# University of Mohaghegh Ardabili

Faculty of Agricultural Sciences and Natural Resources

Department of Water Engineering

# Furrow Irrigation Design and Assessment Tool

**Author**

Amirreza Nemati mansour

**Supervisor**

Majid Raoof

Sunday, March 29, 2024

*Contents*

# 1 Introduction

Reliable and suitable irrigation water supply is crucial for significant improvements in agricultural production and regional economic vitality. Throughout history, countless civilizations have relied on irrigated agriculture as the foundation of their societies and the security of their people. While only 15-20% of the world's cultivated land is irrigated, this relatively small portion contributes a substantial 30-40% of global agricultural output, as evidenced by yield comparisons between irrigated and non-irrigated areas.

Effective agronomic practices are indispensable components of successful irrigation systems. Proper management of soil fertility, crop selection and rotation, and pest control can be as impactful on yield as the irrigation water itself. It's essential to remember that irrigation necessitates drainage, soil reclamation, and erosion control. Neglecting any of these factors, whether due to a lack of understanding or planning, inevitably leads to a decline in agricultural productivity. History provides ample evidence to support this claim.

Irrigated agriculture faces several significant challenges in the future. One major concern is the widespread inefficiency in water resource utilization for irrigation. A conservative estimate suggests that 40% or more of the water diverted for irrigation is wasted at the farm level through deep percolation or surface runoff. While these losses may not be entirely lost in a regional context, as return flows can be reused elsewhere, they represent missed opportunities. They delay the arrival of water at downstream diversions and often degrade water quality.

Another pressing issue is the growing competition for water from urban and industrial sectors. These uses often prioritize water resources and highlight wasteful irrigation practices. Future irrigation science must focus on maximizing efficiency to address these challenges.

## 2 Surface Irrigation

Surface irrigation systems are characterized by two key features:

1. Free Surface Flow: The water flow is not confined, allowing it to respond to gravitational forces.
2. Field Surface Conveyance: The field surface itself serves as the means of conveying and distributing the irrigation water.

A typical surface irrigation event consists of four distinct phases, as illustrated in Figure 1:

1. Advance Phase: Water is applied to the field, gradually advancing across the surface until it covers the entire area. While not all areas may be directly wetted, all flow paths are established.
2. Wetting or Ponding Phase: After the advance phase, the water either runs off the field or begins to pond on the surface. This phase continues until the inflow is cut off.
3. Depletion Phase: Once the inflow is stopped, the water volume on the surface starts to decrease. This phase, known as depletion, continues until the first bare soil appears.
4. Recession Phase: Following depletion, the recession phase begins. During this phase, the remaining water on the surface drains away, either through runoff or infiltration into the soil.

Understanding the hydraulics of surface flows during the drainage period, particularly the depletion and recession phases, is crucial for optimizing irrigation efficiency.

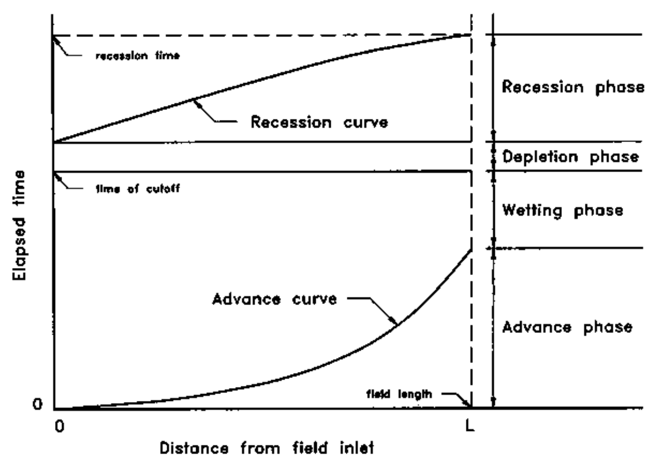



Figure 1. Visual representation of surface irrigation phases

Surface irrigation has evolved into a diverse range of configurations, broadly categorized as:

1. Basin Irrigation
2. Border Irrigation
3. Furrow Irrigation
4. Uncontrolled Flooding

## 2.1 Basin Irrigation

Basin irrigation is the most prevalent form of surface irrigation, especially in regions with smaller fields. A basin is characterized by a level field surrounded by a dike to prevent runoff. Water is applied undirectedly, flooding the entire field. While basins are often square, they can also be irregular or rectangular. Some basins may have furrows or raised beds to accommodate specific crops, but the undirected inflow remains the defining characteristic. Figure 2 illustrates two common basin irrigation systems, where water enters the basin through a gap in the perimeter dike or an adjacent ditch.

Figure 2. basin irrigation System

Precision land leveling is crucial for achieving high uniformity and efficiency in irrigation. However, many basins, particularly small ones, are not suitable for precision leveling equipment. Proper maintenance of perimeter dikes is essential to prevent breaches and water loss. These dikes must be higher than those in other surface irrigation methods. To maximize efficiency, the flow rate per unit width should be as high as possible without causing soil erosion. When an irrigation project is designed for small basins, furrows, or borders, the capacity of control and outlet structures may limit the potential for improving basin irrigation efficiency.

## 2.2 Border Irrigation

Border irrigation is essentially an extension of basin irrigation, applied to sloping, long rectangular or contoured fields with free drainage at the lower end. As depicted in Figure 3, a typical border irrigation system divides a field into sloping borders. Water is applied to individual borders from small, hand-dug checks at the field head ditch. Once the water supply is cut off, it recedes from the upper to the lower end of the border.

Sloping borders are suitable for most crops, except those requiring prolonged ponding. Soils with moderately low to moderately high infiltration rates are well-suited for border irrigation. However, to prevent crust formation, measures such as furrowing or constructing raised beds may be necessary. The stream size per unit width should be significant, especially after major tillage operations, but not as high as in basin irrigation due to the effects of slope. Precise land leveling is crucial, but the extended length of borders allows for more effective leveling using farm machinery.

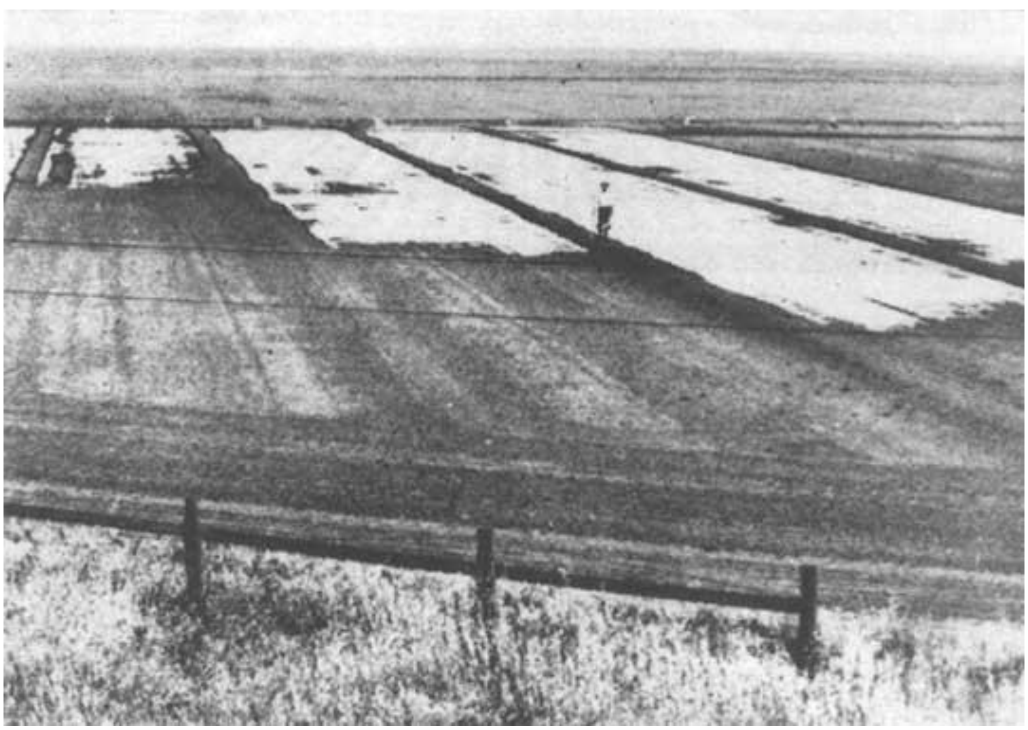


Figure 3. border irrigation System

## 2.3 Furrow Irrigation

Furrow irrigation conserves water by channeling it along furrows, creases, or corrugations, thereby avoiding the flooding of the entire field surface. Water infiltrates through the wetted perimeter and spreads vertically and horizontally to replenish the soil moisture. Furrows are often incorporated into basins and borders to mitigate the impact of topographical variations and crust formation.

A key distinction of furrow irrigation is the independent control of water flow into each furrow, unlike border and basin irrigation, where flow is regulated on a border-by-border or basin-by-basin basis. This provides greater flexibility in on-farm water management. Lower discharge rates per unit width and the ability to handle steeper slopes are advantages of furrow irrigation. Additionally, the reduced wetted area minimizes evaporation losses. By tailoring irrigation practices to specific field conditions, furrow irrigation offers opportunities to achieve higher application efficiencies.

However, furrow irrigation also has drawbacks. These include:

- Salt accumulation between furrows
- Increased tailwater losses
- Difficulty in maneuvering farm equipment
- Additional labor and time for furrow construction
- Higher erosion potential
- Greater labor requirements for efficient operation
- Challenges in automation, particularly in regulating equal flow in each furrow

Figure 4. Furrow Irrigation System

# 3 Research Focus and Motivation

The Water Engineering Department at Mohaghegh Ardabili University has dedicated significant research efforts to furrow irrigation systems. Given the complexity and time-consuming nature of the calculations involved in designing such systems, the development of a computer program was undertaken to streamline the process for engineers.

# 4 Material and Method

## 4.1 Study Area

The research was conducted at the Babolan Research Farm, Faculty of Agricultural Technology, Mohaghegh Ardabili University. This research farm is located at 38°19' North, 48°20' East, approximately 10 kilometers northeast of Ardabil city (Figure5).

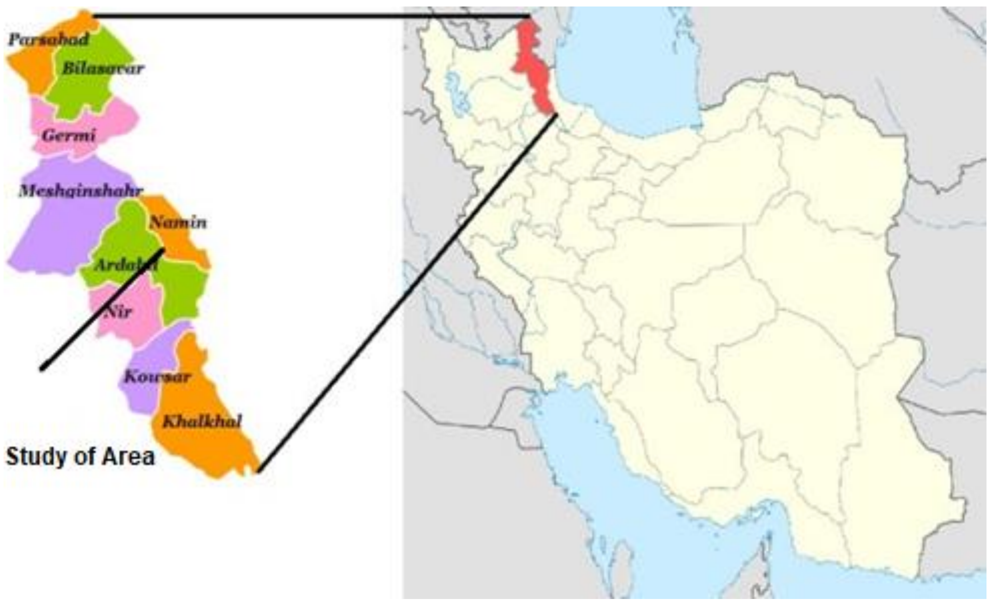



Figure 5. Study of Area

## 4.2 Experimental Methodology

The experimental work comprised both laboratory and field studies:

### 4.2.1 Laboratory Experiments:

Soil Properties: Undisturbed sample and pycnometer methods were employed to determine soil bulk density and particle density, respectively. Sieve and hydrometer analysis were used to assess soil porosity and particle size distribution. Table 1 summarizes the soil properties of the study area.

Table 1: Extract data from soil

| Physical parameters | Unit | Repeat | | | |
|---|---|---|---|---|---|
| | | T0 | T1 | T2 | T3 |
| Bulk Density | $(gr/cm^3)$ | 24.1 | 46.1 | 57.1 | 67.1 |
| Sand | (%) | 58.2 | 57.2 | 57.2 | 58.2 |
| Silt | (%) | 36 | 2.36 | 9.35 | 1.36 |
| Clay | (%) | 36 | 35.6 | 7.35 | 8.35 |
| porosity | (%) | 28 | 2.28 | 4.28 | 1.28 |
| porosity | (%) | 9.51 | 31.43 | 74.38 | 75.34 |
| pH | - | 95.7 | 15.8 | 7.8 | 9.8 |
| Organic matter | (%) | 897.2 | 379.2 | 462.2 | 51.3 |
| EC | $(\mu s/cm)$ | 1171 | 1126 | 1154 | 1182 |

### 4.2.2 Field Experiments

Infiltration Tests: Treatments were established, and a double-ring infiltrometer method was used to measure infiltration rates at saturation.Standard infiltration curves were generated for each treatment. The results of the infiltration tests are presented in Table 2.

Table 2. Cumulative infiltration values at different times (for 4 replicates)

| t(min) | I1(cm) | I2(cm) | I3(cm) | I4(cm) |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 1 | 0.7 | 0.5 | 0.5 | 0.5 |
| 2 | 1.1 | 0.9 | 0.9 | 0.9 |
| 3 | 1.5 | 1.3 | 1.3 | 1.3 |
| 4 | 1.9 | 1.7 | 1.6 | 1.5 |
| 5 | 2.3 | 2 | 1.9 | 1.8 |
| 6 | 2.6 | 2.3 | 2.1 | 2 |
| 7 | 2.9 | 2.6 | 2.3 | 2.2 |
| 8 | 3.2 | 2.9 | 2.6 | 2.4 |
| 9 | 3.5 | 3.2 | 2.9 | 2.6 |
| 10 | 3.8 | 3.5 | 3.1 | 3 |
| 15 | 5.2 | 4.5 | 4.2 | 4 |
| 20 | 6.4 | 5.7 | 5.3 | 5.1 |
| 25 | 7.5 | 6.6 | 6.2 | 6 |
| 30 | 8.5 | 7.4 | 7 | 6.8 |
| 35 | 9.5 | 8.2 | 7.8 | 7.5 |
| 40 | 10.6 | 9.1 | 8.7 | 8.4 |
| 45 | 11.8 | 10 | 9.5 | 9.1 |

| t(min) | I1(cm) | I2(cm) | I3(cm) | I4(cm) |
|---|---|---|---|---|
| 50 | 13 | 11 | 10.4 | 10 |
| 55 | 14.2 | 11.9 | 11.2 | 10.7 |
| 60 | 15.3 | 12.8 | 12 | 11.5 |
| 70 | 17.3 | 14.2 | 13.3 | 12.7 |
| 80 | 19.1 | 15.4 | 14.4 | 13.7 |
| 90 | 20.9 | 16.5 | 15.3 | 14.7 |
| 100 | 22.7 | 17.6 | 16.3 | 15.6 |
| 110 | 24.5 | 18.6 | 17.3 | 16.6 |
| 120 | 26.3 | 19.6 | 18.3 | 17.6 |

Advance-Recession Tests: Furrow irrigation experiments were conducted to measure advance time, recession time, run-on hydrograph, run-off hydrograph, and infiltration opportunity parameters. Table 3 provides the measured values of run-on and run-off flows.

Table 3. values of the run-on flow and out of furrow

| time(min) | Run out (m3/min) | Run in (m3/min) |
|---|---|---|
| 0 | 12 | 0 |
| 20 | 12 | 0 |
| 40 | 12 | 0 |
| 60 | 12 | 0 |
| 80 | 12 | 0 |
| 100 | 12 | 0 |
| 120 | 12 | 0.01 |
| 140 | 12 | 24 |
| 160 | 12 | 37 |
| 180 | 12 | 49 |
| 200 | 12 | 6 |
| 220 | 12 | 71 |
| 240 | 12 | 8 |
| 260 | 12 | 88 |
| 280 | 12 | 88 |
| 290 | 12 | 88 |
| 295 | 0 | 55 |
| 300 | 0 | 3 |
| 304 | 0 | 0 |

Table 4. Advance and Recession Time of Water at Different Time Steps

| Distance (m) | Advanced time (min) | Recession time (min) |
|---|---|---|
| 0 | 0 | 290* |
| 10 | 5 | 293 |
| 20 | 11 | 296 |
| 30 | 18 | 298 |
| 40 | 26 | 300 |
| 50 | 36 | 301 |
| 60 | 48 | 302 |
| 70 | 52 | 302 |
| 80 | 67 | 303 |
| 90 | 87 | 303 |
| 100 | 112 | 304 |

* Water cut off time

Table 5. Properties of the Tested Furrow

| Parameter | Unit | value |
|---|---|---|
| Furrow length | (m) | 100 |
| Furrow's distance | (m) | 0.75 |
| Manning roughness coefficient | - | 0.04 |
| slope of Faro | (m/m) | 0.006 |

Table 6. Advance and Recession Times in a Furrow

| Furrow length | Advance time | Recession time | Recession after Cutoff |
|---|---|---|---|
| X<br>(m) | Ta<br>(min) | Tr<br>(min) | $\acute{T}_{rn}$<br>(min) |
| 0 | 0 | 290 | 0 |
| 10 | 5 | 293 | 3 |
| 20 | 11 | 296 | 6 |
| 30 | 18 | 298 | 8 |
| 40 | 26 | 300 | 10 |
| 50 | 36 | 301 | 11 |
| 60 | 48 | 302 | 12 |
| 70 | 52 | 302 | 12 |
| 80 | 67 | 303 | 13 |
| 90 | 87 | 303 | 13 |
| 100 | 112 | 304 | 14 |

By combining these laboratory and field experiments, a comprehensive dataset was obtained to support the development and validation of the computer program for furrow irrigation design.

# 5 Software Introduction

This Python-based software is specifically designed for furrow irrigation systems. It primarily focuses on two key aspects:

1. **Real-time Efficiency Assessment**

The software receives essential parameters like furrow width, net infiltration rate, Manning's roughness coefficient, land slope, and input flow. By analyzing these parameters the software calculates the current irrigation efficiency of the farm.

2. **Optimal Furrow Length Determination**

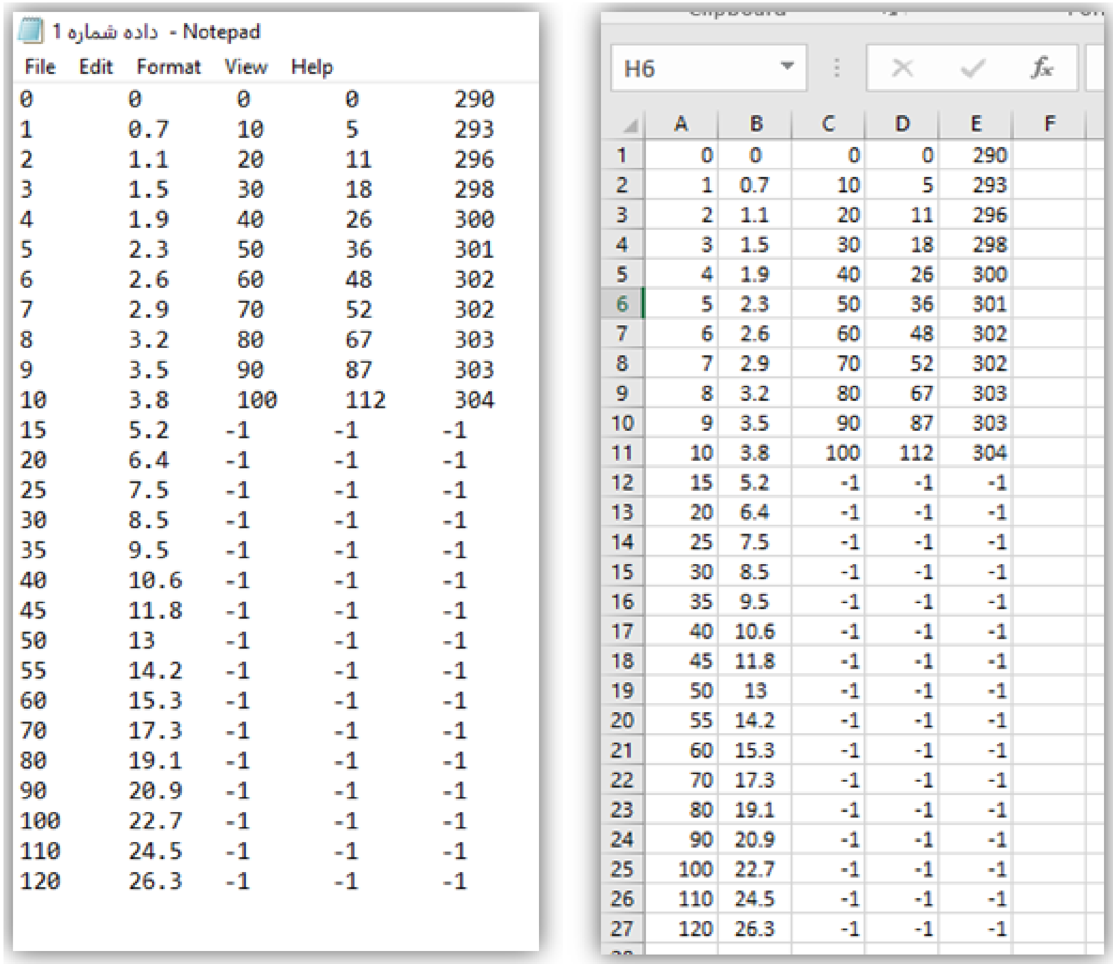
Leveraging this data and the chosen infiltration equation, the software calculates the optimal furrow length that maximizes water use efficiency and minimizes losses.

## 5.1 Software feed data

This software acquires necessary data through two methods. Firstly, data can be directly inputted into the software's line edit fields. Secondly, data must be prepared beforehand in an Excel or TXT file and then imported into the software. Table 7 presents a list of the software's required data. Additionally, Figure 2 provides a visual representation of data entered in Excel and TXT files.

Table 7. List of the software's required data

| **Required data** | **Unit** |
|---|---|
| Width of furrow | (m) |
| Net infiltration | (cm) |
| Manning roughness coefficient | - |
| Land slope | (m/m) |
| Input flow | ($m^3$/min) |
| Infiltration time | (min) |
| Length of furrow | (m) |
| Advance time | (min) |
| Recession time | (min) |
| Cumulative infiltration | (cm) |



داده شماره 1 - Notepad

File Edit Format View Help

| | | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 290 |
| 1 | 0.7 | 10 | 5 | 293 |
| 2 | 1.1 | 20 | 11 | 296 |
| 3 | 1.5 | 30 | 18 | 298 |
| 4 | 1.9 | 40 | 26 | 300 |
| 5 | 2.3 | 50 | 36 | 301 |
| 6 | 2.6 | 60 | 48 | 302 |
| 7 | 2.9 | 70 | 52 | 302 |
| 8 | 3.2 | 80 | 67 | 303 |
| 9 | 3.5 | 90 | 87 | 303 |
| 10 | 3.8 | 100 | 112 | 304 |
| 15 | 5.2 | -1 | -1 | -1 |
| 20 | 6.4 | -1 | -1 | -1 |
| 25 | 7.5 | -1 | -1 | -1 |
| 30 | 8.5 | -1 | -1 | -1 |
| 35 | 9.5 | -1 | -1 | -1 |
| 40 | 10.6 | -1 | -1 | -1 |
| 45 | 11.8 | -1 | -1 | -1 |
| 50 | 13 | -1 | -1 | -1 |
| 55 | 14.2 | -1 | -1 | -1 |
| 60 | 15.3 | -1 | -1 | -1 |
| 70 | 17.3 | -1 | -1 | -1 |
| 80 | 19.1 | -1 | -1 | -1 |
| 90 | 20.9 | -1 | -1 | -1 |
| 100 | 22.7 | -1 | -1 | -1 |
| 110 | 24.5 | -1 | -1 | -1 |
| 120 | 26.3 | -1 | -1 | -1 |

H6

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 290 | |
| 2 | 1 | 0.7 | 10 | 5 | 293 | |
| 3 | 2 | 1.1 | 20 | 11 | 296 | |
| 4 | 3 | 1.5 | 30 | 18 | 298 | |
| 5 | 4 | 1.9 | 40 | 26 | 300 | |
| 6 | 5 | 2.3 | 50 | 36 | 301 | |
| 7 | 6 | 2.6 | 60 | 48 | 302 | |
| 8 | 7 | 2.9 | 70 | 52 | 302 | |
| 9 | 8 | 3.2 | 80 | 67 | 303 | |
| 10 | 9 | 3.5 | 90 | 87 | 303 | |
| 11 | 10 | 3.8 | 100 | 112 | 304 | |
| 12 | 15 | 5.2 | -1 | -1 | -1 | |
| 13 | 20 | 6.4 | -1 | -1 | -1 | |
| 14 | 25 | 7.5 | -1 | -1 | -1 | |
| 15 | 30 | 8.5 | -1 | -1 | -1 | |
| 16 | 35 | 9.5 | -1 | -1 | -1 | |
| 17 | 40 | 10.6 | -1 | -1 | -1 | |
| 18 | 45 | 11.8 | -1 | -1 | -1 | |
| 19 | 50 | 13 | -1 | -1 | -1 | |
| 20 | 55 | 14.2 | -1 | -1 | -1 | |
| 21 | 60 | 15.3 | -1 | -1 | -1 | |
| 22 | 70 | 17.3 | -1 | -1 | -1 | |
| 23 | 80 | 19.1 | -1 | -1 | -1 | |
| 24 | 90 | 20.9 | -1 | -1 | -1 | |
| 25 | 100 | 22.7 | -1 | -1 | -1 | |
| 26 | 110 | 24.5 | -1 | -1 | -1 | |
| 27 | 120 | 26.3 | -1 | -1 | -1 | |

Figure 6. Data Preparation in Text and Excel Files - To equalize the number of rows in different columns the number -1 is inserted

## 5.2 Software Output

The software provides a variety of outputs, each offering valuable information(Table8). It calculates and displays the coefficients of infiltration equations, including parameters such as a, s, A, f, as well as the parameters of Walker's method (p, r, p′, r′). Additionally, it provides information such as the wetted perimeter (P), relative error (RE), and root mean square error (RMSE). The software also offers data related to the current condition of the farm, including parameters such as net water volume (Vn), deep percolation volume (Vdp), inlet water volume (Vin), runoff volume (Vr), water distribution uniformity coefficient (CU), application efficiency (AE), tail water ratio (TWR), deep percolation ratio (DPR), and the furrow length-infiltration diagram. Furthermore, the software provides optimization results for farm conditions, which include the same parameters mentioned above, along with diagrams for the water distribution uniformity coefficient, application efficiency, tail water ratio, and deep percolation ratio. Finally, the software presents detailed information per unit length of furrow, including similar parameters to those above, for more precise analysis.

Table8. Software Output

| **Parameter** | **Unit** | **Description** |
|---|---|---|
| a, s, A, f | - | Coefficients of infiltration equations |
| p, r, p′, r′ | - | Parameters of Walker's method |
| P | Meters | Wetted perimeter |
| RE | Percentage | Relative error |
| RMSE | - | Root mean square error |
| Vn | Cubic meters | Net water volume |
| Vdp | Cubic meters | Deep percolation volume |
| Vin | Cubic meters | Inlet water volume |
| Vr | Cubic meters | Runoff volume |
| CU | Percentage | Water distribution uniformity coefficient |
| AE | Percentage | Application efficiency |
| TWR | Percentage | Tail water ratio |
| DPR | Percentage | Deep percolation ratio |

# 6 Processing an Example

To better illustrate the functionality of the software, data collected from the Babalan farm is used as an example. By inputting this data into the software, the corresponding results are generated and analyzed.

## 6.1 Data Preparation

The data used in this example is provided in Tables 2 (specifically from the first iteration, labeled as I1), 3, 4, and 5.

## 6.2 Data File Preparation

The software supports importing data through either text files or Excel files. To ensure proper functionality, the following parameters should be prepared in the specified order (Figure 6):

- Infiltration time (t)
- Cumulative infiltration (I)
- Length of furrow (x)
- Advance time (Ta)
- Recession time (Tr)

## 6.3 Data Input

The preliminary input parameters required for the software include the following (Figure 7):

- W: Width of furrow (m)
- I: Net infiltration (cm)
- n: Manning roughness coefficient
- S: Land slope (m/m)
- Q: Input flow ($m^3$/min)

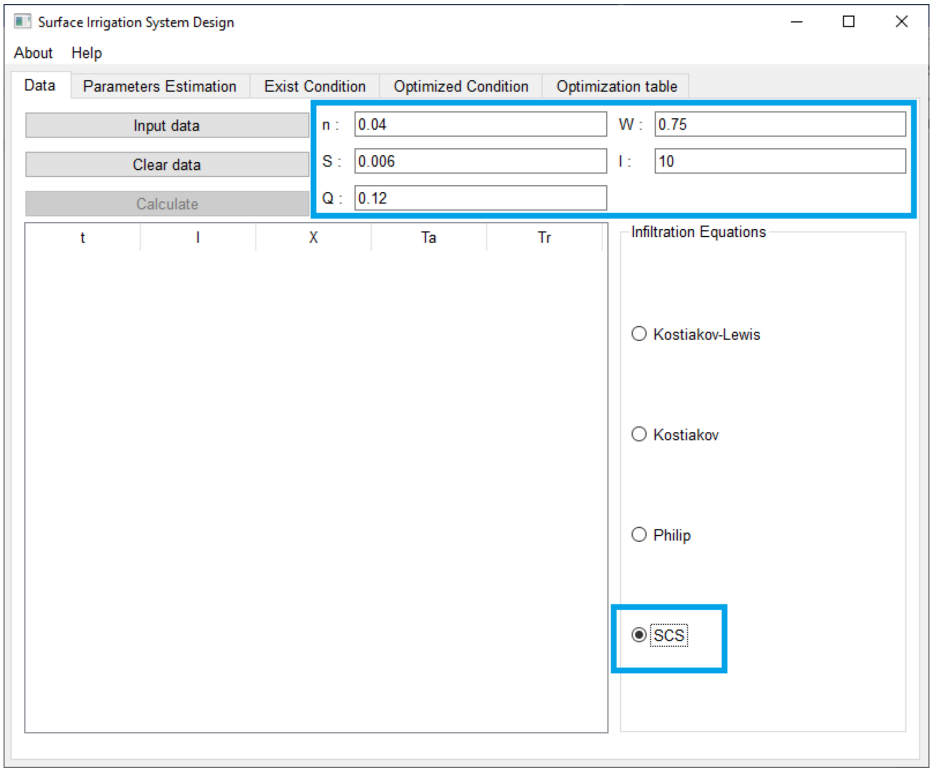



Figure 7: Input of preliminary data

Clicking on the "Input Data" button allows users to import the data file into the program. Once imported, the data is displayed in the program's table for review (Figure 8).

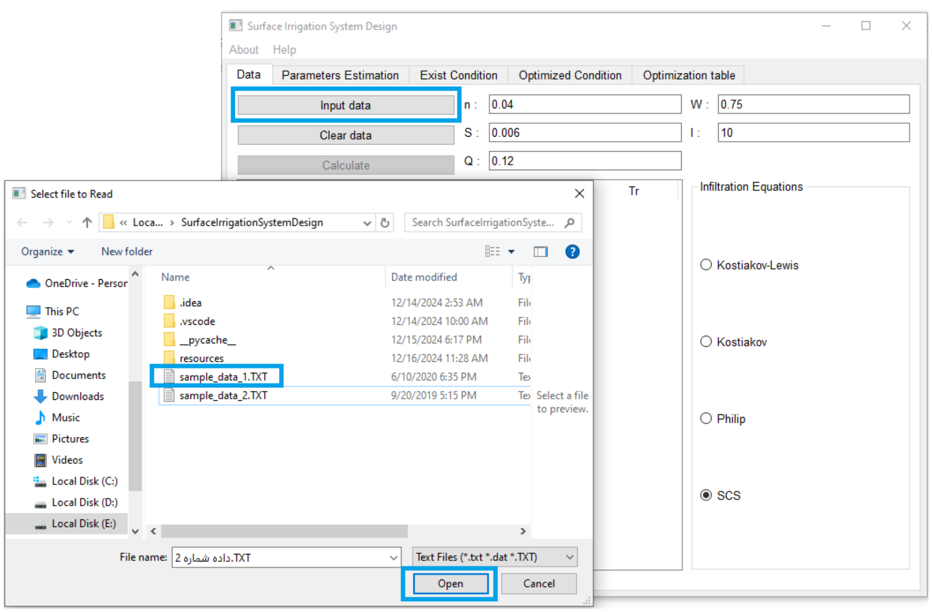



Figure 8: Input of Excel or Text data

## 6.4 Software Output

By clicking the "Calculate" button, the software begins processing the input data. The results are displayed in various formats, as shown in Figures 9, 10, 11, and 12.

In Figure 9, only the coefficients of the SCS equation have assigned values. This is because the SCS equation was selected as the infiltration model during the setup phase.

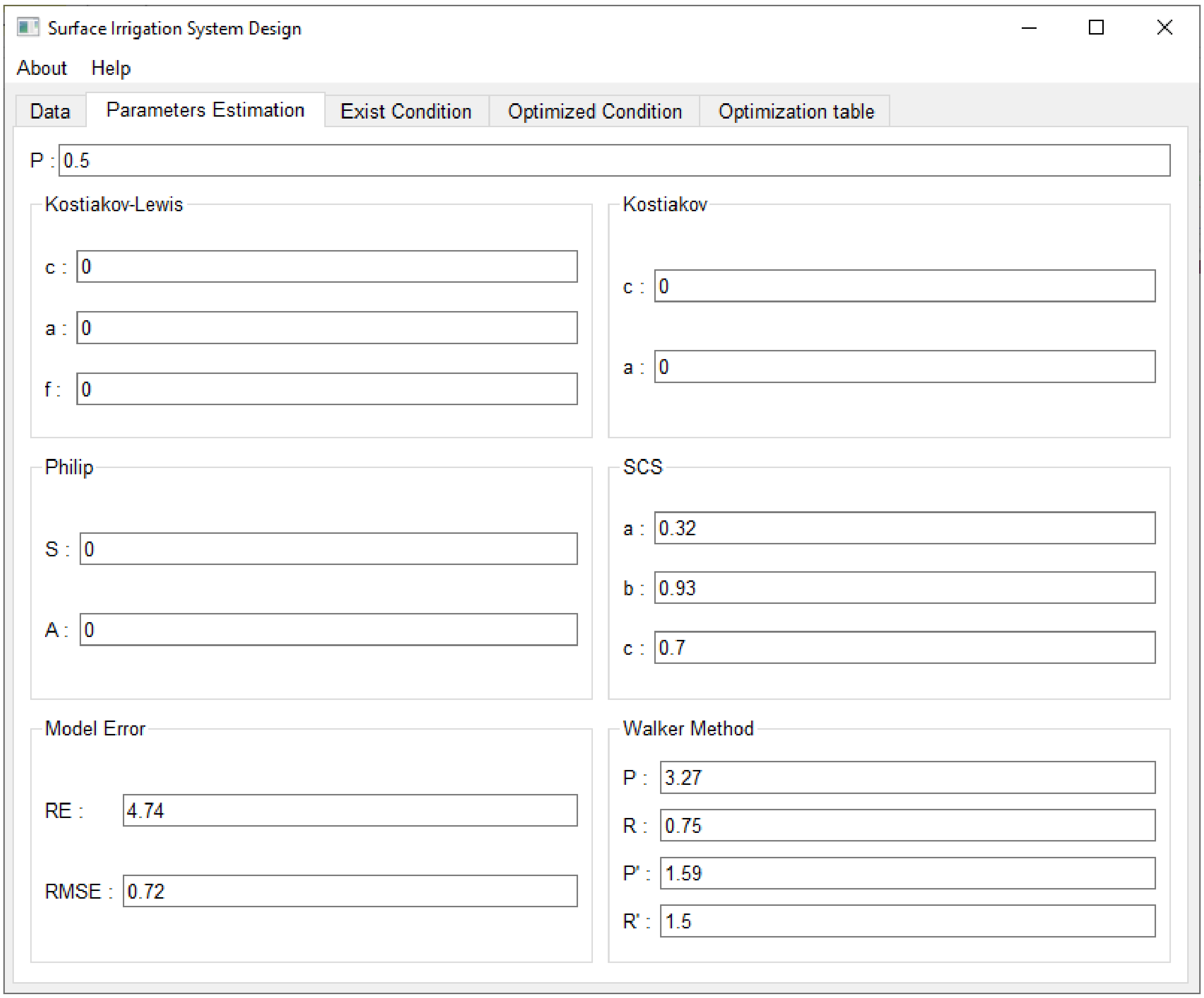



Figure 9: Parameters estimation

The evaluation of the infiltration equation is presented on the third sheet of the software. A sentence model is displayed to help users assess the infiltration equation by analyzing the values of its coefficients. Depending on the accuracy of the data extraction, different sentences may appear for the user (Figure 10).

Additionally, the third sheet contains a chart illustrating the relationship between infiltration and furrow length. The blue curve represents the amount of water infiltrated into the soil, while the red line indicates the net infiltration required by the plants (Figure 10).

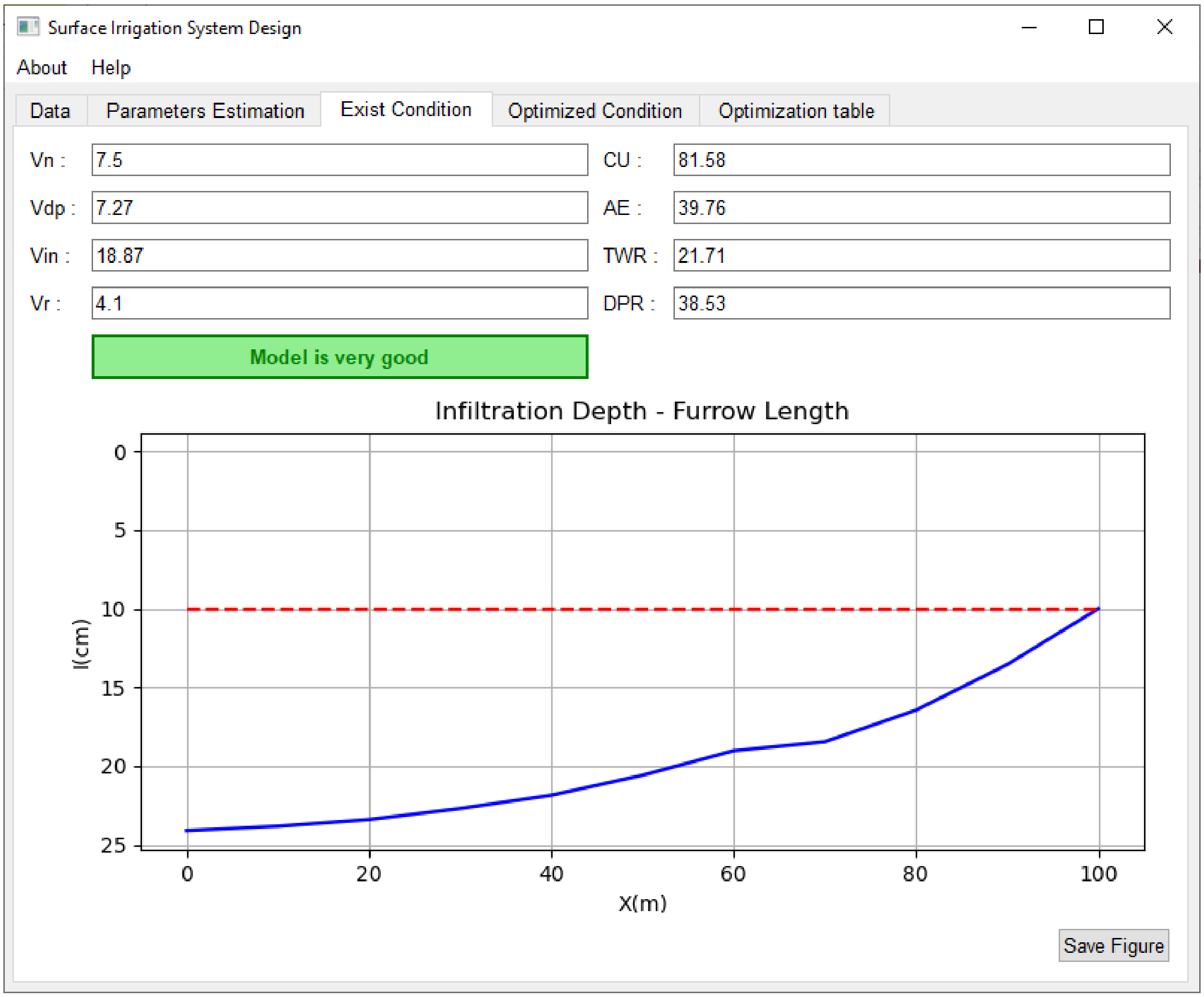



Figure 10: Exist condition

The fourth sheet displays the optimal length of the furrow and other irrigation system parameters under optimal conditions, along with their corresponding diagrams. In this example, the optimal furrow length is 148 meters, and the application efficiency is 46.8% (Figure 11).

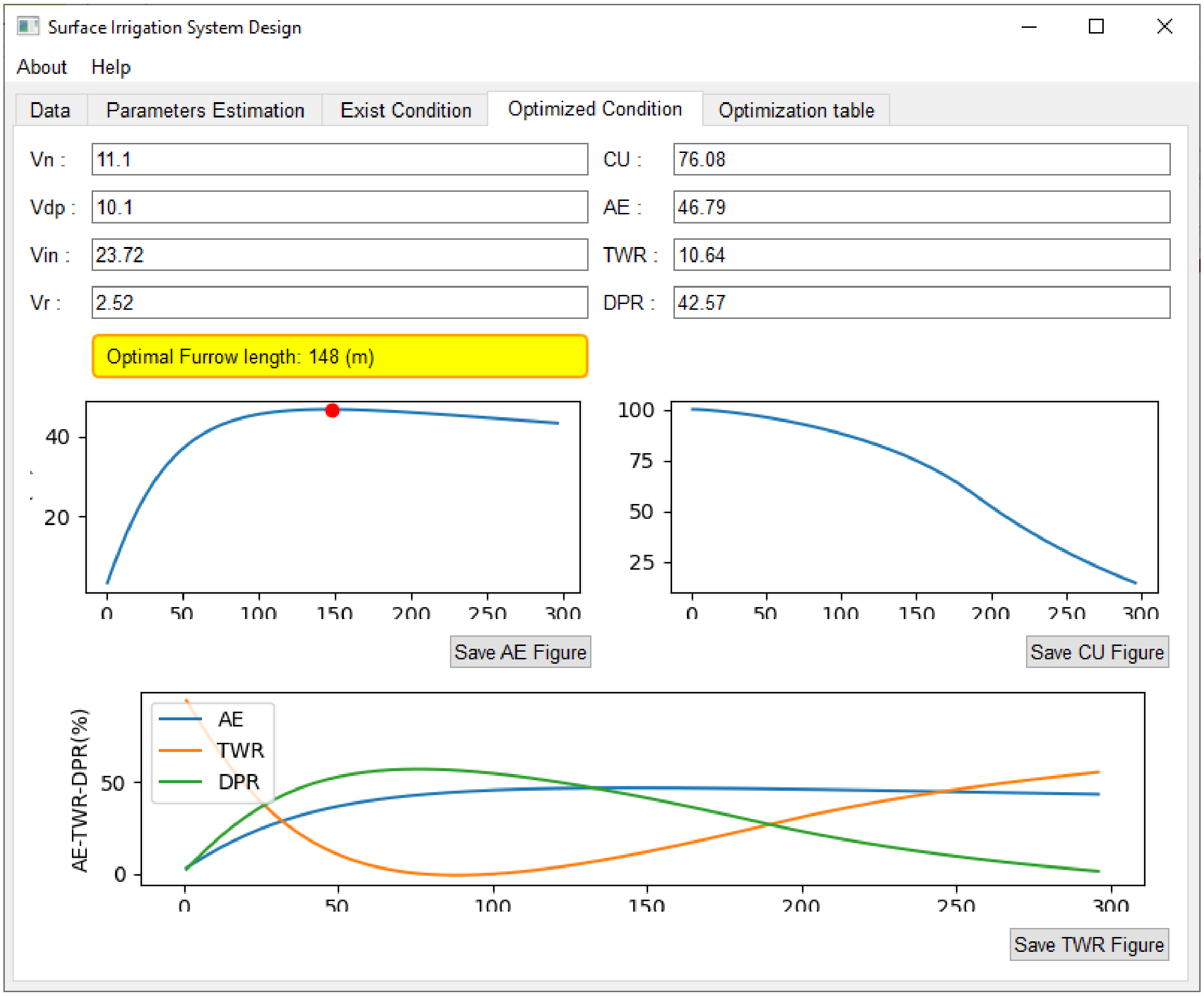
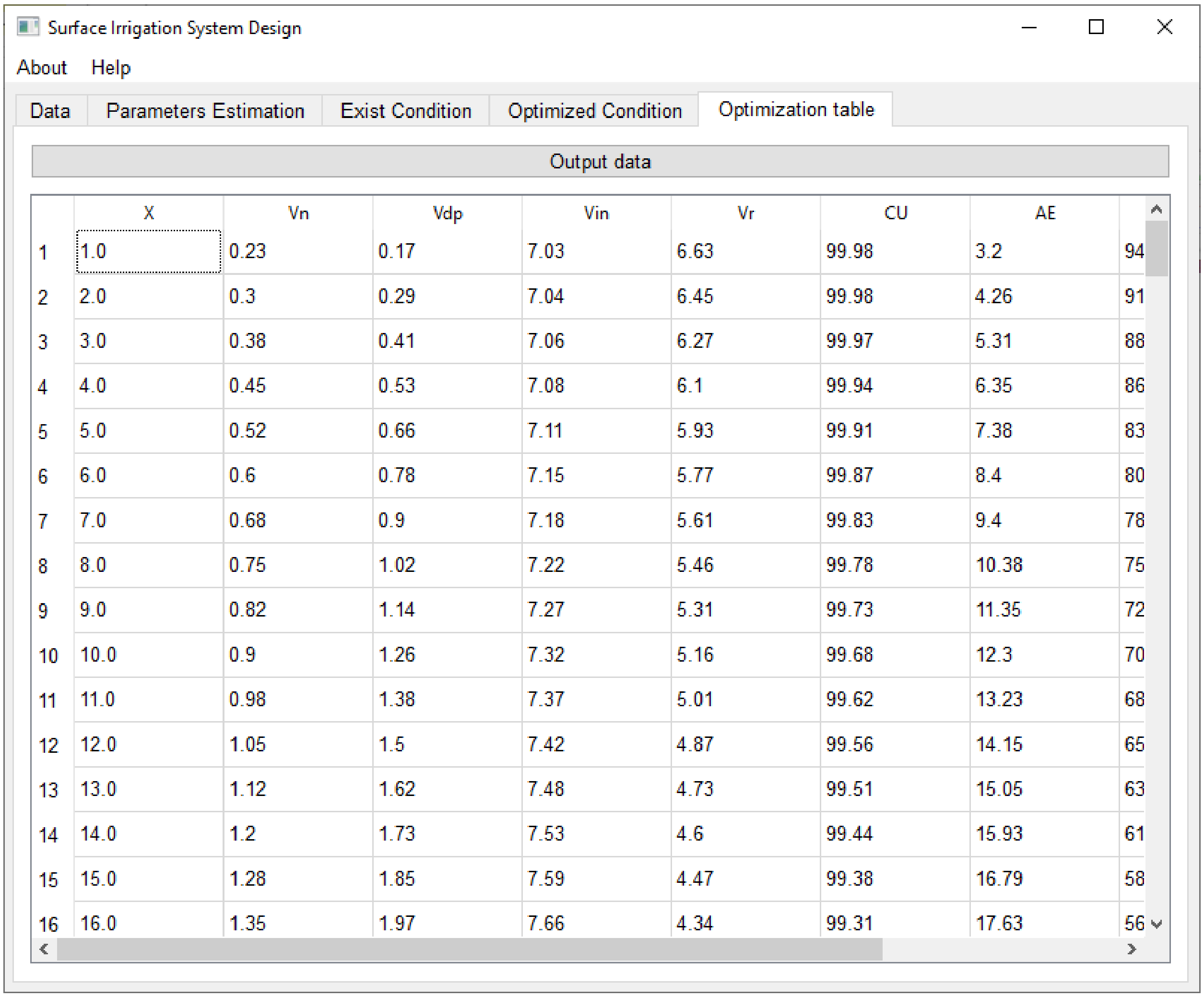



Figure 11: Optimized condition

The fifth sheet includes a table displaying various system parameters for different furrow lengths. This table is useful for verifying the accuracy of the calculated optimal furrow length. Additionally, the fifth sheet features an "Output Data" button that allows users to export the data from the table in CSV format for further analysis (Figure 12).




| | X | Vn | Vdp | Vin | Vr | CU | AE | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 0.23 | 0.17 | 7.03 | 6.63 | 99.98 | 3.2 | 94 |
| 2 | 2.0 | 0.3 | 0.29 | 7.04 | 6.45 | 99.98 | 4.26 | 91 |
| 3 | 3.0 | 0.38 | 0.41 | 7.06 | 6.27 | 99.97 | 5.31 | 88 |
| 4 | 4.0 | 0.45 | 0.53 | 7.08 | 6.1 | 99.94 | 6.35 | 86 |
| 5 | 5.0 | 0.52 | 0.66 | 7.11 | 5.93 | 99.91 | 7.38 | 83 |
| 6 | 6.0 | 0.6 | 0.78 | 7.15 | 5.77 | 99.87 | 8.4 | 80 |
| 7 | 7.0 | 0.68 | 0.9 | 7.18 | 5.61 | 99.83 | 9.4 | 78 |
| 8 | 8.0 | 0.75 | 1.02 | 7.22 | 5.46 | 99.78 | 10.38 | 75 |
| 9 | 9.0 | 0.82 | 1.14 | 7.27 | 5.31 | 99.73 | 11.35 | 72 |
| 10 | 10.0 | 0.9 | 1.26 | 7.32 | 5.16 | 99.68 | 12.3 | 70 |
| 11 | 11.0 | 0.98 | 1.38 | 7.37 | 5.01 | 99.62 | 13.23 | 68 |
| 12 | 12.0 | 1.05 | 1.5 | 7.42 | 4.87 | 99.56 | 14.15 | 65 |
| 13 | 13.0 | 1.12 | 1.62 | 7.48 | 4.73 | 99.51 | 15.05 | 63 |
| 14 | 14.0 | 1.2 | 1.73 | 7.53 | 4.6 | 99.44 | 15.93 | 61 |
| 15 | 15.0 | 1.28 | 1.85 | 7.59 | 4.47 | 99.38 | 16.79 | 58 |
| 16 | 16.0 | 1.35 | 1.97 | 7.66 | 4.34 | 99.31 | 17.63 | 56 |

Figure 12: Optimization Table