OPTIMIZATION OF IRRIGATION FOR EFFICIENT WATER USE IN SURFACE IRRIGATED SOILS

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ABSTRACT

The study was carried to simulate and optimize the furrow irrigation by using SIRMOD model for two different farm fields, one from Queensland, Australia and other Latif Farm from Tandojam, Pakistan. In this connection, the observed data for the advance times at different points along the furrow lengths for both fields has been collected. The advance trajectories were simulated using INFILT-V model, which are matching favourably with the measured curves and establish that the advance trajectories are passing through the advance point selected for the infiltration. Theirparameters were assessed and thereby cumulative infiltration was estimated using the INFILT-V model.The SIRMOD model was used to evaluate the performance of furrow irrigation for all selected fields using five different irrigation strategies. Irrigation application efficiencies under usual farm management for fields P and Q are obtained as 43.2% and 39% respectively. The simple optimization control strategy is feasible. From the computed irrigation efficiencies, it was found that this control optimised system may be used to make noteworthy improvements in irrigation performance over the actual farm management.Total volume of water used under ordinary farm management was 1595 m^3, however, under the optimized system it was computed using SIRMOD model is 963m^3, which shows a saving of about 40% that can be utilized for other crops. Hence, it is suggested that this study can be widely utilized for different soil typesand more benefits may be achieved from in the field of irrigation.

Keywords: Furrow Irrigation, Optimization, SIRMOD Model, Infiltration, Pakistan

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1.INTRODUCTION

Fresh water is in alimitedquantity, today the world uses 70% of all freshwater for irrigating 17% of the total cropped land resulting 40% of the overall agricultural outputs (ICID Congress, 2006). The aim is to have more crop yield using less water, we mean optimized irrigation with improved efficiencies which is only possible with the use of advanced technology.In Pakistan, Australia and other countries of the world, surface irrigation methods are commonly used for cultivating crops. In Australia, more than 70% of the irrigated area and in other countries like Pakistan, India and many other developing countries, over 90% of their cultivated lands are irrigated through these methods (Philip *et al* 2008, Khatri and Smith 2007).

Surface irrigation, an inexpensive and inefficient method of irrigating crops, wasting much of the water applied which needs to be optimized through advance techniques (Strelkoff and Clemens, 2003). In surface irrigation events, there are four phases i.e. advance, wetting or ponding, depletion and recession phases.The performance of furrow irrigation depends upon various parameters such as field design, soil infiltration characteristics, irrigation water management practices, etc. According to Anthony (1995), application efficiencies can be increased up to 90% in properly managed systems. The optimised irrigation system may surmount these spatial and temporal variations (Raine*et al.*, 1997, Smith *et al.*, 2005). In irrigation system, significant improvement can be made with optimised irrigation and optimisation of irrigation events individually. Total volume of water applied per irrigation can be saved substantially by implementation of a simple optimised irrigation system.Furrow irrigation method is considered to be a low efficient method having poorer irrigation efficiency usually around 70%. Actually it is not the method defect but it is because of poor management. In order to optimize the irrigation events of this system and achieving optimized and efficient irrigation; following research objectives are set forth:

(1) To calculate, infiltration rate on the basis of irrigation advance data for various furrow characteristics, advance and inflow rates; and

(2) To simulate the performance gains through various optimization strategies, using infiltrationcharacteristicsof soil and the above data.

2. MATERIALS AND METHODS

2.1. THE STUDY AREA

This study was carried out on two different farms, having cotton crops on both fields (see plate 1).

Plate 1: Cotton fields at both Tandojam Pakistan and Queensland Australia

For easiness above fields were designated as field P for Latif Farm, Tandojam, Pakistan and field Q for field of Queensland, Australia and their salient features are summarised in Table 1.

Table 1: Salient features of the fields P and Q

S. No.	Description	Field	
		P	Q
1	Irrigated Area in m^2	1000	**8160**
2	No. of furrows	10	**17**
3	Length of furrows in m	100	**240**
4	**Furrow spacing in m**	**1**	**2**

2.2 ADVANCE TRAJECTORIES

Data regarding inflow rate, cross sectional area and advance time measurement at various distances (m) and time (min) was collected/observed from the farms P and Q is shown in Table 2 and their measured advance curves are shown in Figures 2 and 3 respectively.

Table 2: Advance Data for Field P and Q

Data Set Number	Field P		Field Q	
	Observation Points (Nos.)	Inflow rates (m^3/min)	Observation Points (Nos.)	Inflow rates (m^3/min)
1	4	0.41	4	0.0498
2	4	0.4	3	0.0498
3	4	0.4	4	0.0498
4	4	0.52	3	0.2244
5	4	0.37	4	0.0498
6	4	0.39	3	0.3126
7	4	0.50	4	0.3126
8	4	0.42	3	0.1566
9	4	0.42	3	0.4752
10	4	0.38	4	0.2700
11	4	0.50	4	0.1566
12	4	0.50	4	0.1566
13	4	0.48	4	0.2700
14	4	0.51	4	0.1134
15	4	0.51	3	0.2700

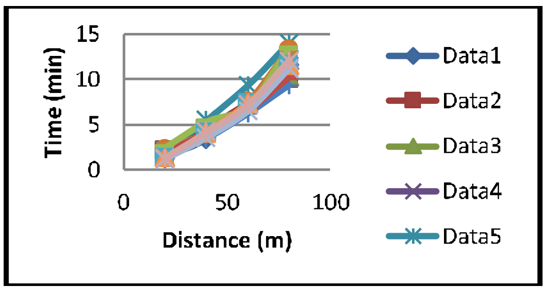

Fig. 2: Measured advance curves for field P

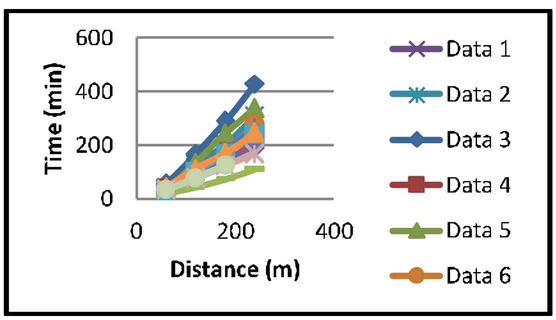

Fig. 3: Measured advance curves for field Q

From Table 2, three irrigation events such as advanced time and flow depth for both fields P and Q have been taken for simulation advance trajectories which have been described and analyzed in section 4.1.

2.3 PERFORMANCE MEASURES OF SURFACE IRRIGATION

The purpose of irrigation application is to apply the requisite amount of water efficiently and uniformly. However, various growers may furnish more or less importance on three relevant performance measures i.e. application and storage efficiencies as well as distribution uniformity, which are summarised in Table 3.

Table 3: Description of Efficiencies (%) and their Dependant Variables

Sr No	Efficiency Type	Equation	Depends upon variables	Expressed in %
1.	Application Efficiency (E_a)	$Ea = \frac{100\, W_s}{W_f}$ Michael (1999)	Volume of water stored in root zone (W_s) = W_f - (R_f + D_f) during irrigation to volume of water delivered in the field (W_f)	%age
2.	Storage Efficiency (E_s)	$Es = \frac{100\, W_r}{W_d}$ Michael (1999)	Water stored in root zone (W_r) during irrigation to water required in root zone (W_d)	%age
3.	Distribution Efficiency (E_d)	$Ed = \frac{100\, W_l}{W_a}$ Merriam and Killer (1999)	Average infiltration depth of water in lower quarter of field (W_l) to average infiltrated depth of water over the field (W_a)	%age

2.4 SIMULATION METHODOLOGY OF THE SIRMOD MODEL

In order to analyse the optimized control system, simulation trials were made for both fields by using the actual INFILT and the scaled infiltration parameters in the SIRMOD model. The simulated values were utilized to check the irrigation efficiencies in order to compute the performance of the farm irrigations through various strategies.

This model requires input data such aslength of field, slope, infiltration properties, target application depth, discharge, Manning's co-efficient of roughness*n* and geometrical parameters of furrowfor simulation component (see Figure 4). After simulation process advance-recession trajectory, infiltrated water distribution, volume balance, run-off hydrograph, water distribution uniformity, water application efficiency and other efficiencies have been computed and their results are shown in Figure 5.

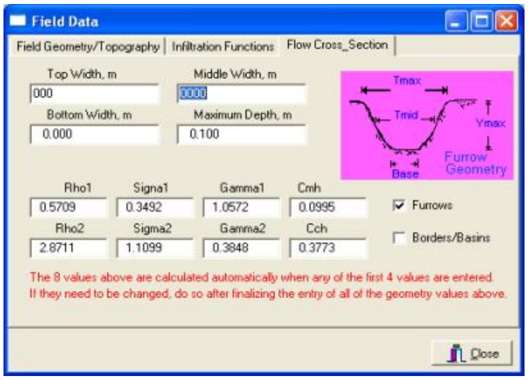

Fig. 4: SIRMOD screen showing the field geometry, infiltration functions and flow cross section

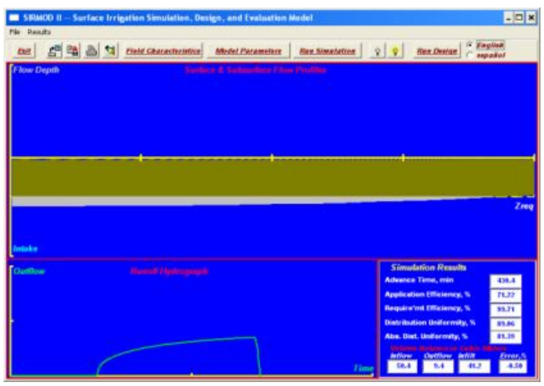

Fig. 5: Computed results shown on SIRMOD screen

3. SIMULATION MODEL STRATEGIES

For simulation purpose (05) strategies were developed to test irrigation system, which are explained as under:

Strategy 1: In thisstrategy, actual irrigation is simulated by taking the infiltration parameters (INFILT a, k, f_o),actual inflow rate (Q_o) and actual cut off time (t_{co}) under common practices.

Strategy 2: Under this strategy, each irrigation event was optimized by using INFILT parameters after changing the inflow rate and cut off time for maximum value of application efficiency.

Strategy 3: In this strategy, the cut off time is taken by90% of advance time and simulation is performed utilizing the INFILT parameters and actual flow rate.

Strategy 4: For this strategy, the cut off time is taken as 90% of advance time and inflow rate is taken same as that of strategy 3 and for simulation INFILT parameters are used.

Strategy 5: Under this strategy, INFILT infiltration parameters are utilizes by a fixed inflow rate while optimising only the cut-off time in order to attain the best irrigation.

4. RESULTS AND DISCUSSIONS

4.1 ADVANCE TRAJECTORIES AND COMMUTATIVE INFILTRATION

For both observed fields P and Q, INFILT-V model was used to simulate the advanced trajectories of both the selected fields P and Q. And data of simulated trajectories curves were compared with measured readings, some of them are represented graphically in Figures 6 and 7.

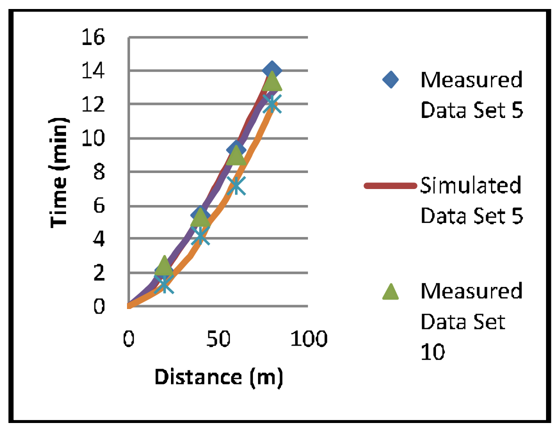

Fig. 6: Graphical representation of some measured and simulated advance trajectories for field P

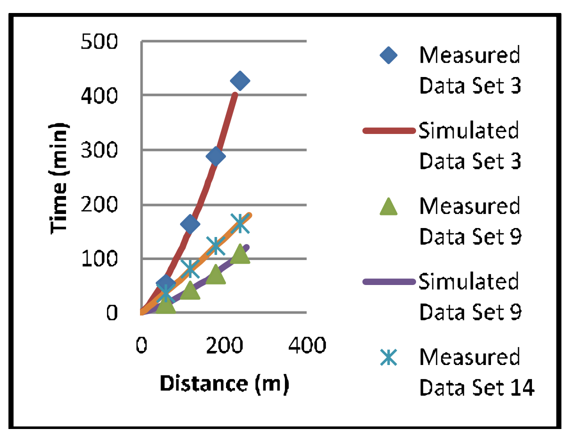

Fig. 7: Graphical representation of some measured and simulated advance trajectories for field Q

From above graphs, it is clear that there is similarity in between simulated advance trajectories and measured trajectories. But there is a small divergence between the advance trajectories and advance point selected for the infiltration in the end of the field for data set 10 of the selected field P.

4.2 IRRIGATION PERFORMANCE

The SIRMOD model was used to compute the application efficiency, storage efficiency as well as uniformity distribution for all strategies of fields P and Q. The average simulated irrigation performance for both fields is described in Table 4.

Table 4: Summary of irrigation performance under different modelling strategies

Management/ Model strategies	Field P (Average of 21 events)			Field Q (Average of 17 events)		
	E_a (%)	E_r (%)	DU (%)	E_a (%)	E_r (%)	DU (%)
Strategy 1 Actual irrigation	**43.2**	**93.6**	**82.6**	**39.1**	**97.9**	**80.2**
Strategy 2 Perfect management	**76.4**	**91.3**	**93.7**	**72.1**	**95.1**	**92.5**
Strategy 3 Simple recipe management (actual inflow)	**71.4**	**82.1**	**75.3**	**68.5**	**79.5**	**72.2**
Strategy 4 Simple recipe management (fixed inflow 6.5 lps)	**43.3**	**88.1**	**85.7**	**34.4**	**88.6**	**86.6**
Strategy 5 Real-time control (INFILT infiltration)	**73.4**	**84.3**	**89.3**	**70.2**	**81.3**	**88.5**

Strategy 1 (Actual irrigation - usual farm management)

From abovedescribed simulation results for fields P and Q, overall average (E_a) is 43.2% and 39.1%, (E_r) is 93.6% and 97.9% and DU is 82.6% and 80.2% respectively.

Strategy2 (Perfect Control and Management)

In this strategy irrigation events were optimized on the basis of INFILT parameters with varying inflow and cut off time to fit soil conditions and excellent performance was obtained for most of the events. The average overall performance (i.eE_a and E_r) for the fields P and Q are 76.4%, 91.3%, 72.1% and 95.1% respectively. In this strategy application of more advanced irrigation management practices is involved which is impracticable for the field. For this strategy, 6.5 lps as over all suitable dischargewas optimized that was considered in strategies 4 and 5 for further optimization in a simple way.not touch end of the furrow.

Strategy 3 and 4 (Simple Recipe Management actual and fixed)

For this, performance was improved by taking cut off time as 90% of the advance time but in most of the events the advance did not touch end of the furrowovercomethis difficulty, strategy 4 was applied by takingsame parameters as described in strategy 3 but rate of flowwas increased upto 6.5 lps. The simple recipe management indicated poorer results for both of fields P and Q, in both strategies 3 and 4. The advance was unable to reach the end of the field for many of the furrows and yet the fields were indicated to have low application efficiencies.

Strategy 5 (Optimized control)

From Table 4 it is clear that this strategy simulates an improved performance and clearedthat strategy 5 based on INFILT infiltration is closest to the observed results. Hence, this strategy is feasible having significant improvement which is also practicable for this strategy.

4.3WATER SAVING DUE TO OPTIMIZED CONTROL

Total volume of water applied to 27 furrows for both of fields P and Q under ordinary farm management has been observed. These 27 furrows cover an area of 0.916 hectares, which is comprised of 10 furrows having 100m length with spacing of 1m in case of field P and 17 furrows having 240 m length and spacing of 2 m for Q field. Under optimized control system, by using SIRMOD model, the quantity of water was computed which isdescribed in Table 5.

Table 5: Volume of water applied for the required time for various fields $Q_0 = 6.5$ lps

S.No.	Field P		Field Q	
	t_{co} (min)	Water diverted (m^3)	t_{co} (min)	Water diverted (m^3)
1	10	3.90	150	58.50
2	8	3.12	150	58.50
3	7	2.73	130	50.70
4	10	3.90	125	48.75
5	9	3.51	140	54.60
6	10	3.90	140	54.60
7	12	4.68	130	50.70
8	7	2.73	155	60.45
9	7	2.73	155	60.45
10	9	3.51	135	52.65
11	9	3.51	145	56.55
12	13	5.07	130	50.70
13	13	5.07	110	42.90
14	8	3.12	100	39.00
15	8	3.12	120	46.80
16	7	2.73	140	54.60
17	7	2.73	130	50.70
18	8	3.12	--	--
19	8	3.12	--	--
20	7	2.73	--	--
21	8	3.12	--	--
Total		72.15	--	--

However, by utilizing optimized control system, the summary of above values along with water saving is described in Table 6.

Table 6: Volume of water applied to both fields before and after optimization

Field	Actual Farm Management (AFM)(m^3)	Optimized Control(OC) (m^3)	Water savings due to OC (m^3)	%
Field P	104	72	32	30.77
Field Q	1491	891	600	40.24
Total	1595	963	632	39.6

However, by utilizing optimized control system, the summary of above values along with water saving is described in Table 6.

From Table 6, it can be seen that volume of water applied to various furrows of fields P and Q before optimization was 1595m^3; however, under optimized control system, it can be reduced to up to 963m^3, which prevails the potential savings of 632m^3 (0.632 million litres) of water during each irrigation over an area of 0.916 hectares.

Farmers while growing cotton crop, generally apply 10 to 11 irrigations which represents annual water saving of 1.73 to 1.90 ML/ha that may be constructively utilized to grow more crops and significant profits may be achieved in the field of irrigation

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5. CONCLUSIONS

From this study, following conclusions are made:

- The data regarding different parameters for different points was observed and compared with the simulated advance trajectories and found that the advance trajectories were passing through the advance point selected for the infiltration
- By using the INFILT V model, the cumulative infiltration was also computed successfully.
- The simple optimized control strategy has the potential to bring significant improvements to enhance the irrigation performance, and
- By using the simple optimized control system, volume of water applied during irrigation may be significantly reduced which can be utilized to cultivate more farm lands.

6. RECOMMENDATIONS

From this study, it is clear that the irrigation performance may be significantly improved by adopting simple optimized control system. That optimized system was evaluated for two farm fields of different characteristics.

In continuation of this study, prototyping of the system may be considered as next step and research may be extended largely to achieve significant benefits in the field of irrigation.

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