International Journal of Agriculture, Environment & Biotechnology
Citation: IJAEB: 7(4): 869-874 December 2014
DOI Number: 10.5958/2230-732X.2014.01398.9

AGRICULTURE ENGINEERING

Non-linear optimization model for border irrigation system for wheat crop (Triticum aestivum)

Shweta Vishwakarma, Sunil Garg*, Chetan Singla, Rakesh Sharda and Mahesh Chand Singh

Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana, Punjab, India.

*Corresponding author: sunil1765@rediffmail.com

Paper No. 279 Received: 19 September, 2014 Accepted: 18 October, 2014 Published: 18 December, 2014

Abstract

Nonlinear optimization design models were developed for field conditions to design and manage border irrigation system using Lewis-Kostiakov infiltration equation. The design criterion used in the models was the depth of irrigation and basic infiltration rate of the soil. The objective function of the nonlinear model was constructed on the basis of a relationship between net returns and water application efficiency. The design variables of the models were the inflow rate, length of run, cutoff time, number of borders per set and number of sets. The nonlinear model gives a better representation of the design parameters and is more flexible because it permits easy changes in the objective function.

Highlights

- The non linear model developed can be used to compare different types of border irrigation management strategies.
- Optimization technique can be used as a tool for the design and management of border irrigation system.
- The optimal design of border irrigation can be used to increase farm income by optimizing design variables.
- The model gives the optimal values of design variables.

Keywords: Border, non linear, optimization, net returns

The optimal design of border irrigation method can be an important way to increase farm profits and to use the water most efficiently. A better understanding of decision variables and constraints of irrigation systems in relation to the design and management of border irrigation method can contribute to the development of improved systems. Effective designs of border systems have frequently been based on arbitrary constraints and performance criteria. As a result, there may be many possible solutions to the objective of specifying a maximum profit or a minimum cost. The farmer, as the owner of the farm, is interested in the highest net benefits from crop production. In the design of an irrigation system, there are many combinations of values for the variables that would fulfill the requirements of the system. There will be a combination that will involve minimum expenditure and at the same time meet all the system constraints. Reddy and Clyma (1981b) used combined approach of simulation and mathematical programming to develop an optimal design of border irrigation systems. Holzapfel *et al.* (1985) analyzed several parameters that measure the irrigation performance for their relation to surface irrigation design variables and yield. Holzapfel *et al.*(1986) presented furrow and border irrigation design optimization models for corn. The models, which have nonlinear objective functions and constraints, were linear zed to take advantage of existing linear programming code that perform sensitivity analysis and can be run in microcomputers. Moreover, field topography (i.e., the field slope and its spatial variability, and precision in land grading) also affects the performance of border irrigation systems due to its influence on the advance and recession processes (Bai et al 2010). Juanjuan *et al.* (2010) studied that the measured values are in accordance with optimized objective values. It showed that the optimization model and its solution can satisfy the demand of water saving and guarantee for irrigation effect simultaneously. Chen et al (2012) evaluated the performance of border irrigation systems by using agricultural irrigation survey data, field experimental data and a simulation model. The design variables i.e., inflow rate, border dimensions, and relative cutoff distance, in the irrigation districts were found to be diverse. However, after optimizing border dimensions through simulation and field testing, it was found that the applied depth per irrigation event could be decreased by an average of 49 mm, and the application efficiency could be increased on average by 26.7 % in the three irrigation districts along the lower Yellow river in China. Valipour (2013) studied the use of different types of inflow regimes in border irrigation for increasing irrigation efficiency which has always been one of the main concerns of experts and farmers. By using SIRMOD software the results showed that cutback and surge irrigation methods were able to increase irrigation efficiency to the amount of 11.66% and 28.37%, respectively. Neil et al (2014) verified reliability of infiltration parameters and Manning roughness estimated with SIPAR_ID software and presented an optimized method for design of closed-end furrow system. The results showed that adequate and efficient irrigations can be obtained using closed-end furrows through a proper selection of inflow discharge and cutoff time.

The literature reviewed above reveals that there is not much work reported on border irrigation design optimization models for maximization of net profit from farm. Moreover, optimization models so far developed, assume infiltration characteristics do not change during the season. Besides, the models did not consider deep percolation losses. However, infiltration rates generally change during the season and these changes should be reflected in the border irrigation design. Therefore, the study was planned to develop an optimization model for design of border irrigation system incorporating infiltration characteristics of soil, and to apply the model for efficient design of border irrigation system for wheat crop.

Materials and Methods

Optimization models developed for design and management of border irrigation are very few. However, these models have not considered basic infiltration rate and deep percolation losses while arriving at solution. Nonlinear optimization model was developed by taking into consideration the relationship between irrigation performance parameters (water application efficiency, water storage efficiency, and water distribution efficiency) and design variables (border length, inflow rate, cutoff time and depth). The relationship between irrigation performance parameter and yield was developed. Infiltration characteristics of soil advance and recession data, water and labour cost was used for formulating the constraints. The developed relationship along with constraints was used in developing the nonlinear optimization model.

Basic Infiltration Rate

Basic infiltration rate affects design, operation and management of surface irrigation systems. It directly influences the border length, required inflow rate and cutoff time to provide a uniform and efficient irrigation without excessive deep percolation. It is one of the most important factors in designing surface irrigation systems.

Depth of Irrigation Water

Depth of irrigation water can be determined on the basis of the maximum depth of water required in one irrigation during the irrigation season, and on the peak evapotranspiration of the crop. In general, however, the depth of irrigation water can be adjusted to any particular criterion selected by the designer.

Table 1. Input Data for optimization model of border irrigation

Model	Units	Input data
A		-0.299
B		0.898
C		-0.57
E		0.66
Q_T	l/s	15
Qmax	l/s	10
Qmin	l/s	7.5
L_{max}	M	100
L_{min}	M	63
A_{min}	m^2	1575
EFF_{max}	%	71.97
EFF_{min}	%	53.4
T_{max}	Min	480
K		621.84
K_E		356.00
K_F		-8.75
K_G		0.071

Design Variables

Irrigation designer can manipulate design variables (length of border, flow rate, cutoff time, slope and depth) to find the best irrigation performance for a given field.

Irrigation Performance Parameter

The performance of an irrigation method can be evaluated by determining how well the irrigation meets the water requirements, and how well the applied water is distributed throughout the field. Water applied for irrigation should meet the plant water requirements at the time of irrigation. It should not exceed the available water storage capacity of the soil profile. All of these factors should be analyzed to estimate the performance of irrigation.

Model Inputs

Prices of wheat, water and labour considered were ₹ 1000/ quintal, ₹ 0.14/m^3 and ₹ 10.0/hour, respectively.

The input data for the nonlinear model is shown in Table 1.

Optimization Model

Lingo 10.0 software tool will be used to run non linear optimization model. It is a software tool designed to efficiently build and solve linear, nonlinear and integer optimization models. This software uses basic algorithms, the simplex method, the quasi-Newton method and the reduced gradient method to solve linear, nonlinear and integer optimization problems.

Results and Discussion

Relationship between design variables and irrigation performance parameter

In the present study, water application efficiency (E_a), water distribution efficiency (E_d) and water storage efficiency (E_s) were the parameters that were analyzed for their relation to design variables. Their selection was based on the fact that they take into account the depth of water required by the crop in the irrigation as based on previous studies (Seginer, 1978). Multiple regression analysis was used to determine mathematical relationships between irrigation performance parameters E_a, E_s and E_d with the design variables. The NLREG, non-linear regression model was used to obtain the equation (via multiple regressions) for the irrigation performance parameters as a function of the design variables. Based on the results analyzed, water application efficiency was the irrigation performance parameter that best correlated with the design variables. The relationship between water application efficiency and the design variables is

$$E_a = K\,(Q)^{-0.29}\,(L)^{0.898}(T)^{-0.57}\,(D)^{-0.66} \quad (1)$$

Where

E_a = Irrigation performance parameter

K = Constant for the equation

a, b, c and e = Exponential coefficients of inflow rate, length, cutoff time and depth.

Table 2. Border irrigation optimization model

Model	Q (l/s)	L (m)	T (min)	W (m)	NR (₹/ha)
Nonlinear model	5.53*	63	83.92	5	43237.65
	7.73**	63	69.25	5	43374.63
	10***	63	60	5	43443.54

$* \, T_{7.5a} = 0.994\,x^{1.05}$ $\quad ** \, T_{8.5a} = -0.772\,x^{1.06}$

$*** \, T_{10a} = 0.663\,x^{1.06}$

Relationship between relative yield and irrigation performance parameter

Based on the relationship between the design variables and irrigation performance parameters, water application efficiency (E_a) showed best correlation as compared to water distribution efficiency (E_d) and water storage efficiency (E_s). So water application efficiency was chosen as irrigation performance parameter for developing relation with relative yield. The relationship between water application efficiency and relative yield is

$$Y_R = 356 - 8.75\,(E_a) + 0.071\,E_a^{\,2} \quad (2)$$

Where

Y_R = Relative yield, percent, and

E_a = Water application efficiency, percent.

Relationship between Water Requirement Efficiency and Net Returns

The objective function was to maximize net returns from the farm. Net returns are defined as total revenue minus total cost, and it may be computed as:

$$NR = YPc - (WC + LC) - OC \quad (3)$$

Where,

NR = Net returns, ₹/ha,

Y = Yield, q/ha,

Pc = Price of crop, ₹/q,

WC =Water cost, ₹/ha,

LC = Labor cost, ₹/ha, and

OC = Other costs.

This study assumed that other costs (cost of fertilizer, pesticide, harvesting, etc.) were constant. So, the analysis considered the change in net returns as a function of total revenue minus water cost and labour cost only.

The function between net return and water application efficiency is:

$$NR = 276314.02 - 8006.30\,E_a + 67.91E_a^{\,2} \quad (4)$$

Relationship between Advance Time and Distance

The time required for the water to advance from the head to the end of the field is an important consideration in managing border irrigation system. This time is often a close approximation of the cut-off time. Relationships of the following forms were obtained between advance time and distance for discharge 7.5 l/s, 8.5 l/s and 10 l/s by two-point method (Elliot *et al.*, 1982) as:

$$T_{7.5a} = 0.994\,x^{1.05} \quad (5)$$

$$T_{8.5a} = 0.772\,x^{1.06} \quad (6)$$

$$T_{10a} = 0.663\,x^{1.06} \quad (7)$$

Objective Function

The objective function for model is

Maximize

$$P_c\{(K_A\, Q^{2a}L^{2b}T^{2c}D^{2e} + K_B Q^a L^b T^c D^e) + K_c\} - 10^4 \alpha_1 \alpha_2 P_w Q_u L^{-1} T_i N_i B_s^{-1} - 10^4 \alpha P_L L^{-1} T_i N_i B_s^{-1} \quad (8)$$

Constraints

Based on the characteristics and resources of the farm, the design variables can be restricted to be within the appropriate limits. To achieve the above objective, the following constraints were considered:

$$C_1 = Q \leq Q_{max} \quad (9)$$

$$C_2 = L \leq L_{max} \quad (10)$$

$$C_3 = L \geq L_{min} \quad (11)$$

$$C_4 = QN_b \leq Q_T \quad (12)$$

$$C_5 = TN_s \leq T_{max} \quad (13)$$

$$C_6 = KQ^a L^b T^c D^e \leq IPP_{max} \quad (14)$$

$$C_7 = KQ^a L^b T^c D^e \geq IPP_{max} \quad (15)$$

$$C_8 = LN_b N_s W \geq A_{min} \quad (16)$$

$$C_9 = N_b \geq 1 \quad (17)$$

$$C_{10} = k(T_i - T_x)^e + f\,(T_i - T_x)^1 \geq Z_d \quad (18)$$

$$C_{11} = (K_1 QT - K_2 L Z_d W)(K_1 QT)^{-1} \leq DPL \quad (19)$$

Where

Q = inflow rate per border, l/s

Q_{max} = stream size litre per minute per meter width of border

L = length of run, m

L_{max}, L_{min} = maximum and minimum length of run, m

N_b = number of border per set

Q_T = total available flow rate, l/s

T = cutoff time per border, minutes

N_s = number of irrigation sets per day

T_{max} = the maximum time per day to irrigate the minimum area, minutes K, a, b, c and e are regression coefficients

IPP_{max} = irrigation performance parameter, %

IPP_{min} = the minimum irrigation performance parameter allowable for the irrigation, %

A_{min} = the minimum area to be irrigated per day, m^2

Z_{req} = water requirement depth prior to each irrigation, mm

$T_i - T_x$ = intake opportunity time, min k and e are constants

f = basic infiltration rate, mm/min

Z_d = depth of irrigation applied, mm

W = border width, m

DPL = Deep percolation losses, % K_1 and K_2 are unit conversion factors

The optimization model of border irrigation was run on computer, using LINGO 10 package. These packages use as basic algorithms, the simplex method, the quassi- Newton method and the reduced gradient method to solve linear, nonlinear and integer optimization problems, guaranteeing a global optimal solution. The optimization model for border irrigation considered all the parameters involved in the design procedure, thus providing a close representation of reality as reported by other workers (Neil *et al.* 2014 and Holzapfel *et al.* 1986). By setting the right hand side of model's restriction to desired values, different irrigation management schemes can be tested. Also, by specifying the values of the design variables and right hand sides of the restrictions, actual field conditions can be simulated. Table 2 shows the result of model for border irrigation.

Conclusion

It is concluded that the nonlinear model gives better representation of the design parameters and is more flexible as it permitted easy changes in the objective function. The model could be used to compare different types of border irrigation management strategies.

References

Bai, M. J., Xu, D., Li, Y. N. and L.S. Pereira 2010. Stochastic modeling of basins microtopography: analysis of spatial variability and model testing. *Irrigation Science* **28**(2): 157–172

Bo Chen Bo, Ouyang Zhu, Zhigang Sun, Lanfang Wu and Li Fadong 2012. Evaluation on the potential of improving border irrigation Performance through border dimensions optimization: A case Study on the irrigation districts along the lower Yellow River. *Irrigation Science* **30**: 1-14

Holzapfel, E. A., Marino, M. A. and J. Chavez-Morales 1985. Performance of irrigation parameters and their relationship to surface-irrigation design variables and yield. *Agric Water Management* **10**: 159-174.

Holzapfel, E. A., Marino, M. A. and J. Chavez-Morales 1986. Surface irrigation optimization models. *Journal of Irrigation and Drainage Engineering* **112**(1): 1-19.

Elliot, R. L., Walker, W.R. and G.V. Skogerboe 1982. Infiltration parameters from furrow irrigation advance data. ASAE Paper No. 82-2103, ASAE, St. Joseph, MI.

Juanjuan ,M., Xihuan, S., Xianghong, G. and L. Yanfeng 2010. Multi objective fuzzy optimization model for border irrigation technical parameters. *Journal of Drainage and irrigation Machinery Engine* **28**(2):160-163

Niel, W. B., Fi,e L. J. and X.Y. Ma 2014. Applied closed-end furrow irrigation optimized design based on field and simulated advance data. *Journal of Agricultural Science and Technology* **16***:* 395-408

Reddy, J. M. and W. Clyma 1981(b). Optimal design of border irrigation systems. *Proceedings of the American Society of Civil Engineering* **107**(IR3): 289-306.

Seigne,r I. 1978. A note on economic significance of uniform water distribution. *Irrigation Science* **1**(1): 19-25.

Valipour, M. 2013. Increasing irrigation efficiency by management strategies: Cutback and Surge Irrigation. *ARPN Journal of Agricultural and Biological Science* **8**(1): 35-43.