ABSTRACT

Estimation of infiltration parameters is very difficult in furrow irrigation while they have very important effect in design and evaluation of surface irrigation systems. There are different methods for estimating infiltration parameters based on mathematical models such as SIPAR_ID model. SIPAR_ID model uses inverse solution to estimation of infiltration parameters and manning roughness. The objective of this study is to evaluate these models to estimate infiltration parameters in furrow irrigation. The study consisted of field experiments and numerical simulation. Field experiments were conducted in Zarand district of Iran in April 2012. Infiltration parameters and Manning roughness values were estimated with SIPAR_ID software. The estimated values were put into the WinSRFR software, and then the advance trajectory, flow depths in the upstream, and irrigation performance were simulated on each test furrow. The results showed that the simulated values with the WinSRFR software were in excellent agreement with the measured data. Therefore, the infiltration parameters and Manning roughness estimated with SIPAR_ID software were reliable. Also that adequate and efficient irrigation can be obtained using closed-end furrows through a proper selection of inflow discharge and cutoff time.

Key words: Infiltration parameter; Irrigation performance; SIPAR_ID model; Manning Roughness

INTRODUCTION

Furrow irrigation is widely used because of its low cost and energy requirement. The pressurized irrigation systems i.e. sprinkler and drip irrigation systems, are usually more efficient than the furrow irrigation. Therefore, the furrow irrigation system should be designed in such a way to ensure an adequate and uniform water application over the fields and to minimize the potential water losses (Rodriguez and Martos, 2010).

Many researchers in this field have engaged in optimizing the design of furrow irrigation systems to improve irrigation performance. However, furrow irrigation performance is affected by a range of factors including the inflow discharge, soil infiltration characteristic, field length, required application volume, cutoff time, surface roughness, and field slope (Pereira and Trout, 1999; Eldeiry et al., 2005). Dimensional sensitivity analysis technique has been employed to reduce the number of independent irrigation variables within a manageable range and empirical functions have been developed for a predictive performance and design of furrow irrigation systems (Zerihun et al., 1997a,b; Navabian et al., 2009), but this technique is rather complex and tedious. Eldeiry et al. (2005) demonstrated that the furrow length and application discharge were the main factors affecting application efficiency in design of furrow irrigation in clay soil. Gillies et al. (2008) conducted a furrow irrigation experiment in cotton field, which evaluated and optimized the irrigation performance, and the results showed that the use of IrriProb software (Gillies, 2008) could optimize the field management to the maximum irrigation performance. However, the results of these studies were only adapted to the free drainage furrow irrigation. Sanchez et al. (2009) developed management tools and guidelines for efficient irrigation of vegetables using closed-end level furrows. Results of the study indicated that adequate and efficient irrigations could be achieved through a proper selection of unit inlet flow rate and cutoff time. Ma et al. (2010)
proposed a multi-objective optimized model for design of closed-end border irrigation system, in which a fuzzy relationship was analyzed and a fuzzy solution was presented. However, storage efficiency was not considered in their analysis.

The objectives of this study were to verify reliability of infiltration parameters and manning roughness estimated with SIPAR_ID software of closed-end furrow irrigation system based on field data from Zarand district with clay loam soils.

MATERIALS AND METHODS

Field Experiments
The furrow irrigation experiments for Pistachio trees were conducted in Hamidieh village in Zarand district in April 2012. Table 1 presents the details of the furrow irrigation events. The furrow lengths used in the experiment was 80 m. Typical furrows spacing were 1.2 m (soil texture was clay loam). A trapezoidal section was adopted for each test furrow with the maximum depth of 150 mm, bottom width of 200 mm and a 1:1 side slope. The required application water depth was 80 mm. The data of the inflow discharge, cutoff time, depth hydrograph, and advance trajectory of each test furrow were collected in the irrigation process.

SIPAR_ID Software
SIPAR_ID, proposed by Rodriguez and Martos in 2007, is software for estimating the infiltration parameters of the Kostiakov formula and the roughness value of the Manning’s equation in a surface irrigation event under both steady and variable inflow conditions (Rodriguez and Martos, 2010).

The basic features of SIPAR_ID are: (1) robust multi-objective inverse modeling for surface irrigation parameter identification, (2) hybrid model that combines a volume balance approach with four artificial neural networks for simulating the surface irrigation advance phase, (3) fast and efficient evolutionary optimization algorithm known as Differential Evolution (DE). DE is a simple and efficient heuristic for global optimization over continuous spaces derived from the genetic algorithm. Although DE usually converges faster, especially in the more difficult cases, it is still in its infancy and can most probably be improved (Storn and Price, 1997; Mayer et al, 2005), and (4) advance distance and flow depth data can be used for defining the objective function based on the aggregation procedure (Madsen, 2003). The following equations are used as the objective functions:

\[
\min \sum_{i=1}^{m} (x_{i\text{sim}} - x_{i\text{obs}}) \quad (1)
\]

\[
\min \sum_{j=1}^{p} (h_{j\text{sim}} - h_{j\text{obs}}) \quad (2)
\]

Where, \(x_{i\text{sim}}\) is the simulated advance distance with SIPAR_ID software, \(x_{i\text{obs}}\) is the observed advance distance, \(h_{j\text{sim}}\) is the simulated flow depth data with SIPAR_ID software, \(h_{j\text{obs}}\) is the observed flow depth data, \(m\) and \(p\) are the number of advance distances and flow depth, respectively. The basic data of field length, bottom slope, cross-section parameters, inflow discharge, advance trajectory and flow depth in the upstream obtained in field experiments were provided as input in SIPAR_ID software, then, the parameters were used to estimate the infiltration parameter and Manning roughness.

Compared with the conventional optimization, the SIPAR_ID tries to avoid most typical violations of the mass conservation principle. for example, the volume balance methods use a uniform flow equation, like Manning, to describe the cross sectional area of flow at the field inlet and then an assumption regarding the shape of the flow profile downstream, downstream, generally assuming the cross sectional area is constant. The assumption of a constant cross-sectional area is known to introduce substantial errors.

WinSRFR Software
WinSRFR, proposed by USDA Agricultural Research Service, is an integrated software package for analyzing surface irrigation systems. It consists of two models: the zero-inertia (ZI) model and the kinematic-wave (KW)
model (Bautista et al., 2009a). Closed-end furrows were used for apple trees in the above mentioned experiments, and the ZI model was chosen to simulate the irrigation performance of each test furrow. The ZI model used in these procedures was as follows:

\[
\begin{align*}
\frac{\partial A}{\partial t} + \frac{\partial q}{\partial x} + \frac{\partial z}{\partial t} &= 0 \\
\frac{\partial h}{\partial x} - \frac{z_0 - z_f}{t} &= 0
\end{align*}
\]

Where, in Eq 3, A is the cross-sectional area of flow, q is the inflow discharge, Z is the depth of infiltrated water in unit length of furrow, x and t are the distance down the furrow and time, respectively. In Eq 4, h is the surface-flow depth; S0 and Sf are the bottom slope of the furrow and friction slope, respectively. Indices of irrigation performance were analyzed by WinSRFR, and the indices were application efficiency (Ea.), distribution uniformity (Du), and storage efficiency (Es) (Bautista et al., 2009b).

The mathematical expressions for these indices were given as below:

\[
\begin{align*}
E_a &= \frac{W_i}{W_f} \times 100\% \\
D_u &= \frac{Z_{av}}{Z_{av}} \times 100\% \\
E_s &= \frac{W_f}{W_s} \times 100\% = \frac{W_f - D_p - R_o}{W_n} \times 100\%
\end{align*}
\]

Where, \(W_s\) is the infiltrated depth contributing to the irrigation target, \(W_f\) is the average depth of applied water, \(Z_{av}\) is the low quarter average infiltrated depth, \(Z_{av}\) is the average depth of infiltrated water, \(W_n\) is the required or target application water depth, \(D_p\) is the depth of deep percolation, and \(R_o\) is the depth of surface runoff. If closed end, then \(R_o = 0\).

RESULTS

Estimation of Infiltration Parameters and Manning Roughness

Infiltration parameters and Manning roughness values were estimated with SIPAR_ID software. The results are listed in Table 2, which shows that the infiltration parameters and Manning roughness were significantly different in each test furrow. The reasons were that the cross sectional area (or wetted perimeter) varied with different inflow discharges and the spatial variability of soil characteristics caused the differences in the infiltration parameters and Manning roughness for each furrow. Meanwhile, the Manning roughness presented in Table 2 had high values for those furrows. The reasons were that the bottom was unsmoothed and many clods in side slope of furrow were manually excavated, and, also, the interaction between the infiltration parameters and Manning roughness when the SIPAR_ID software was used to perform the inverse solution. Fortunately, the data of flow depth in the upstream were collected, which can be used to help sort between these competing influences. The accuracy of estimation was dependent upon how accurate the data of flow depth in the upstream was collected (Clemmens, 2009).

However, collecting accurate data of flow depth on each test furrow was never an easy job. Here, the accuracy of the infiltration parameters and Manning roughness values estimated with SIPAR_ID software was given more concern. The estimated values (Table 2) were put into the SIPAR_ID software, and the advance trajectory and flow depths in the upstream were simulated on each test furrow to ensure the reliability of the estimated parameters. Then, the simulated values were compared with the measured values. The results are presented in Figure 2 and Table 2. As shown in Figure 2 and Table 2, the simulated water advance trajectory by using the SIPAR_ID software were in excellent agreement with the measured data. The absolute error average values of advance distance between measured and simulated were 5.89%. The simulated and measured flow depth in the upstream showed acceptable agreement, with the absolute error average values of 10.24%. This was probably due to the flow depth in the upstream that had not yet become steady enough at the beginning of irrigation (Figure 2), or the variation in flow depth during irrigation. However, the error of flow depth between measured and simulated values were within a reasonable

<table>
<thead>
<tr>
<th>Site No</th>
<th>Kostiakov Formula</th>
<th>Manning’s n</th>
<th>Average Absolute Error 1</th>
<th>Flow Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(K)</td>
<td>(a)</td>
<td>Advance Distances</td>
<td>Flow Depth</td>
</tr>
<tr>
<td>W1</td>
<td>0.00636</td>
<td>0.698</td>
<td>0.085</td>
<td>5.30</td>
</tr>
<tr>
<td>W2</td>
<td>0.00556</td>
<td>0.687</td>
<td>0.100</td>
<td>4.26</td>
</tr>
<tr>
<td>W3</td>
<td>0.00626</td>
<td>0.688</td>
<td>0.110</td>
<td>7.23</td>
</tr>
<tr>
<td>W4</td>
<td>0.00575</td>
<td>0.705</td>
<td>0.111</td>
<td>7.30</td>
</tr>
<tr>
<td>W5</td>
<td>0.01023</td>
<td>0.597</td>
<td>0.099</td>
<td>6.63</td>
</tr>
<tr>
<td>W6</td>
<td>0.00939</td>
<td>0.627</td>
<td>0.088</td>
<td>6.76</td>
</tr>
<tr>
<td>W7</td>
<td>0.00887</td>
<td>0.580</td>
<td>0.085</td>
<td>3.72</td>
</tr>
<tr>
<td>Average</td>
<td>0.00753</td>
<td>0.655</td>
<td>0.097</td>
<td>5.89</td>
</tr>
</tbody>
</table>

1Average Absolute Error of Advance Distances = ((\(X_{obs} - X_{sim}\))/\(X_{obs}\))×100 and Flow Depth = ((\(H_{obs} - H_{sim}\))/\(H_{obs}\))×100
Table 3. Simulated indices of irrigation performance with WinSRFR software compared with the measured values

<table>
<thead>
<tr>
<th>No</th>
<th>Measured values of irrigation performance %</th>
<th>Simulated values of irrigation performance %</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ea</td>
<td>Du</td>
<td>Es</td>
</tr>
<tr>
<td>W1</td>
<td>93.21</td>
<td>77.82</td>
<td>79.98</td>
</tr>
<tr>
<td>W2</td>
<td>91.45</td>
<td>79.54</td>
<td>73.74</td>
</tr>
<tr>
<td>W3</td>
<td>98.64</td>
<td>85.47</td>
<td>94.14</td>
</tr>
<tr>
<td>W4</td>
<td>86.89</td>
<td>80.21</td>
<td>97.50</td>
</tr>
<tr>
<td>W5</td>
<td>66.89</td>
<td>74.26</td>
<td>96.72</td>
</tr>
<tr>
<td>W6</td>
<td>77.59</td>
<td>84.50</td>
<td>98.75</td>
</tr>
<tr>
<td>W7</td>
<td>95.64</td>
<td>86.06</td>
<td>78.34</td>
</tr>
</tbody>
</table>

Average absolute error: 6.87 7.67 6.15

Note: Error of irrigation performance = (simulated values - measured values)/ measured values ×100%.

Figure 1. Simulated advance trajectory by the WinSRFR software compared with the measured values

Figure 2. Simulated flow depth in the upstream by the WinSRFR software compared with the measured values
range based on the actual situations of furrow irrigation.

Therefore, the validity of the infiltration parameters and Manning roughness estimated with SIPAR_ID software was reliable. Evaluating Irrigation Performance the parameters of Table 1 and Table 2 were provided as input in WinSRFR software to simulate the irrigation performance. The simulated indices of irrigation performance were compared with the measured values. The results are listed in Table 3. It can be seen from Table 3 that the simulated irrigation performance with the WinSRFR software were in agreement with measured values, and the absolute error average values of Ea, Du, and Eo of all the irrigation furrows were 6.87%, 7.67%, and 6.15%, respectively.

Besides, while the spatial variability of soil infiltration characteristics and Manning roughness are the most important factors affecting the performance of surface irrigation (Khatri and Smith, 2006), constant values of infiltration parameters and Manning roughness were provided as input in WinSRFR software when simulating irrigation performance of furrow irrigation. As a whole, the irrigation performance of furrow irrigation simulated with the Win SRFR software was reliable. According to the measured values of irrigation performance in Table 3, the W5 site had low application efficiency. The reasons were that the inflow discharge was relatively small and the cutoff time was too long, which led to the volume of applied water being larger than the required application. Therefore, deep percolation loss was serious in W5. The results showed that, generally, adequate and efficient irrigations could not be obtained in closed-end furrows due to the improper selection of inflow discharge and cutoff time.

CONCLUSION

This study was conducted to develop method and guidelines for the efficient irrigation by using closed-end furrows. The results of this research can be summarized as follows:

(1) Infiltration parameters and Manning roughness values were estimated with the SIPAR_ID software for closed-end furrows, and reliability of the estimated values were verified. The absolute error average values of advance distances and flow depth in the upstream between measured and simulated values were 5.89% and 10.24%. The results showed that the infiltration parameters and Manning roughness estimated with SIPAR_ID software were reliable.

(2) The irrigation performance was evaluated for the existing closed-end furrow system based on measured values. The results showed that irrigation in the W5 sites were inefficient due to improper selection of inflow discharge and cutoff time. Meanwhile, the irrigation performance was simulated by using WinSRFR software and the results were satisfactory compared with the measured values.

REFERENCES


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