges during the irrigation event. (Figures 24-25) show the advance - recession curves of the first and the last two furrows of both systems.

The results also revealed that WinSRFR is more valid for simulating gated pipe systems over traditional one. The simulated AE was 79 % while the DU 89% in 30 min cutoff time. The measured application efficiency of the self-compensated gated system was almost 82% while the total DU was higher 96%. The interpretation lays in the simulation process of the advance time. The main assumption of one dimensional modeling is the behavior of water flow pattern over and under the soil surface, which is assumed to be repeated across the width of the field. Such assumption is neglecting the spatial variability and micro topography (undulations) impact on water infiltration and assumes repetitive identical furrows. In fact the simulated time of advance was 16min, while the actual advance time ranged between 7-14 min. the fast advance in some furrows generated higher overall DU, thus the actual DU was higher by 7%.

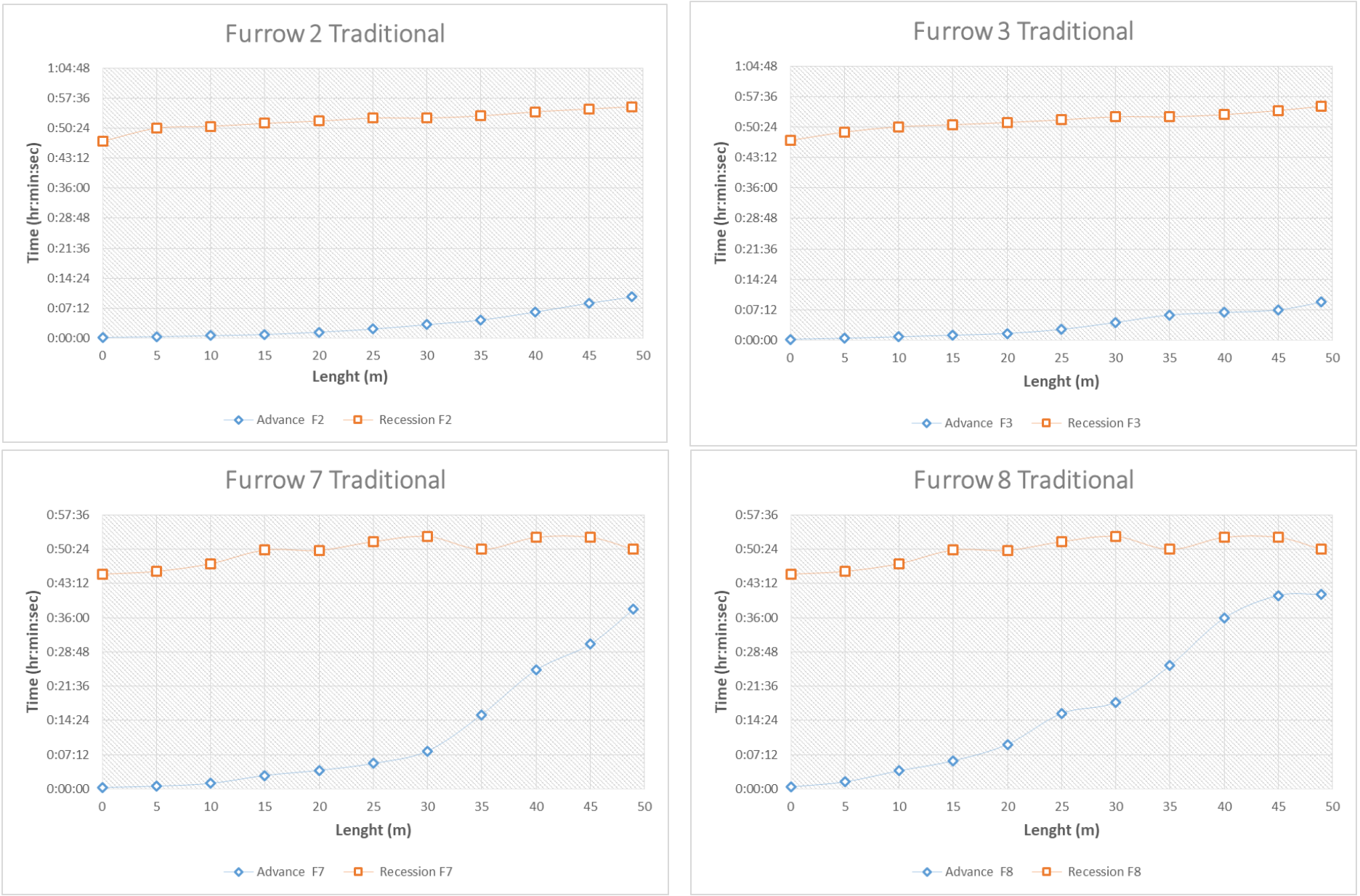

Figure 24 Advance a Recession curves of the first and last two furrows under traditional furrow irrigation

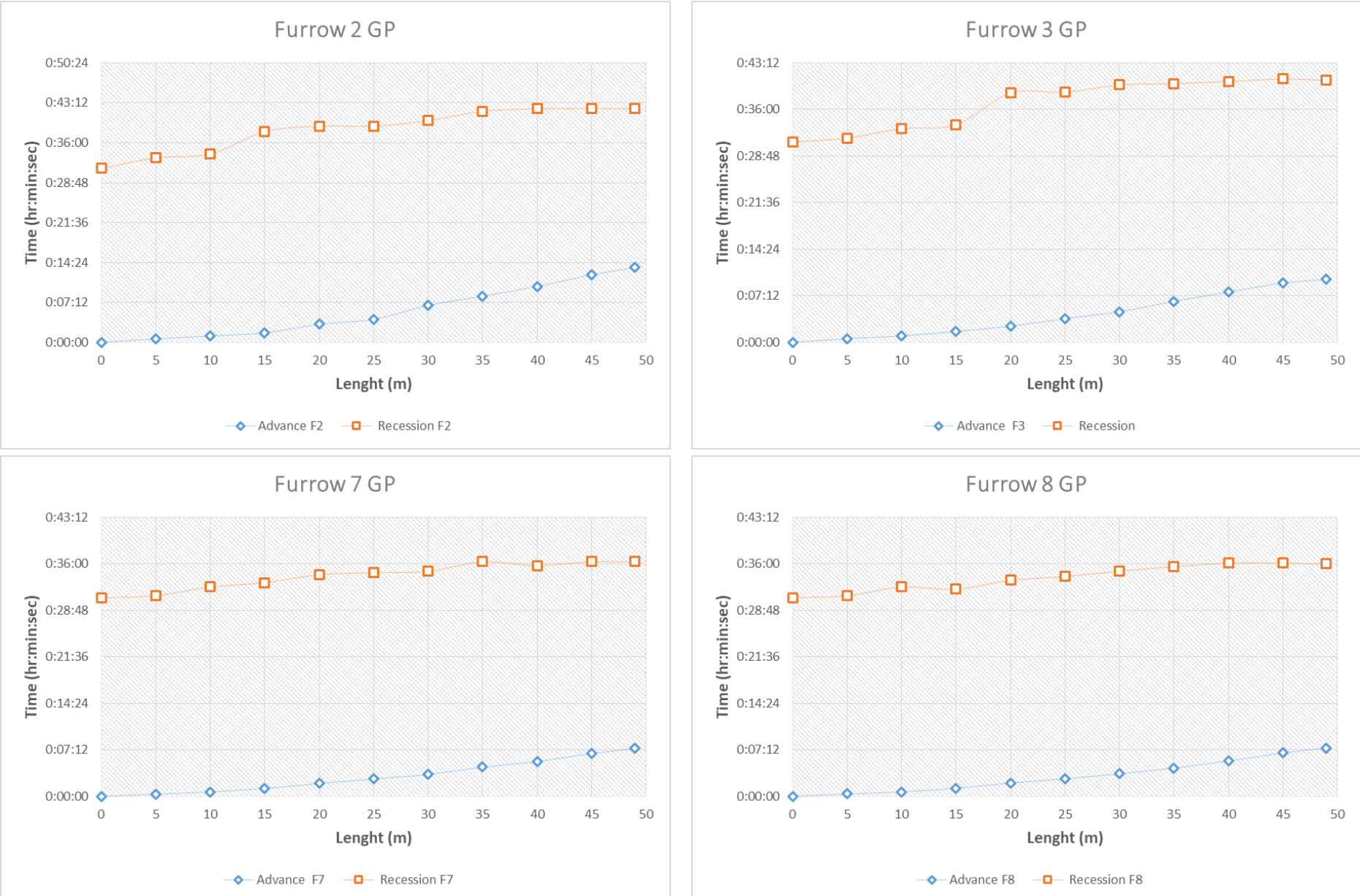

Figure 25 Advance - Recession Curves of the first and last two Furrows under self-compensated gated pipes

Conclusion

With proper management, using modified gated pipe systems can significantly enhance the surface irrigation performance in terms of Application Efficiency and Distribution Uniformity even to be comparable to pressurized systems, furthermore it consumes less energy and needs less maintenance. The modified gated pipes raised the performance by 11% in terms of AE, 17% in DU and reduced the irrigation time by 30% compared to traditional systems. The proposed system could also be a wining alternative in regions distinguished with seasonal water availability or rotational schedules (high fixed discharges in small fixed durations), flat topography and traditional legacy of surface irrigation, where low irrigation performance can mainly be interpreted to mismanagement rather than water scarcity. In addition to the proved enhancement in DU and AE, on farm level, it is expected that the system will have an environmental impact by reducing drained polluted water due to application efficiency improvement, and social impact by reducing the irrigation time, increase the number of events per week and consequently reduce rotational intervals. Such impacts had to be assessed on district level.

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