*Plant Archives* Vol. 19, Supplement 2, 2019 pp. 2108-2115 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

# VALIDATION OF WINSRFR FOR SOME HYDRAULIC PARAMETERS OF FURROW IRRIGATION IN EGYPT

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## Abstract

Surface irrigation is considered as the most common and important irrigation systems in Egypt, and as one of the most extensive methods used for irrigation in the Nile Delta and the old valley, Egypt. Well designed and managed furrow irrigated systems have the potential to operate at application efficiencies above 90 %. WinSRFR is a new generation of software for analyzing surface irrigation systems (basin, border, and furrow). Founded on an unsteady flow hydraulic model, the software integrates event analysis, simulation, design, and operational analysis functionalities. This is study aimed to validate WinSRFR simulation model as a prediction tool of the furrow irrigation performance under the Egyptian conditions using different furrow lengths and slopes. This work has been carried out at Private farm in Damanhur, El-Beheira Governorate, Egypt to represent the old alluvial soil of the Nile Delta (clay loam). Results revealed that the statistical indicators of $R^2$ (> 0.9), *SE* (nearest to 0), *d* (> 0.9), and *E* were used for the comparison between measured and simulated advance time, recession time, and *DU*. These indicators were high satisfactory to use the software under the Egyptian conditions for furrow irrigation. Generally the results were sufficiently acceptable to fulfill the objective of this work, this was confirmed by the good agreement between the simulated and measured advance time, recessions time, and *DU*. Also, Using the infiltration function of modified kostiakov formula in the WinSRFR Simulation World was more adequate than using kostiakov formula in the most run cases.

***Keywords:*** WinSRFR, Simulation Model, Furrow Irrigation, Distribution Uniformity.

## Introduction

Water resources in Egypt are limited, which considered the first obstacle for crop production in the newly reclaimed lands because of the present intensive agricultural production in the Nile Delta and valley area, as well as agriculture in Egypt depends mainly on irrigation process. The agricultural sector consumes more than 84% of the available water resources (El-Beltagy and Abo-Hadeed, 2008; El-Noemani *et al.*, 2015 a and El-Noemani *et al.*, 2015 b ). Furrow irrigation system is the most used irrigation system in Egypt(El-Shafie *et al.*, 2018). Surface furrow irrigation characterized by low application efficiency (45 – 60 %) and causes significant water losses, mainly due to the excess deep percolation from the irrigated fields (Mitchell *et al.*, 1995 and Raine and Bakker, 1996). Accordingly, using simulation models for well design and simulation of the irrigation process will lead to the proper decisions to maximize the irrigation efficiency.

### *WinSRFR model*

Modified WinSRFR is one of the most popular evaluation, simulation, and design tool for surface irrigation system's users (basin, border, and furrow methods). Bautista *et al.* (2009a) revealed that the functionality of WinSRFR was defined based on the analytical process typically followed in assessing and improving the hydraulic performance of surface irrigation systems. Program functionalities of WinSRFR are Event Analysis, Operation Analysis, Physical Design, and Simulation, users can analyze the performance irrigation events and estimate field-average infiltration parameters based on field measured data, formulate design and operational alternatives, and conduct simulation studies using an unsteady one dimensional flow model. Because of the needed integration among functionalities, the WinSRFR development project has led to enhancements and modifications to existing parameter estimation, design and operations analysis procedures. WinSRFR is mainly a practical tool, but will also serve as foundation for future development of hydraulic modeling and analysis techniques for surface irrigation.

Badawi *et al.* (1986) reported that the best inflow rate per each furrow for Nubaria sandy soil, Egypt, was 1.11 lit/sec at 100 m furrow length and furrow spacing 0.6 m, and Hassan (1990) refereed that the best flow rate per each furrow in clay soil in Egypt was 1.2 lit/sec at furrow length 100m, and furrow spacing of 0.6 m. Heerman *et al.* (1990) mentioned that the combination of non uniformity and the lack of control over total infiltrated volume, both reduce irrigation efficiency. Using low flow rates for long fields, the advance time will be long and will reduce irrigation efficiency. Hydraulically rough, flat or very gently sloping, for bare soil or vegetated soil, impede water advance lead to the less irrigation efficiency. They also reported that land planning to establish consistent longitudinal slope also improves the uniformity of intake opportunity time. Precisely leveling the field cause the soil infiltration characteristics to become more heterogeneous. Mehanna *et al.* (2009) mentioned that the SIRMOD model adequately describes advance and recession times and infiltrated depth under experimental site conditions for the furrow irrigation practice.

## Materials and Methods

### *Experimental Site*

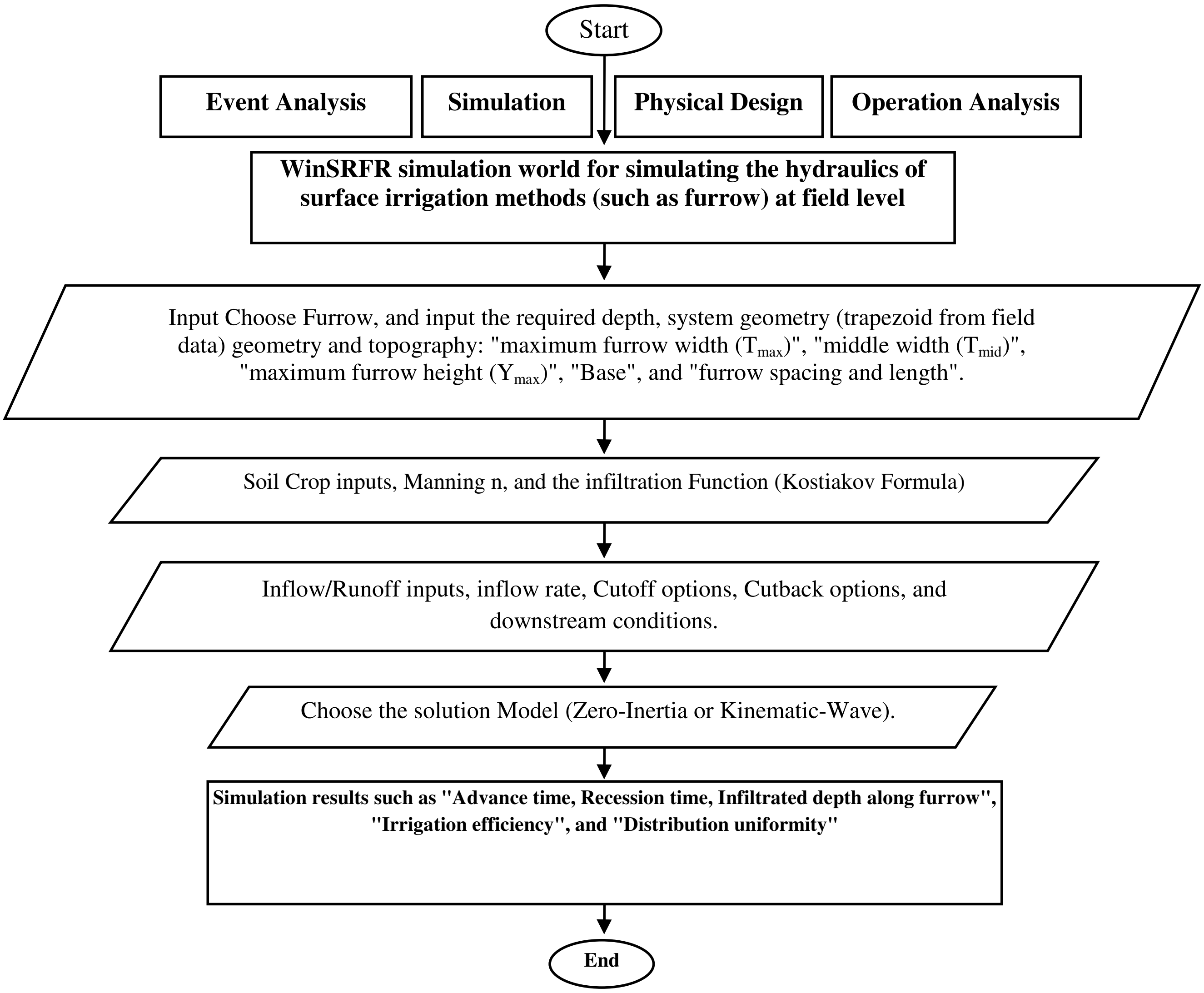
A study site was chosen in Damanhur El-Beheira Governorate, Egypt. Soil analysis were conducted according to standard procedures and represented in Table (1). Two slopes were selected 0.2% and 0.5% and three furrow lengths (100 m, 75 m and 50 m) as hydraulic parameters of furrow irrigation. The inflow to every furrow was 2 l/s using gated pipes irrigation system. The cutoff time differed from treatment to another depending on the furrow length. The Manning n value for bare soil was 0.04.

Furrow geometry was measured (as an average of cross sections along 30 individual furrows, Table, 2) manually by a locally manufactured furrow profile meter (Fig. 1), a wooden frame was manufactured to measure the furrow geometry, consisted of two vertical legs and steel rods with constant lengths fixed in the horizontal piece with 80 cm length, through holes and a drawing paper was fixed behind the rods on the frame. The furrow shape was measured four times for each furrow and the average for the all furrows was calculated to get the overall furrow shape parameters as mentioned in Table (2). Advance and recession times were taken manually using markers at known distances (25 m) along the furrow during the irrigating process. Cutoff time was determined when the water reaches the last quarter of the furrow length then the recession time was measured at each pointer.

**Table 1 :** Some physical properties of soil.

| Soil depth, cm | Particle Size Distribution, % | | | | F.C., % | W.P., % | AW | Texture |
|---|---|---|---|---|---|---|---|---|
| **0 - 20** | 0.9 | 28 | 42.1 | 29 | 30.8 | 14.6 | 16.2 | C.L. |
| **20 - 40** | 0.8 | 27.8 | 41.5 | 29.9 | 32.2 | 16.5 | 15.7 | C.L. |
| **40 - 60** | 0.7 | 27.8 | 39.5 | 32 | 32.3 | 17.5 | 14.8 | C.L. |

Bautista *et al.* (2009a) mentioned that the Simulation World is used to analyze the performance tradeoffs among different combinations of flow rate and cutoff time for a system of known dimensions, slope, and soil characteristics. The analysis is conducted with the help of performance contours, which depict the variation of irrigation performance measures as a function of the decision variables. Burt *et al.*, 1997 reported that the performance measures, analyzed by WinSRFR include distribution uniformity, potential application efficiency, runoff and deep percolation fractions, minimum infiltrated depth, total applied depth, the ratio of advance distance at cutoff time relative to field length (for cases where cutoff precedes advance to the end of the field), or the ratio of cutoff time to final advance time (for cases where cutoff follows completion of advance). These tools allow the user to search for combinations of the decision variables that will result in high levels of uniformity and efficiency while taking into account practical and hydraulic constraints. Flow chart (1) shows the inputs and outputs of WinSRFR simulation world.




**Flow chart (1):** Components of WinSRFR for simulating the hydraulics of surface irrigation (furrow) at field level.

**Table 2 :** Unit width flow cross section of furrows.

| Parameter | Measured value, m |
|---|---|
| Top width | 0.550 |
| Middle width | 0.400 |
| Base | 0.120 |
| Maximum depth | 0.140 |

Advance and recession times, as well as *DU* (Equ., 1) were measured under different hydraulic parameters of furrow (100 m, 75 m and 50 m furrow lengths, and 0.5% and 0.2% furrow slopes) for determining the possibility of using WinSRFR as a prediction tool of the furrow irrigation performance under the Egyptian conditions, as shown in Layout (1).

$$\mathrm{DU} = \frac{\text{q low, average of low quarter gate discharge, lit/sec}}{\text{qavg average of all gates discharge, lit/sec}} \quad (1)$$

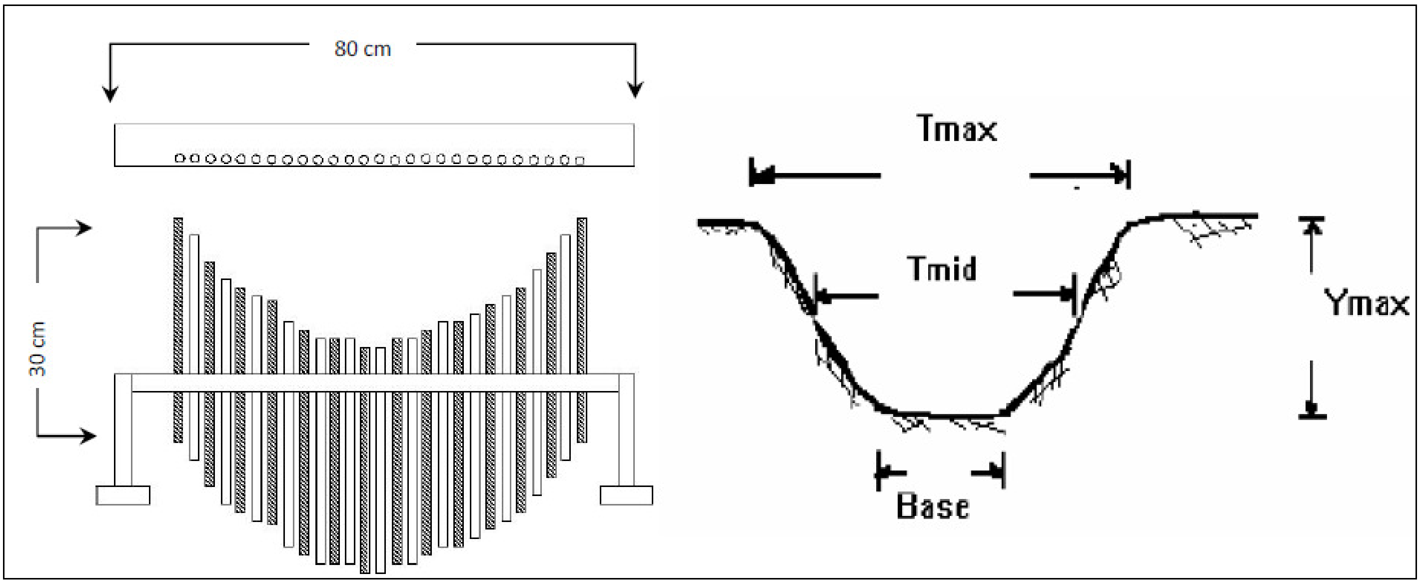
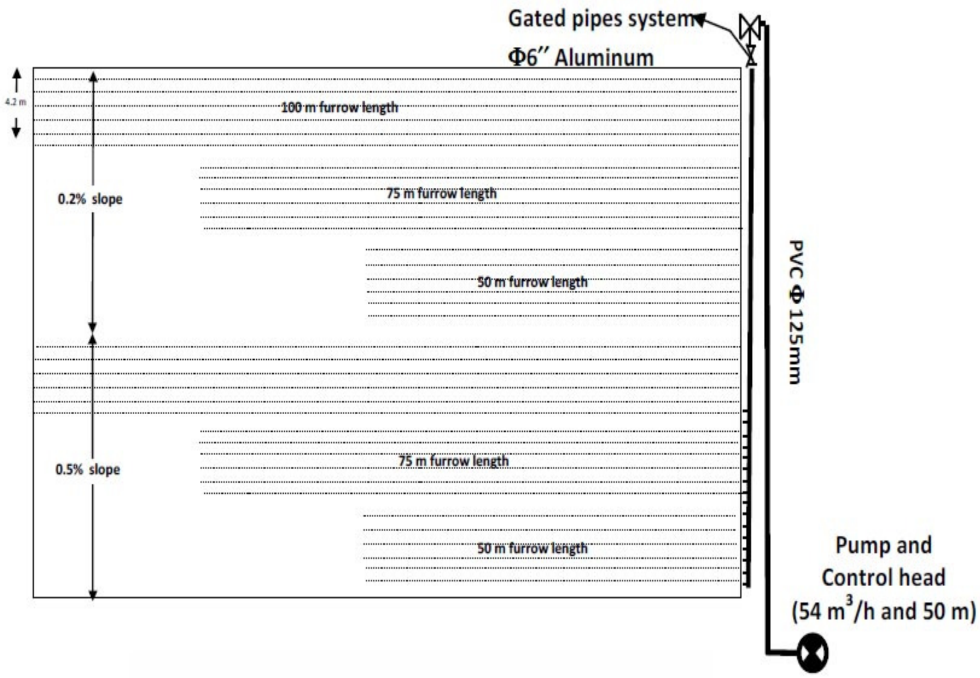



**Fig. 1 :** Locally manufactured furrow profile meter.




**Layout 1 :** The layout of the experimental site.

***Statistical indicators***

The goodness of fit expressions were the coefficient of determination ($R^2$) and the Standard Error (SE). For a perfect fit between observed and simulated data, *SE* (the standard error of the sample mean is an estimate of how far the sample mean is likely to be from the population mean) should be close to 0, and Correlation Coefficient ($R^2$) should equal 1.0. The $R^2$ statistics demonstrate the ratio between the scatter of simulated values to the average value of measurements (Equ., 2):

$$R^2 = \left\{ \frac{1}{N} \frac{\sum \left(y_m - \bar{y}_m\right)\left(y_s - \bar{y}_s\right)}{\left(\sigma y_m - \sigma y_s\right)} \right\} \quad ....(2)$$

where $y_m^-$ is the averaged measured value, $y_s^-$ is the averaged simulated value, σ $y_m$ is the measured data standard deviation and σ $y_s$ is the simulated data standard deviation.

In order to check the accuracy of the model in predicting different parameters, the statistical indicators such as Willmott agreement index (*d*), Equ. (3), (Willmott *et al.*,

1985) and the coefficient of efficiency ($E$), Equ. (4), (Nash and Sutcliffe, 1970) were calculated as follows:

$$d = 1 - \left(\sum\nolimits_{\downarrow}(i=1)^{\uparrow} n\right)\left[(y_1 m - y_1 s)^{\uparrow 2}\right] \quad ....(3)$$

$$E = 1 - \frac{\sum_{i=1}^{n}(y_m - y_s)^2}{\sum_{i=1}^{n}\left(y_m - \overline{y_m}\right)^2} \quad ....(4)$$

where $y_s$ is the simulated value, $y_m$ is the observed value, $\bar{y}_m$ is the mean of observed value and n is the number of observations. The coefficient of efficiency (E) varies from $-\infty$ to 1. A value approaching 1 indicates a better agreement between observed and simulated data. The closer the model efficiency is to 1, the more accurate the model is. An efficiency of 0 (E = 0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (E < 0) occurs when the observed mean is a better predictor than the model, Essentially, the closer the model efficiency is to 1, the more accurate the model is. Threshold values to indicate a model of sufficient quality have been suggested between $0.5 < NSE < 0.65$ (Ritter and Munoz-Carpena, 2013, and Moriasi *et al.*, 2007).

## Results and Discussion

Data illustrated in Table (2) show the measured field data which used as inputs for WinSRFR to simulate the performance of furrow irrigation under different hydraulic parameters of furrow lengths and slopes using kostiakov formula and modified kostiakov formula infiltration functions. As mentioned in Flow chart (1) and Table (2), the runs of WinSRFR were done under the different furrow hydraulics parameters (100 m, 75 m and 50 m furrow lengths, and 0.5% and 0.2% furrow slopes) using two infiltration functions (kostiakov formula, and modified kostiakov formula) to determine the proper function to evaluate and/or simulate the furrow hydraulics under the Egyptian conditions. Fig. (3) shows the screens of WinSRFR run under 100m furrow length, 0.5% slope, and using kostiakov formula infiltration function as an example of the running screens, which expressed (1) WinSRFR Worlds, (2) Start Simulation World, (3) System Geometry, (4) Soil Crop Properties, (5) Inflow/Runoff, and Execution, respectively. After the execution have been done, the results of simulated advance time and recession time, infiltration depth, and Hydraulics Summary will be simulated, and a summary file of all simulated outputs will be got (Fig., 4). The simulated data of advance and recession times, as well as *DU* were be compared by the measured data under different furrow lengths and slopes, using $R^2$, *SE*, *d*, and *E* comparisons for measuring the possibility of using WinSRFR as a prediction and simulation tool under the Egyptian conditions of clay loam soil.

**Table 2 :** Inputs of WinSRFR simulation world.

| **Field Topography/Geometry** | | | |
|---|---|---|---|
| **Field Geometry:** | *Inputs depending on furrow length* | | |
| **- Field length, m:** | 100 | 75 | 50 |
| **- Furrow spacing, m:** | 0.7 | 0.7 | 0.7 |
| **Field system:** | Furrow irrigation | | |
| **Down stream boundary;** | Open End | | |
| **Slopes:** | 0.2% or 0.5% | | |
| **Manning n values determined from reviews for bare soil:** | 0.04 | | |
| **Type of simulation model:** | Zero-inertia | | |
| Run parameters: | | | |
| **- Furrow inflow lit/s:** | 2 | | |
| **- Time of cutoff depending on furrow length (min):** | 20 | 15 | 10 |
| **Infiltration characteristics of soil type** | Clay loam soil | | |

Data illustrated in Table (3) show the good predictions of the simulated advance time gained by using kostiakov formula as well as modified kostiakov formula, for the different furrow lengths and slopes. The simulated and measured advance time under all experimental treatments show a strong correlation with good $R^2$ values. The average of correlation value was more than 0.9, moreover the *SE* values were close to zero, and *d* nearest to 1. In general these statistical indicators were very good, meanwhile *E* values were < 0. For that, WinSRFR proved its ability to simulate the advance time even using kostiakov formula or modified kostiakov formula as an infiltration function. These data was in the same concern with Mehanna *et al.* (2009), and Beutista *et al.* (2009b).

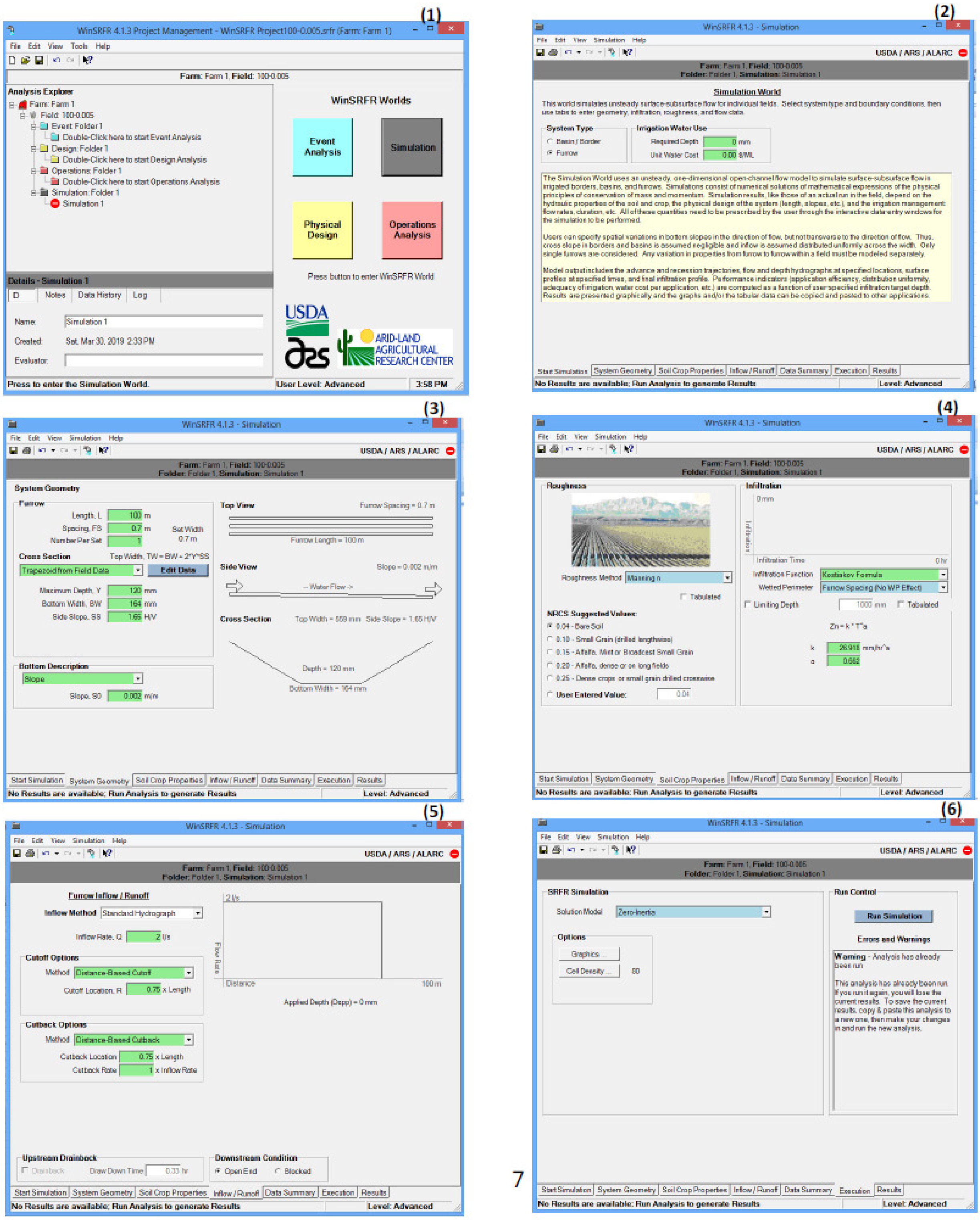



**Fig. 3 :** WinSRFR Screens (1) WinSRFR Worlds, (2) Start Simulation World, (3) System Geometry, (4) Soil Crop Properties, (5) Inflow/Runoff, and Execution.

**Table 3 :** The relationship between the measured and the simulated advance time (hr) using kostiakov formula and modified kostiakov formula under different furrow hydraulic parameters.

| Furrow Slope | Furrow length | Using Kostiakov formula | | | | Using modified Kostiakov formula | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R^2$ | SE | d | E | $R^2$ | SE | d | E |
| 0.5% | 100 m | 0.998 | 0.00496 | 0.923 | -0.127 | 0.997 | 0.00545 | 0.918 | -0.228 |
| | 75 m | 0.999 | 0.00178 | 0.919 | -0.335 | 0.996 | 0.00507 | 0.916 | -0.394 |
| | 50 m | 0.999 | 0.00175 | 0.937 | -0.335 | 0.997 | 0.00295 | 0.937 | -0.394 |
| 0.2% | 100 m | 0.997 | 0.00757 | 0.930 | 0.135 | 0.998 | 0.00425 | 0.922 | -0.070 |
| | 75 m | 0.999 | 0.00216 | 0.923 | -0.062 | 0.998 | 0.00332 | 0.916 | -0.232 |
| | 50 m | 0.999 | 0.00128 | 0.939 | 0.002 | 0.999 | 0.00194 | 0.934 | -0.123 |
| **Mean** | | **0.998** | **0.00325** | **0.928** | ------ | **0.997** | **0.00383** | **0.923** | ------- |

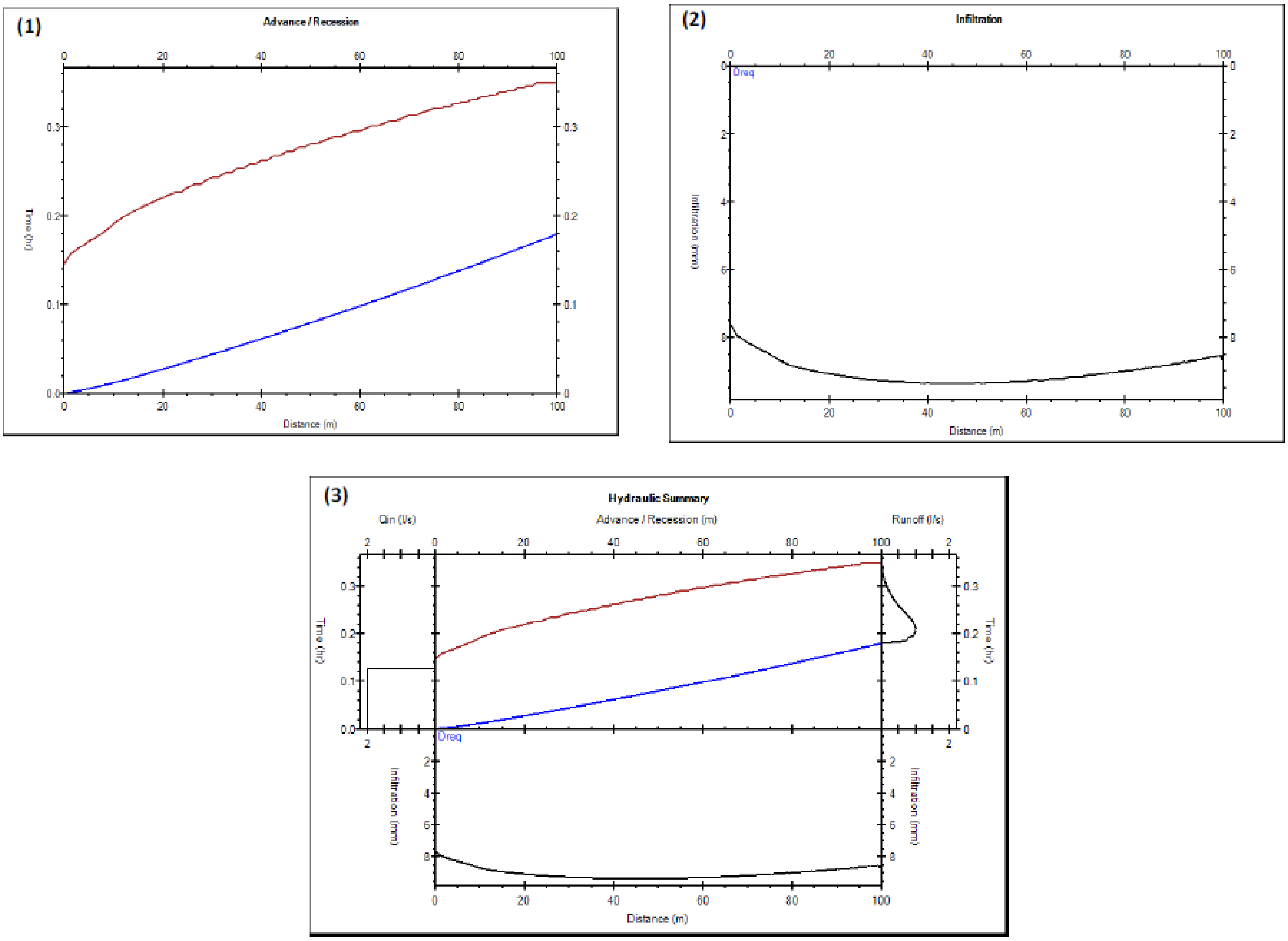



**Fig. 4:** WinSRFR Simulation World Results Screens (1) Advance and Recession Times, (2) Infiltration Depth, (3) Hydraulics Summary.

Recession time was measured under the field conditions for different furrow lengths and slopes. The statistical indicators obtained from the comparison between simulated and measured recession time were very good which reflects that there were very good fits between them. The values of $R^2$ were more than 0.9, and the *SEs* were close to zero (Table, 4). On the other hand, *d* value using modified kostiakov formula (> 0.9) was better than using kostiakov formula (> 0.85), but it is still acceptable. In general, *E* values were close to 1 which reflects that the simulated mean was good, the closer the model efficiency is to 1, the more accurate the model is. For that WinSRFR is a good tool to simulate the recession time even using kostiakov formula or modified kostiakov formula as an infiltration function.

**Table 4 :** The relationship between the measured and the simulated recession time (hr) using kostiakov formula and modified kostiakov formula under different furrow hydraulic parameters.

| Furrow Slope | Furrow length | Using Kostiakov formula | | | | Using modified Kostiakov formula | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R^2$ | *SE* | *d* | *E* | $R^2$ | *SE* | *d* | *E* |
| **0.5%** | **100 m** | 0.910 | 0.06017 | 0.878 | 0.262 | 0.920 | 0.11354 | 0.953 | 0.597 |
| | **75 m** | 0.878 | 0.06032 | 0.834 | 0.214 | 0.870 | 0.12544 | 0.952 | 0.649 |
| | **50 m** | 0.992 | 0.01289 | 0.863 | 0.214 | 0.982 | 0.03837 | 0.998 | 0.649 |
| **0.2%** | **100 m** | 0.973 | 0.04607 | 0.947 | 0.521 | 0.985 | 0.07340 | 0.997 | 0.964 |
| | **75 m** | 0.968 | 0.04438 | 0.904 | 0.365 | 0.983 | 0.06930 | 0.990 | 0.892 |
| | **50 m** | 0.940 | 0.05012 | 0.851 | 0.281 | 0.986 | 0.05261 | 0.976 | 0.819 |
| **Mean** | | **0.943** | **0.04565** | **0.879** | **------** | **0.954** | **0.078776** | **0.977** | **------** |

Overall measured and simulated advance time were drawn in Fig. (5) and Fig. (6) using kostaikov formula and modified kostiakov formula, respectively. Data shown in Fig. (5) shows the relationship between the measured and simulated advance time, expressed by linear equation with high correlation coefficient (0.976), and *d* of 0.977, which indicate the high accuracy of simulating the advance time under the different experimental conditions using kostiakov formula, and $R^2$ of 0.986, and *d* of 0.976 using modified kostaikov formula. Consequently the simulated advance time using the modified kostiakov formula was better than using kostiakov formula. Overall measured and simulated recession time were in the same trend with that gained from the comparison of measured and simulated advance time under the experimental conditions using the kostiakov formula and modified one (Fig., 7 and 8, respectively), with good predictions and acceptable outputs. These results are in the same trend with that mentioned by Mehanna *et al.* (2009), Beutista *et al.* (2009b), and Nie *et al.* (2014).

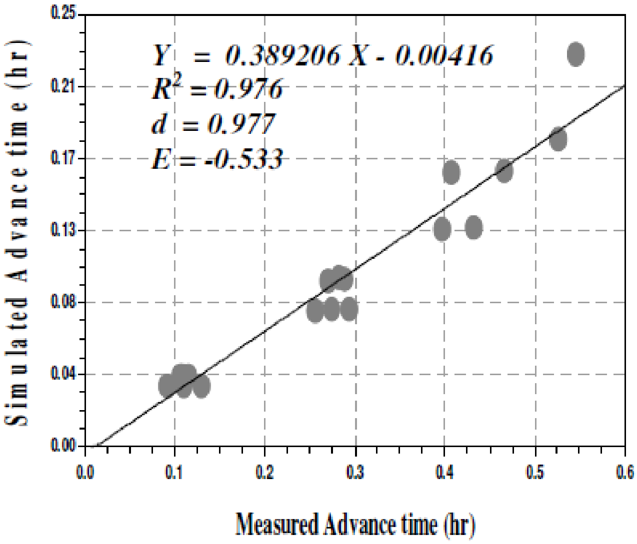



**Fig. 7 :** Overall measured vs simulated recession time (using Kostiakov formula).

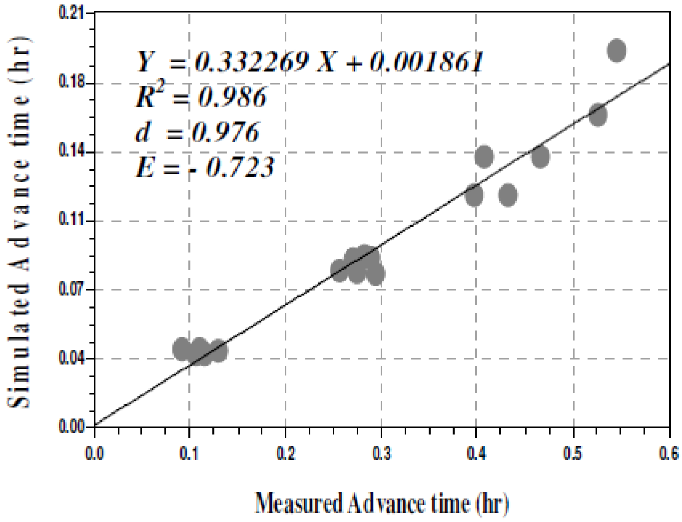



**Fig. 8 :** Overall measured vs simulated recession time (using modified Kostiakov formula).

Sanchez *et al.* (2009) and Ma *et al.* (2010) reported that the application efficiency and distribution uniformity are the most important indices of irrigation efficiency. According to that the distribution uniformity have been measured under the different furrow lengths (100 m, 75 m and 50 m) and furrow slopes (0.5 % and 0.2 %), as well as *DU* have been simulated using WinSRFR using kostiakov formula and modified kostiakov formula, and compared each other in Fig. (9) and Fig. (10), respectively. The measured and simulated Distribution Uniformity (*DU*) values were very close. Linear relationship was gained with fit predictions and high values of $R^2$ and *d*, and with satisfactory values of *E*. Generally the results were sufficiently acceptable to fulfill the objective of this work, this was confirmed by the good agreement between the simulated and measured advance time, recessions time, and *DU*.

## Conclusion

This study was conducted to measure the validity of using WinSRFR software as a tool of simulation furrow irrigation under clay loam condition in Egypt. The statistical indicators of $R^2$, *SE*, *d*, and *E* were used for the comparison between measured and simulated advance time, recession time, and *DU*. These indicators were high satisfactory to use the software under the Egyptian conditions. Generally the results were sufficiently acceptable to fulfill the objective of this work, this was confirmed by the good agreement between the simulated and measured advance time, recessions time, and *DU*. Also, Using the infiltration function of modified kostiakov formula in the WinSRFR simulation world was more adequate than using kostiakov formula in the most run cases.

**Acknowledgments**

The Science and Technology Development Fund in Egypt, (STDF), Short Term Fellowship program, through the project, funded this research “Water Saving under Surface and Sub-Surface Drip Irrigation: Field and Modelling Study.

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