DESIGNING PRECISE SURFACE IRRIGATION SYSTEMS AT FIELD SCALE

CONCEPTION PRÉCISE SYSTÈME D'IRRIGATION DE SURFACE À L'ÉCHELLE DU CHAMP

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ABSTRACT

Determination of optimum field's dimensions, together with optimum design parameters have important role in enhancement of application efficiency and reduce of drainage needs in surface irrigation systems. Therefore, this research was conducted in the Ramshir irrigation and drainage project, as one of the project units of a Mega irrigation development plan in the south of Iran, namely as "Velayat Plan", during years 2013-14. Four water advance-recession measurements in three irrigation borders with different lengths (120, 150, 180 m) in different irrigation intervals during different crop growth stages were conducted. Based on WinSRFR simulation results, in border irrigation of wheat crop in the Ramshir network, different optimum design alternatives which can achieve reasonable water application efficiency, even more than 70%, could be selected. In general the selected lengths and wide of fields could be selected in the range of 100-300 m and 4-12 m respectively. The border design alternative of 7 m wide, 200 m length, and slopes of 0.005 or 0.001 m/m are best alternative for all ranges of selected inflow discharges (10-20 l/s) and depths of irrigations (50- 90 mm).

RÉSUMÉ

Détermination des dimensions du champ optimale, ainsique les paramètres de conception optimalesontrôle important dansl'amélioration de l'efficacité de l'application et de réduire les besoins de drainage dans les systèmesd'irrigation de surface. Par conséquent, cetterecherche a étéménéedans le irrigation et de drainage projetRamshir, commel'une des unités du projet d'un plan de développement de l'irrigation Mega dans le sud de l'Iran, à savoir que le «Plan Velayat", au cours des années 2013-14. Quatre eau avance-récession des mesuresdanstroisfrontières irrigation avec des longueursdifférentes (120, 150, 180 m) dans les différentsintervallesd'irrigation au cours des différentesétapes de croissance des cultures ontétéréalisées. Sur la base des résultats de simulation WinSRFR, dansl'irrigation de la frontière de la récolte de blédans le réseauRamshir, différentes alternatives de conception optimales qui peutatteindrel'efficacité de l'application de l'eauraisonnable, même plus de 70%, pourraitêtresélectionné. En général, les longueurssélectionnéeset large de champs pourraientêtrechoisisdans la gamme de 100-300 m et 4-12 m respectivement. La conception alternative de la frontière 7 m de largeur, de 200 m de longueur, et les pentes de 0,005 ou 0,001 m / m sontmeilleure solution pour toutes les gammes de rejetssélectionnésd'entrée (10-20 l / s) et des profondeurs de irrigations (50- 90 mm).

Keywords: Border irrigation, Field, Optimum length, Application efficiency, Distribution uniformity, Ramshir, Khuzestan

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1. Introduction

Despite great developments in irrigation technologies and modern pressurized irrigation systems, surface irrigation systems are still the main irrigation systems in the world, especially in the developing countries. In Iran, and most of the world's countries, more than 90 percent of the irrigated lands, i.e., 7.3 million hectare, are still irrigated with traditional surface irrigation systems (Abbasi, 2012). However, improvement of irrigation efficiency and precise application of water in the traditional surface irrigation systems are challenging, especially in regard to water scarcity crises and agriculture production sustainability issues. If these systems are designed well and also are practiced by the farmers properly, they could achieve reasonable irrigation efficiencies and fair distribution uniformities in the field without use of huge amount of energy and high costs as are associated with the use of the sophisticated systems such as pressurized irrigation systems.
The Khuzestan province in the south west of Iran has hot climate condition with fertile heavy soil. Almost two thirds of country's rivers flow to this province. Favor climate conditions for crop production and water availability, has changed this province to the main agricultural production zone of the country. However because of low irrigation efficiencies (less than 40%), heavy textured soil (mainly SiCl-Cl) with low infiltration rate, and high evaporation demand (more than 1500 millimeter), the lands are facing with waterlogging and salinity-sodicity problems with different degrees of drainage requirements.
Recently, a mega irrigation development project namely "Velayat Plan"has started in the region. It covers almost 550,000 ha irrigated lands in the Khuzestan and neighboring province, i.e., Ilam province. The plan mainly focuses on construction of tertiary and quarterly canals, land leveling, construction of subsurface drainage networks, farm roads, land consolidation, and all other activities related to the on-farm water activities, with the main goal of enhancement of irrigation efficiency (AE) and crop production. The plan has executed in different sub-projects in the different irrigation networks, e.g. Ramshir irrigation network, the network which this research was conducted.
Horst et al. (2004), to assess the potential for improving the performance of furrow irrigation in the central part of the Fergana Valley, Uzbekistan, conducted a set of evaluation experiments. Irrigation management alternatives included several furrow inflow rates (1.2–2.4 l/s) and furrow lengths (130 and 400 m); comparing every-furrow irrigation with alternate-furrow irrigation. Their results were evaluated through the application efficiency (AE), the distribution uniformity (DU) and total applied irrigation depths. The best performances were obtained for alternate long furrows adopting the inflow rate of 1.8 l/s, which produced high AE and DU, superior to 80 and 83%, respectively, and led to seasonal water savings from 200 to 300 mm when compared with actual water use in every-furrow irrigation.
Pereira et al. (2007) conducted a research for assessing basin irrigation and scheduling strategies for saving irrigation water and controlling salinity in the upper Yellow River Basin, China, focusing on the farm scale. Their studies for potential water savings included: (a)
field evaluation of current basin irrigation practices and further use of the simulation models SRFR and SIRMOD to generate alternative improvements for the surface irrigation systems and (b) the use of the ISAREG model to simulate the present and improved irrigation scheduling alternatives taking into consideration salinity control. Models were used interactively to define alternatives for the irrigation systems and scheduling that would minimize percolation and produce water savings. Foreseen improvements refer to basin inflow discharges, land leveling and irrigation scheduling that could result in water savings of 33% relative to actual demand. These improvements would also reduce percolation and maintain water table depths below 1m thereby reducing soil salinization.
Precise water application in surface irrigation systems of the Ramshir irrigation network area still is a challenging issue, considering that hot climate condition and high evaporation demand of the region, is questioned the use of pressurized irrigation systems, especially in soils with low infiltration rate which is common soil characteristics of the lands in the region.
Determination of optimum field's dimensions, together with other design parameters, including slope, inflow rate, and irrigation time, have important role in enhancement of application efficiency and reduce of projects drainage costs. Considering heavy textured soil and low soil infiltration rates of the lands, improvements in current surface irrigation systems of the region could help much in in improvement of irrigation AE with lower costs and also more in accordance with the farmer's knowledge and local cultures of them. Therefore, this research was conducted in the Ramshir irrigation and drainage project, as one of the project units of a "Velayat Plan", during years 2013-14.

2. Materials and methods

Ramshir irrigation and drainage project covers an area of 5305 ha. The area is along the Jarrahi River and locates between E347000-N3422500 and E346500-N3424000 till E334728- N 3414999 and E332500-N3417500. This research project was conducted in U29-2 plot of the Ramshir irrigation and drainage project. The main crop in the network is Chamran salinity tolerant winter wheat, which are irrigated traditionally with the closed-end regime border surface irrigation system.
The research was mainly conducted in two parts, i.e., the field measurements and the use of WinSRFR model. In the field measurements, four water advance-recession measurements in three irrigation borders with different lengths (120, 150, 180 m) in different irrigation intervals during different crop growth stages were conducted. Inflow to the border and runoffs were measured using the WSC flume type 4.

The WinSRFR 3.1 (USDA-ALARC, 2009) was used in this research. WinSRFR is an integrated hydraulic analysis application for surface irrigation systems that combines a simulation engine with tools for irrigation system evaluation, design, and operational analysis.WinSRFR provides its functionality in four color-coded Worlds namely Event Analysis World (Irrigation event analysis and parameter estimation functions), Physical Design World (Design functions for optimizing the physical layout of a field), Operations Analysis World (Operations functions for optimizing irrigations), and Simulation World (SRFR's simulation functions for testing and sensitivity analysis).
Data and information collected from four irrigation event and three selected border length were entered to the model for model calibration. In this stage, using the Event Analysis World of the model and based on fair compatibility of the observed advance and recession curves with the simulated ones (Fig. 1), the average of coefficients of the selected soil infiltration function, i.e. a, b, c, and k parameters of the Kostiakov-Lewis infiltration equation parameters (Eq.1), were determined.

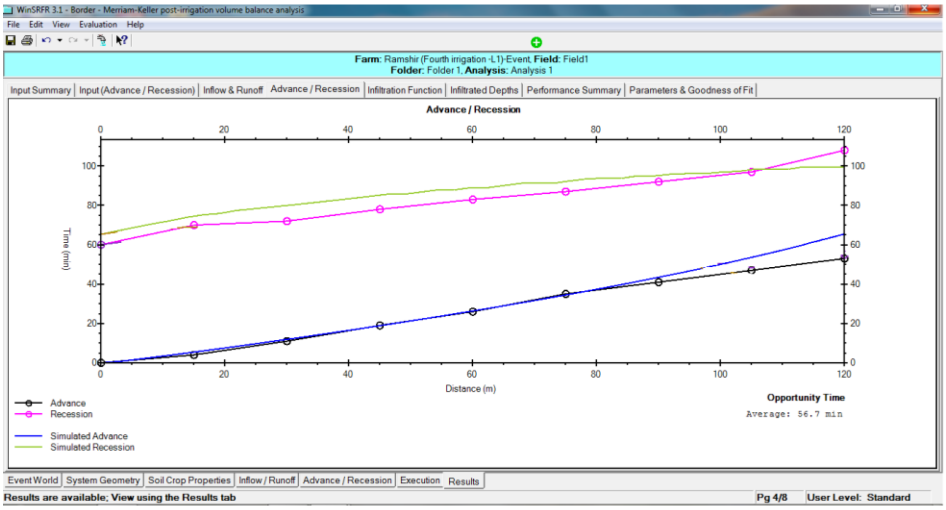

Fig. 1: The simulated by the model and observed advance and recession curves together with the infiltrated depth of water along the border (4th irrigation event, border length= 120 m)

$$Z = k \times t^a + b \times t + c \quad (1)$$

In the later stage, the calibrated infiltration function was used for optimizing and developing different design alternatives using the Simulation World of the model. In the optimization stage, considering fulfillment of two main criteria, i.e. fully advance of water in the border length and also the adequacy of irrigation and fully infiltration of water to the desired depth in the crop root zone, the model was executed for the different design alternatives and in different iterations. The optimized results were recorded in the tabulated forms shown in table 1, so called as "Design alternative tables". In this stage, finally the optimized length of border (L), optimized irrigation time (T) were resulted for the selected specific longitudinal slope of border (S), border wide, and inflow discharges (Q) together with the other design parameters which were determined in the calibrations stage, i.e., values of a , b, c, k parameters and border Manning roughness (n). The tabulated form of the record of results obtained from optimization process together with the simulation results of the model in the case of required irrigation depth (D_{req}) equal to 60 mm and border wide (W) of 4 m is presented in table 1 as sample. In table 1 the highlighted cells show the design alternatives in which reasonable application efficiencies (AE) greater than 70% could potentially be achieved.
Overall, the SRFR model was executed 1125 times (5 border length× 3 border wide× 5 border slope× 3 inflow discharge× 5 Required irrigation depth) without accounting different iterations (more than 3 iterations per every alternative) done for reaching optimum result for every design alternative. The results again were tabulated in the tables similar to the table 1 and the design alternatives with AEs greater than 70% were highlighted in these tables.

3. Results

Based on the calibration results, the Kostiakov-Lewis infiltration function of the soil was determined as shown in Equation. 2.

$$Z = 3.661 \times t^{0.584} + 18 \times t + 7 \quad (2)$$

In which:

Z= infiltrated depth of water (in mm);
t= irrigation time (from start of irrigation) (in hr)

Table 1: A sample tabulated form of recording simulation results containing optimization results of the model for D_{req} =60 mm and W= 4 m

Border Length (L) (m)	Border Wide (W) (m)	Border Depth (Y) (mm)	Required Irrigation Depth (Dreq) (mm)	Border slope (S) (m/m)	Inflow rate (Q)								
					Q= 20 lps			Q= 15 lps			Q=10 lps		
					Application Efficiency (AE) (%)	Distribution Efficiency (DULQ)	Irrigation Time (T) (min)	Application Efficiency (AE) (%)	Distribution Efficiency (DULQ)	Irrigation Time (T) (min)	Application Efficiency (AE) (%)	Distribution Efficiency (DULQ)	Irrigation Time (T) (min)
100	**4**	**210**	**60**	0.0005	71.4	0.81	28	72.1	0.81	37	72.7	0.83	55
				0.0010	57.1	0.67	35	55.6	0.68	48	57.1	0.68	70
				0.0015	44.4	0.60	45	44.4	0.60	60	44.4	0.61	90
				0.0020	36.4	0.56	55	38.1	0.54	70	38.1	0.54	105
				0.0025	33.3	0.49	60	33.3	0.49	80	33.3	0.50	120
150	**4**	**210**	**60**	0.0005	65.2	0.74	46	66.7	0.75	60	66.7	0.76	90
				0.0010	46.2	0.60	65	47.0	0.59	85	48.0	0.60	125
				0.0015	35.3	0.52	85	36.4	0.51	110	42.8	0.47	140
				0.0020	28.6	0.48	105	29.6	0.46	135	40.0	0.42	150
				0.0025	25.0	0.42	120	28.5	0.37	140	40.0	0.41	150
200	**4**	**210**	**60**	0.0005	57.1	0.70	70	59.3	0.70	90	66.7	0.71	120
				0.0010	38.1	0.56	105	39.5	0.54	135	57.1	0.60	140
				0.0015	30.3	0.45	132	35.6	0.42	150	53.3	0.57	150
				0.0020	27.6	0.36	145	33.3	0.37	160	51.6	0.55	155
				0.0025	25.0	0.31	160	32.3	0.37	165	50.0	0.54	160
250	**4**	**210**	**60**	0.0005	52.6	0.66	95	55.6	0.66	120	80.0	0.84	125
				0.0010	38.4	0.46	130	47.6	0.51	140	74.0	0.75	135
				0.0015	34.5	0.37	145	44.4	0.48	150	71.3	0.71	140
				0.0020	32.3	0.35	155	43.0	0.47	155	66.6	0.69	150
				0.0025	31.3	0.35	160	41.7	0.46	160	62.5	0.67	160
300	**4**	**210**	**60**	0.0005	50.0	0.62	120	69.5	0.73	115	85.7	0.90	140
				0.0010	42.9	0.47	140	59.3	0.62	135	80.0	0.83	150
				0.0015	40.0	0.44	150	55.2	0.59	145	75.0	0.79	160
				0.0020	37.5	0.43	160	51.6	0.57	155	70.6	0.77	170
				0.0025	36.4	0.42	165	50.0	0.55	160	68.6	0.76	175

By applying the equation 2 in the WinSRFR model, the optimization process for the different combination of the selected, L, W, S, Q, and Dreq was done and the results were provided in the design alternative tables for every design cases[2]. In table 2 the results of model simulation for the design alternative of W= 7 m and Dreq= 70 mm is provided as sample. In table 2 the colored cells are design alternatives which potentially could provide AEs greater than 70%. These tables are indeed guidelines for designing irrigation borders (Length, Wide, Slope), which could be used by the designers, and also instructions for the operation and management of irrigation events (Inflow discharge, Irrigation time, Required irrigation depth), which could by practiced by the farmers in the Ramshir irrigation and drainage network.
As it could be seen from table 2, for the different combination of design parameters of the border (L, S, W, Q, S, Dreq), different values of irrigation time (T), AE, and DU are obtained from the model results. Therefore the design engineer with assuming a reasonable basic level of designed AE (e.g., > 70%), could select different design parameters (L, S, W, Q, S, and Dreq) based on local irrigation circumstances and project economy.
The results indicated that in the Ramshir irrigation and drainage network, application of low inflow rates in relatively long border lengths (till 250 m) with low slope and proper irrigation time, could potentially create high application efficiencies. In a same condition, generally the borders with short wide create lower application efficiencies than the longer wide ones. Based on relatively high slopes (0.002 m/m) of the Ramshir lands obtained from land leveling, the optimum border wide could be between 7-12 m.
Based on reciprocated effects of border length-irrigation time analysis, the border lengths of 100-200 m and border wide of 4-7 m for inflow rates of 10-20 lps are optimum design selections. Reciprocated effects of border slope-application efficiency analysis also indicated that the AEs vary from 70-90 percent in border slope of 0.0005 m/m to 35-70 percent in higher slope (0.0025 m/m). Therefore, selection of smaller slopes i.e. 0.0005-0.001 is more advisable.

4. Conclusions and recommendations

Different design alternatives could be selected for the dimensions and hydraulics characteristics of the irrigation border of which reasonable AEs could be obtained. However, considering the irrigation method (closed-end border irrigation), heavy texture soils, low soil infiltration rate, soil salinity, land slope, and the economic issues, it is recommended that in the Ramshir network, the plots to be designed with long borders, proper maximum non-erosive inflow rate, and with minimum land slope. This will prevent water ponding in soil surface, especially in the tail end of the border and also will increase DU greatly.
In the closed-end border irrigation, the common method of irrigating wheat in the Ramshir network, the design alternative of L= 200, W=7 with border slopes S= 0.0005 m/m or 0.001 m/m for the different inflow discharges (Q= 10-20 lps), and different selected required irrigation depths (Dreq= 50-90 mm), are ideal alternatives in regard to obtaining higher AEs. However, based on results, the design alternative of L=200 m, S= 0.0005 m/m is the best alternative.

2-The set of complete design alternative tables are provided in the annex of project research report entitle: "A study of effective parameters in determination of field's optimum dimensions: A case study of Ramshir irrigation project", report no.47190, Iranian Agricultural Engineering Research Institute, May 30, 2015, Karaj, Iran.

Table 2: Design of border dimensions and hydraulic characteristics of closed-end border irrigation in the Ramshir irrigation and drainage network (W = 7 m and Dreq=70 mm)

Border Length (L) (m)	Border Wide (W) (m)	Border Depth (Y) (mm)	Required Irrigation Depth (Dreq) (mm)	Border slope (S) (m/m)	Inflow rate (Q)								
					Q= 20 lps			Q= 15 lps			Q=10 lps		
					Application Efficiency (AE) (%)	Distribution Efficiency (DULQ)	Irrigation Time (T) (min)	Application Efficiency (AE) (%)	Distribution Efficiency (DULQ)	Irrigation Time (T) (min)	Application Efficiency (AE) (%)	Distribution Efficiency (DULQ)	Irrigation Time (T) (min)
100	7	210	70	0.0005	81.4	0.83	50	77.8	0.84	70	81.6	0.85	100
				0.0010	58.3	0.72	70	60.5	0.71	90	62.8	0.71	130
				0.0015	49.8	0.62	82	49.5	0.63	110	51.0	0.63	160
				0.0020	40.8	0.58	100	41.9	0.57	130	46.6	0.54	175
				0.0025	37.1	0.52	110	36.3	0.53	150	45.4	0.48	180
150	7	210	70	0.0005	68.1	0.79	90	71.0	0.79	115	79.0	0.81	155
				0.0010	51.0	0.63	120	51.0	0.64	160	73.9	0.73	165
				0.0015	39.5	0.55	155	48.0	0.51	170	70.0	0.70	175
				0.0020	38.0	0.43	160	47.9	0.47	170	69.7	0.69	175
				0.0025	35.0	0.38	175	45.4	0.46	180	66.2	0.68	185
200	7	210	70	0.0005	62.8	0.74	130	72.5	0.75	150	98.7	0.93	160
				0.0010	50.9	0.54	160	67.7	0.67	160	93.6	0.88	170
				0.0015	45.4	0.48	180	62.2	0.64	175	81.7	0.85	200
				0.0020	44.1	0.47	185	60.5	0.63	180	79.7	0.84	205
				0.0025	43.0	0.46	190	58.9	0.61	185	77.8	0.83	210
250	7	210	70	0.0005	68.0	0.71	150	90.2	0.89	150	70.4	0.80	290
				0.0010	63.7	0.64	160	82.0	0.81	165	75.6	0.84	270
				0.0015	56.7	0.60	180	73.6	0.77	185	75.6	0.86	270
				0.0020	55.2	0.59	185	71.6	0.75	190	77.0	0.85	265
				0.0025	55.2	0.58	185	69.8	0.73	195	n.c.	n.c.	265
300	7	210	70	0.0005	81.7	0.84	150	86.0	0.91	190	-	-	n.f.a.
				0.0010	72.1	0.75	170	79.7	0.87	205	-	-	n.f.a.
				0.0015	68.1	0.71	180	77.8	0.84	210	-	-	n.f.a.
				0.0020	64.5	0.69	190	76.0	0.83	215	-	-	n.f.a.
				0.0025	62.8	0.67	195	74.2	0.81	220	-	-	n.f.a.

* n.c.: The model could not converged and no reasonable solution achieved in simulation
** n.f.a: The water advance front could not reached to the end of the border length and advance phase did not completed

As a trend, increase in border slope from the minimum value of 0.0005 m/m to the value of 0.0025 m/m, field AE reduces potentially. Therefore in the Ramshir project smaller slopes are favorable and should not increase from 0.0025 m/m and preferably should the range of 0.0005-0.001 m/m. The S= 0.0005 m/m is the best slope for all the combination of design parameters with reasonable AEs. When the border become widen and longer, design discharge should be selected higher. For an efficient irrigation when the border wide increases, the border length should be shortened. For the inflow rates up to 15 lps, the border length should not increase more from 150 m. For border wide of 4-12 and the border slopes of 0.0005 – 0.0025 m/m the inflow rate per unit wide of closed-end border (q), could be selected between 0.002-0.005 m^2/s.

Overall by calibrating soil infiltration and by use of the WinSRFR surface irrigation model, surface irrigation design could easily be done. Model calibration could provide a set of design alternatives with reasonable AEs. Therefore, using optimum field dimensions together with other optimized irrigation management parameters obtained from a calibrated model from field data, achieving high AEs, even greater than 70% in surface irrigation easily and with low costs, in comparison to the pressurized systems, is possible.

The results of this research argue with opinions of some engineers and managers in the region who just thinking of using pressurized irrigation in the area for improving irrigation efficiency despite not much favorable climatic and soil conditions of the lands in the region in regard to use of these systems and considering its economic and environmental consequences when these system are used.

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