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Evaluation of basin irrigation events with WinSRFR model for resource conservation

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ABSTRACT

The study aimed to evaluate the irrigation events with WinSRFR to understand the different hydraulic parameters on irrigation performance. Three irrigation events in the basin irrigation system were analyzed with the event analysis world of the WinSRFR 5.1.1 model. WinSRFR is a one dimensional irrigation hydraulic analysis tool to analyze, the optimal physical and operational design of surface irrigation systems to enhance irrigation application efficiency. Kostiakov's infiltration parameters and Manning's surface roughness coefficient were estimated with WinSRFR as it is very difficult to observe in the field. The irrigation performance indicators such as irrigation application efficiency, distribution uniformity, and deep percolation losses were quantified with WinSRFR in each irrigation event. The results suggest that Kostiakov's infiltration parameters slope varied from 0.13 to 0.59 and the intercept varied from 20.84 to 66.84 mm hr^{-1}. The Manning's surface roughness coefficient varied from 0.045 to 0.071. The maximum deep percolation losses were observed in the third irrigation (at milking stage) followed by the second (at flowering stage) and first irrigation events (at booting stage) in wheat crop. The surface roughness infiltration parameters and inflow rate play a significant role in the performance of an irrigation event. It can be concluded that the surface irrigation model WinSRFR successfully evaluated the performance of the irrigation system which helps to identify the design or operational problem in the system. This information helps to optimize the design and operation condition of the irrigation system to achieve maximum irrigation application efficiency and conserve water resources.

1. INTRODUCTION

Water is a vital natural resource which is under pressure due to excessive use and population explosion. Agriculture is one of the largest consumers of fresh water. Surface irrigation is one of the widely adopted methods of irrigation in India due to its simplicity and easy operation (Bjorneberg, 2013). However, it is frequently associated with poor irrigation application efficiency and labor-intensive farming (Smith *et al.,* 2005; Dhawan, 2017). The growing population and diminishing water supplies emphasize the importance of boosting water productivity through improved irrigation efficiency. By enhancing Irrigation efficiency, significant amount of water could be saved (Rathore and Singh, 2009; Ranjan *et al*., 2015). The poor irrigation application efficiency is mainly reported due to deep percolation and excessive runoff in surface irrigation. Many researchers suggest that by increasing the inflow rate, irrigation efficiency could be enhanced significantly in the basin irrigation system (Katopodes *et al*., 1990). It is critical to analyze each irrigation event to understand the effects of various hydraulic parameters such as inflow rate, slope, time of cut-off and waterfront advance, surface roughness, and infiltration parameter on irrigation application efficiency and distribution uniformity (Clemmens, 1998, 2001; Playan *et al.,* 1996). The surface irrigation simulation model helps to understand the hydraulics of irrigation event which help to identify the constraint of the system. Many simulation models such as SIRMOD, SRFR, and WinSRFR model successfully simulated irrigation events under different scenarios and helped to develop better operational and design management to enhance the performance of the system (Khatri and Smith, 2005; Khanna and Malano, 2006; Shirsath *et al*., 2009). This study aims to analyze the surface irrigation events to evaluate the hydraulic performance of basin irrigation systems under wheat crops. This information helps to identify the problems and better operational management of the basin irrigation system.

2. MATERIALS AND METHODS

Study Area

A field experiment was conducted during the *rabi* growing season (Nov to April) in 2020-21 at the Research Farm of the ICAR-Indian Agricultural Research Institute, New Delhi, India (28°37'55" N latitudes, 77°09'36"E longitudes and 230 m above mean sea level). According to the Koppen classification, the research region has a semi-arid and sub-tropical climate with bitterly cold winters and scorching summers. The hottest month is June, with a mean daily maximum temperature of 45°C, while the coldest is January, with a mean daily minimum temperature of 7°C. About 703 mm of rainfall a year on average, of which 75 to 80% fall between July and Sept during the monsoon season. Pan evaporation ranges from 1.0 to 8.6 mm day^{-1}. The soil texture of the study area was loam and the basic infiltration rate was 6 mm hr^{-1}. The bulk density, field capacity, and permanent wilting point were 1.55 Mg m^{-3}, 35.5% (v/v), and 15.5 (v/v), respectively.

Experimental layout

The irrigation basin plot of size 60 × 15 m with 0.0005 m m^{-1} slope was laid out at research farm, ICAR-Indian Agricultural Research Institute, New Delhi. Wheat (variety HD 3271) was sown in the second fortnight of December 2019 and harvested in the first fortnight of April 2020. An ultrasonic flow meter (Model Unidata 6526E) was placed at the inlet to measure the flow rate. Three capacitance-based soil moisture sensors were installed in the field at a distance from the inlet 25%, 50%, and 75% of field length (L) at 37.5 cm, 15 cm, and 7.5 cm depth, respectively (Fig. 1).

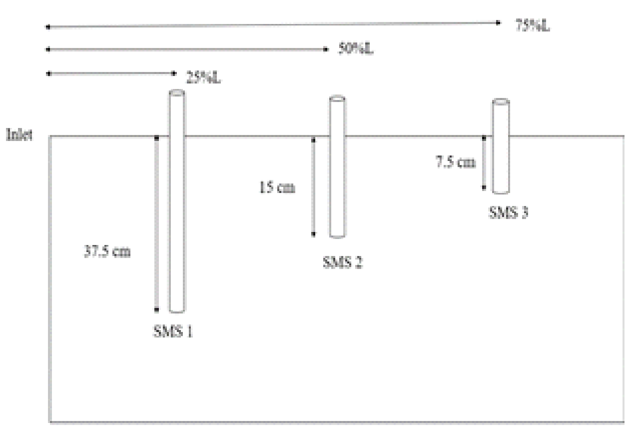

Fig. 1. Placement of soil moisture sensor in the field

Irrigation was scheduled when soil moisture reached or exceeded 50% soil moisture depletion. Three irrigation events were monitored during the growing period. Regardless of the threshold soil moisture content, the initial irrigation was applied at the crown root initiation stage after 21 days of sowing. After that, three irrigation events were scheduled and monitored on 20 Jan, 2020 (first irrigation, booting stage), 14 Feb, 2020 (second irrigation, flowering stage) and 10 Mar, 2020 (third irrigation, milking stage), depending on the threshold level of soil moisture depletion. As the soil moisture reached or exceeded 50% soil moisture depletion level, the next day irrigation was scheduled.

Field Observations

During the irrigation event, soil moisture status, inflow rate, waterfront advance, and time cut-off were observed in the field. The method / instrument used for measurement is presented in the following sub-sections.

Soil Moisture Sensors

Capacitance soil moisture sensors were installed in the field for soil moisture monitoring (Fig. 2). The capacitance-based soil moisture sensor is based on the dielectric constant of soil and water. Compared to the resistance-type sensor, it is corrosion-resistant because the electrodes do not come into direct contact with the soil. The three primary parts of a capacitance sensor are a positive plate, a negative plate, and a dielectric gap between the plates. The significant difference in dielectric constants between soil and water aids in identifying water molecules present in the soil mass.

Inflow Rate

Inflow measurement at the inlet was measured with an ultrasonic flow meter (Model Unidata 6526E) placed the downstream of inlet (Fig. 3). The flow meter was able to record data every second. Flow velocity, total flow, flow rate, and flow depth were recorded in the data logger. Water

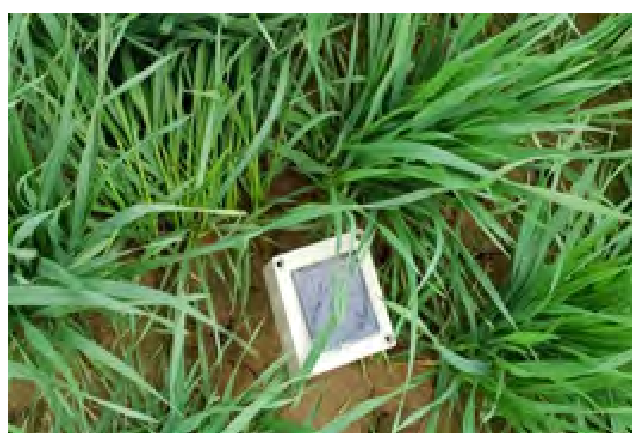

Fig. 2. Soil moisture sensor under wheat crop in basin layout during *rabi* cropping season 2019-20

Fig. 3. Ultrasonic Starflow meter for inflow measurement

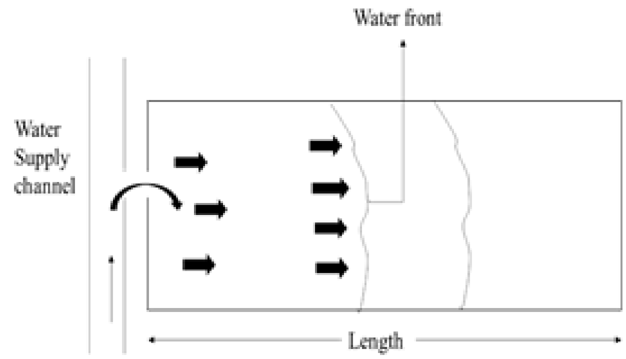

Fig. 4. Waterfront advance in the basin during irrigation

Fig. 5. Irrigation event in wheat crop under basin irrigation system

velocity is measured by the ultrasonic Doppler principle which relies on suspended particles or small air bubbles in the water to reflect the ultrasonic detector signal. The instrument will not operate in very clean, vented water.

Waterfront Advance

The waterfront advance phase starts as the water first enters the field plot and continues up to the time when it has advanced to the end of the plot (Fig's. 4 and 5). The time interval between the time of the advance, completion, and the time when the inflow is cut off is referred to as the ponding / storage phase. The rate of advance depends on the flow rate, the infiltration rate of the soil, surface roughness, and the slope of the field. Waterfront advance time is a very important parameter that is required for the hydraulic evaluation of an irrigation event. To measure waterfront advance time, pegs were inserted in the field at every 5 m distance along the slope. Time was noted with the help of a stopwatch as the waterfront reached the peg after water entered the field.

Time of Cut-off

The time of cut-off was observed with a stopwatch and it can also be determined with a flow hydrograph generated while measuring the inflow rate at the inlet.

Estimated Parameters

Infiltration parameters and surface resistance are important hydraulic parameters that are difficult to measure in the field. Thus, these hydraulic parameters were estimated using the simulation model WinSRFR.

WinSRFR Model

WinSRFR is a one-dimensional hydraulic analysis tool for surface irrigation systems. The software combines simulation, evaluation, operational analysis, and design functionalities. A new generation of surface irrigation software, WinSRFR, was developed in 2004 with the initial goal of converting the DOS-based SRFR, BORDER, and BASIN programs into a Windows application. The long-term goals were to create a tool for performing realistic studies on various surface irrigation system types and to create a new software basis for ongoing surface irrigation hydraulics research. WinSRFR 5.1.1 (Bautista and Schlegel, 2019) model is free software and can be downloaded from the USDA site and installed on the computer. The WinSRFR has four main worlds: event analysis, operational analysis, physical design and simulation. Under the event analysis module system geometry, inflow data, advance-recession data and soil / crop properties data were required as input parameters to analyze the irrigation event. The event analysis can be done based on any four methods; probe penetration analysis, merriam-keller post-irrigation volume balance, eliott-walker two-point method and EVALUE volume balance method. EVALUE module gives the best value of Kostiakov's infiltration parameter by reducing the error between the observed and simulated value of waterfront advance. In this model, the inverse methodology approach was used for estimating Manning's roughness coefficient to be used in the simulation of basin irrigation events. The input parameters required for any irrigation event analysis are field size, slope, inflow, and advance time (Fig. 6).

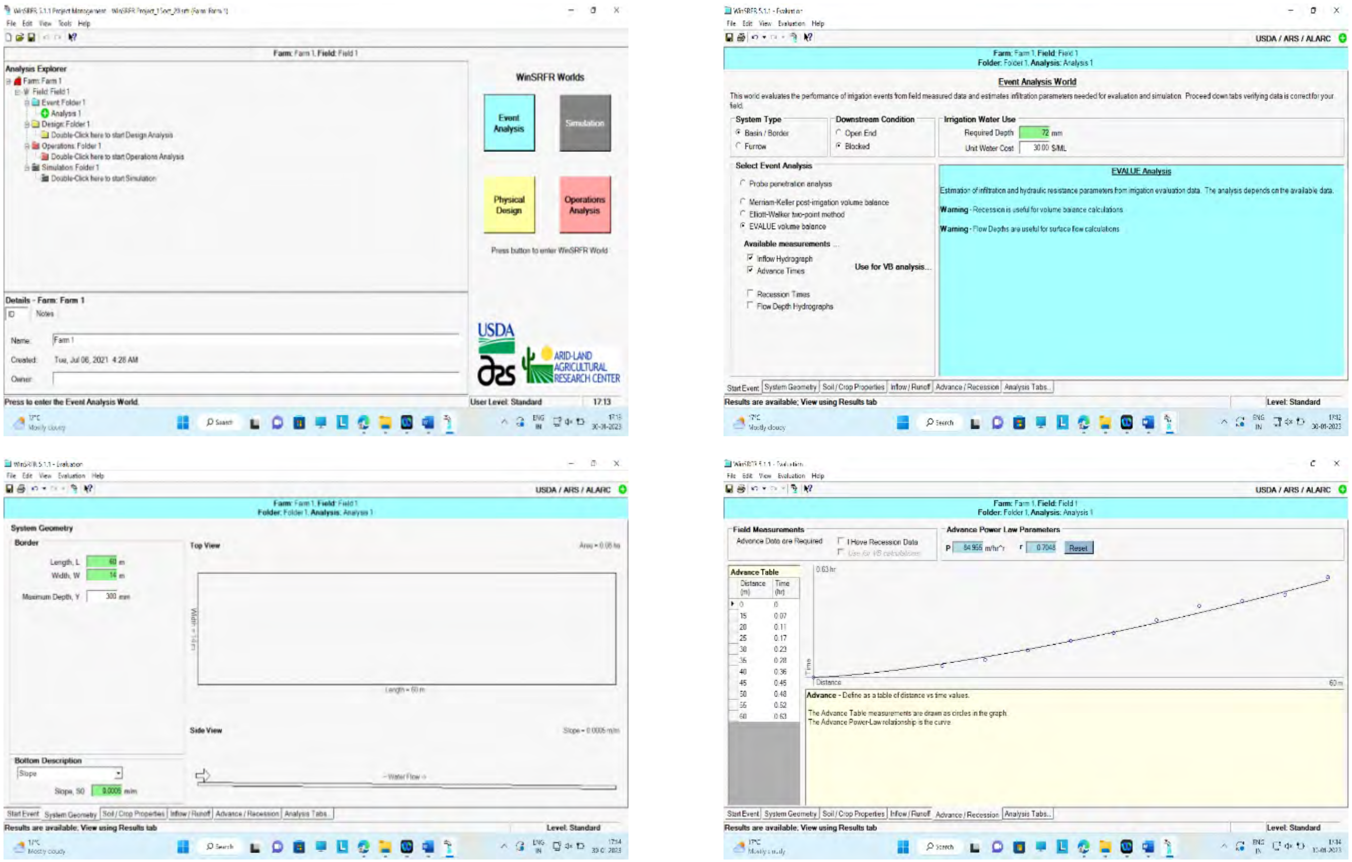

Fig. 6. Different input tab of WinSRFR 5.1.1 model

Kostiakov Infiltration Parameters

Kostiakov infiltration equation was chosen for irrigation event analysis using WinSRFR 5.1.1 due to its simplicity and wide applicability. The Kostiakov equation can be written as:

$$I = kt^{a} \qquad ...(1)$$

Where, I = cumulative infiltration capacity (L), t = time (T), k (L/T^{a}), a = constants, dimensionless exponent a is restricted to $0 < a < 1$. The parameters in the Kostiakov Equation were determined from the log (I) versus log (t) plot on a simple XY axis. The best-fit linear Equation was drawn through the plotted points. The slope value of the plot was 'a' and the ordinate axis intercept value represented log (k).

Irrigation Performance Indicators

The following indicators were calculated and compared to assess the irrigation performance for basin irrigation plots.

The ratio of the amount of water held in the root zone of the crops to the amount of water applied to the field is known as irrigation application efficiency (BoS, 1979). A flow meter with an ultrasonic sensor was mounted in the channel right after the field inlet to measure the total amount of water applied during each event. Irrigation application efficiency is given by eq. 2.

$$E_a = \frac{V_s}{V_a} \times 100 \qquad \text{(Burt } et\ al.\text{, 2000)} \qquad ...(2)$$

Where, V_s is the amount of water stored in the root zone and V_a is the volume of applied irrigation. V_s was calculated before each irrigation using the formula $V_s = \sum_{i=1}^{3} \theta_i \times \rho_i \times Z_i$

Where, θ_i is gravimetric water content before irrigation, ρ_i is the bulk density and Z_i is the depth of the soil layer in cm for i^{th} layer (Ranjan *et al.*, 2017).

How evenly water is applied to the target area is gauged by a distribution uniformity (DU) metric. The low quarter DU (DU_{lq}) is calculated by dividing the average of the lowest quarter of samples by the average of all samples. The greater the DU_{lq}, the better the coverage of the measured region. To assess the uniformity of the distribution, soil samples were taken from a grid of 10 m by 4.5 m after each irrigation session. Using eq. 3, DU_{lq} was determined.

$$DU_{lq} = \frac{Average\ of\ the\ lowest\ 1/4}{Average\ of\ all} \times 100$$

(Merrian and Keller, 1978) ...(3)

3. RESULTS AND DISCUSSION

Simulation of Irrigation Events

Using the event analysis world tool in WinSRFR 5.1.1, three irrigation events in wheat crops were analyzed. The input parameters included field geometry, soil / crop properties, inflow rate and advance, time. The observed inflow rate and estimated infiltration parameters and Manning's surface resistance are presented in Table 1. The waterfront advance of three irrigation events is shown in Fig. 7. When the irrigation was turned on, the water inflow entered the field, and the waterfront gradually progressed along the slope. The time to reach the waterfront advance at the end of the field was 0.65 hrs (39 min), 0.47 hrs (28.2 min) and 0.37 hrs (22.2 min) during the first, second, and third irrigations, respectively. The maximum time was observed in the first irrigation event followed by the second and third irrigation events. Time of cutoff was observed at 1.50, 0.65, and 0.60 hrs in the first, second, and third irrigation events. In three irrigation events, the inflow rate ranged from 22 lit sec^{-1} to 37.1 lit sec^{-1}. The highest inflow rate 37.1 lit sec^{-1} was observed in the third irrigation event. In the first, second, and third irrigations, the best-fit Manning's surface roughness coefficients were 0.045, 0.60, and 0.71, respectively. The Manning's surface roughness was determined using the Inverse method. The estimated and observed waterfront advance time were compared with different *'n'* values. The value at which the root means square error between observed and estimated waterfront advance found minimum, that value of *'n'* was selected for the irrigation event. The value of *'n'* increased as the crop growth stages progressed. Initially, the surface resistance is created by the soil surface but afterward, it increases due to resistance created by the plant stems. The values of '*n'* were within the range reported by previous researchers (Harun-Ur-Rashid, 1990; Bautista *et al*., 2009; Salahou *et al.,* 2018; Mazarei *et al*., 2021).

Infiltration parameters are highly variable, temporally and spatially, and are one of the crucial characteristics of irrigation system design (Khanna and Malano, 2006). Estimated Kostiakov's infiltration slopes ('a') for the first, second, and third irrigations were 0.59, 0.13, and 0.50, while the corresponding intercepts ('k') were 20.84, 66.84, and 42.84. The infiltration slope indicates how rapidly water infiltrates into the soil and the intercept represents the infiltration depth at the initial time of infiltration. The value of '*a*' was less than one in both the crop and bare soil conditions, falling within the theoretical range ($0 < a < 1$). The value of *'a'* less than one indicates that the infiltration rate decreases over time.

Performance of Basin Irrigation System

Table 2 and Fig. 8 show the irrigation performance metrics, including irrigation application efficiency, distribution uniformity, and deep percolation losses. The first irrigation had the highest irrigation application efficiency (76%), followed by the second (69%) and third irrigations (68%). Consequently, deep percolation losses were maximum in the third irrigation event, followed by the second and first irrigation events. Maximum deep percolation losses of 32% were found in the third irrigation event. This may happen due to more crop growth and the hardness

Table: 1
Estimated and observed irrigation hydraulic parameters of the irrigation events at various growth stages of wheat

Date	Growth stage	Inflow rate (lit sec^{-1})	Time of cut-off (hrs)	Estimated infiltration parameters		Manning's surface roughness coefficient, n
				Slope 'a'	Intercept 'k' mm hr^{-a}	
Jan 20, 2020	Booting	22	1.50	0.59	20.84	0.045
Feb 14, 2020	Flowering	36.2	0.65	0.13	66.84	0.06
Mar 10, 2020	Milking	37.1	0.60	0.50	42.84	0.071

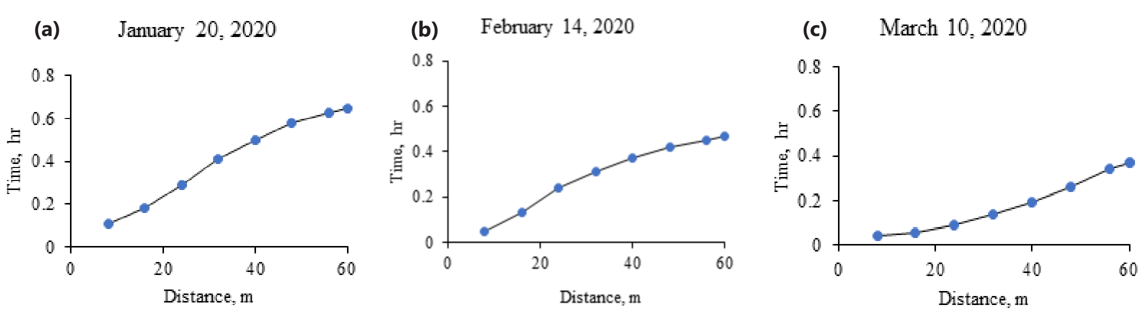

Fig. 7. Waterfront advance in three irrigation events at different growth stages of wheat on (a) Jan 20, 2020 (b) Feb 14, 2020 and (c) Mar 10, 2020

Table: 2
Estimated irrigation performance indicators of three irrigation events in wheat crop using event analysis world of WinSRFR 5.1.1

Date	Growth stage	Applied depth (mm)	Deep percolation (mm)	Distribution uniformity Du_{lq}	Irrigation application efficiency E_a (%)
Jan 20, 2020	Booting	132	33	0.92	76
Feb 14, 2020	Flowering	94	29	0.89	69
Mar 10, 2020	Milking	95	31	0.90	68

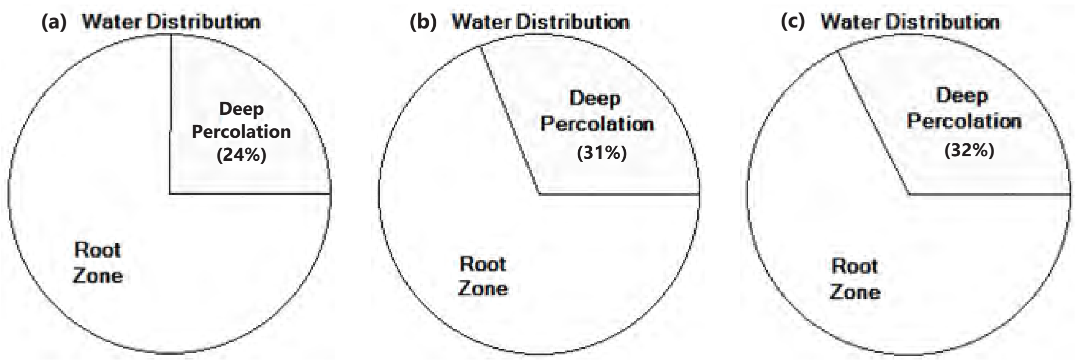

Fig. 8. Percentage of irrigation water deep percolated during three irrigation events at different growth stages of wheat on (a) Jan 20, 2020 (b) Feb 14, 2020 and (c) Mar 10, 2020

of the plant stem creates more resistance to flow which leads to increased ponding depth and more infiltration time. Our finding is also corroborated by other researchers (Sacks *et al*., 2009; Abelti, 2022; Radmanesh *et al*., 2023). These performance indicators show that as crop growth increases, surface resistance increases, allowing more water to enter the subsoil and potentially contributing to deep percolation losses. Selection of a suitable time of cutoff according to flow rate is very important. The manning roughness increased with crop growth showing that at the later stage of crop growth flow resistance was greatly caused by stem and leave rather than soil surface. Thus, deep percolation losses are the function of flow rate, time of cutoff, surface resistance, and infiltration parameters. To achieve a high irrigation application efficiency optimization of manage-able parameters (flow rate, time of cut-off) under different scenarios is needed.

4. CONCLUSIONS

The event analysis world of WinSRFR 5.1.1 success-fully evaluated three irrigation events under the basin irrigation system. The results suggest that surface irrigation performance is influenced by several factors, which must be considered in the design: soil infiltration rates, hydraulic roughness, inflow discharge and duration, field length and slope, land shape, and surface micro-topography. It can be concluded that a higher inflow rate with low surface resistance helps to improve irrigation application efficiency and reduces the deep percolation losses in the basin irrigation system. The results showed that the interaction of observed and estimated hydraulic parameters helps to understand the behavior of the system and leads a step ahead toward an efficient irrigation system by quantifying losses. The event analysis module of WinSRFR 5.1.1 enables the user to evaluate the surface irrigation system with easily monitorable input parameters in the field. The irrigation application efficiency of the basin irrigation could be increased by reducing the surface roughness and increasing the water flow rate. The time of cutoff according to the flow rate is very important to achieve high irrigation application efficiency. The manageable parameters are field size, slope, flow rate, and time of cut-off. Practically field size and flow rate could not control much in the field condition. Thus, managing cut-off time according to flow rate and field size helps the irrigator reach the desired irrigation application efficiency. WinSRFR is a powerful tool with simulation, operation, and design world which could help to suggest the best operational and design parameters for surface irrigation after evaluating the existing irrigation system performance. A significant water resource could be conserved with proper design and operational management under different scenarios.

REFERENCES

Abelti, C. 2022. Performance evaluation of furrow irrigation using WinSRFR model: The case of Batu Degaga small scale. *Irri. Sch. Irri. Drain. Sys. Engg*., 11:12. doi: 10.37421/2168-9768.2022.11.361.

Bautista, E. and Schlegel, J.L. 2019. WinSRFR 5.1. Software and user manual. Washington, DC: USDA.

Bautista, E., Clemmens, A.J., Strelkoff, T.S. and Schlegel, J. 2009. Modern analysis of surface irrigation systems with WinSRFR. *Agric. Water Manag.,* 96(7):1146-1154. doi:10.1016/j.agwat.2009.03.007.

Bjorneberg, D.L. 2013. Irrigation methods, reference module in earth systems and environmental sciences, Elsevier Inc. doi.org/10.1016/B978-0-12-409548-9.05195-2.

BoS, M.G. 1979. Standards for irrigation efficiencies of ICID. *J. Irrig. Drain. Div. ASCE,* 105 (IR1): 37-43.

Burt, C.M., Clemmens, A.J., Solomon, K.H., Bliesner, R.D., Hardy, L.A and Howell, T.A. 1997. Irrigation performance measures: efficiency and uniformity. *J. Irrig. Drain. Eng.,* 123: 423-442. doi 10.1061/(ASCE)0733-9437(1997)123:6(423)11.

Clemmens, A.J. 1998. Level basin design based on cut-off criteria. *Irrig. Drain. Syst*., 12:85-113. doi.org/10.1023/A:1005986006030.

Clemmens, A.J., Eisenhauer, D. and Maheshwari, B. 2001. Infiltration and roughness equations for surface irrigation: how form influences estimation. *Am. Soc. Agric. Bio. Engg.*, 012255 10.13031/2013.4126.

Dhawan, V. 2017. Water and agriculture in India, background paper for the south asia expert panel during the global forum for food and agriculture (GFFA).

Harun-ur-Rashid, M. 1990. Estimation of Manning's roughness coefficient for basin and border irrigation. *Agric. Water Manag.,* 18(1): 29-33. doi.org/10.1016/0378-3774(90)90033-U.

Katopodes, N.D., Tang, J. and Clemmens, A.J. 1990. Estimation of surface irrigation parameters. *J. Irrig. Drain. Eng.,* 116(5): 676-696. doi:10.1061/(asce)0733-9437(1990)116:5(676).

Khanna, M. and Malano, H.M. 2006. Modelling of basin irrigation systems: A review. *Agric. Water Manag.,* 83: 87-99. doi.org/10.1016/ j.agwat.2005.10.003

Khatri, K.L. and Smith, R.J. 2005. Evaluation of methods for determining infiltration parameters from irrigation advance data. *Irrig. Drain*., 54(4): 467-482. doi:10.1002/ird.198.

Mazarei, R., Mohammadi, A.S., Ebrahimian, H. and Naseri, A.A. 2021. Temporal variability of infiltration and roughness coefficients and furrow irrigation performance under different inflow rates. *Agric. Water Manag.,* 245, 106465. https://doi.org/10.1016/j.agwat.2020.106465.

Merrian, J.L. and Keller, J. 1978. Farm irrigation system evaluation, 3rd Ed., Logan, Utah: Agricultural and Irrigation Engineering Department, Utah State University.

Playan, E., Faci, J.M. and Serreta, A. 1996. Characterizing micro-topographical effects on level-basin irrigation performance. *Agric. Water Manag.,* 29(2):129–145. doi:10.1016/0378-3774(95)01197-8

Radmanesh, M., Ahmadi, S.H. and Sepaskhah, A.R. 2023. Measurement and simulation of irrigation performance in continuous and surge furrow irrigation using WinSRFR and SIRMOD models. *Sci. Rep.,* 13: 5768. doi.org/10.1038/s41598-023-32842-8.

Ranjan, R., Chopra, U.K., Sahoo, R.N., Pramanik, Monalisha, Singh, A.K., Pradhan, S. and Alam, N.M. 2015. Resource conservation in wheat (*Triticum aestivum* L.) under different water and nitrogen stress levels. *Indian J. Soil Cons.,* 43(2):159-165.

Ranjan, R., Sahoo, R.N., Chopra, U.K., Pramanik, Monalisha, Singh, A.K. and Pradhan, S. 2017. Assessment of water status in wheat (*Triticum aestivum* L.) using ground based hyperspectral reflectance. *Proc. Natl. Acad. Sci., India, Sect. B. Biol. Sci*., 87:377-388. doi.org/10.1007/s40011-015-0618-6.

Rathore, A.C. and Singh, J.N. 2009. Optimization of nitrogen application and irrigation for improved growth and spike production of tuberose (*Polianthes tuberosa* L.). *Indian J. Soil Cons*., 37(1): 45-49.

Sacks, W.J., Cook, B.I. and Buenning, N. 2009. Effects of global irrigation on the near-surface climate. *Clim. Dyna.*, 33:159-175. doi.org/10.1007/ s00382-008-0445-z.

Salahou, M.K., Jiao, Xiyun, Haishen, Lü. 2018. Border irrigation performance with distance-based cut-off. *Agric. Water Manag.,* 201: 27-37. doi.org/10.1016/j.agwat.2018.01.014.

Shirsath, P.B., Sharma, R.K., Nathan, K.K., Singh, S. and Singh, D.K. 2009. Hydraulic evaluation of the border-check method of irrigation. *J. Soil Water Conserv*., 8(2): 25-29.

Smith, R.J., Raine, S.R. and Minkovich, J. 2005. Irrigation application efficiency and deep drainage potential under surface irrigated cotton. *Agric. Water Manag.,* 71(2): 117-130. doi.org/10.1016/j.agwat.2004.07.008.