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Development of a computer aided decision support system for the design of drip irrigation laterals

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ABSTRACT

Drip Design Check (DDC) is a powerful software solution designed to assist irrigation system designers in evaluating the effectiveness of their drip irrigation designs for non-uniform slope conditions. The software makes use of recent developments in drip design methods as well as the advancements in software development methodologies for simulating and optimizing the design of laterals. The software features an easy-to-use interface that allows users to input key design parameters, including slope details, discharge rate of drippers, length of lateral, spacing between drippers and pressure head at the inlet of lateral. The software calculates relative pressure head variation (v_h) and pressure head values at each outlet. The software evaluates the goodness of the design based on the allowable relative pressure head variation. Simulation of lateral also considers dripper connection losses. Variations in lateral and dripper configurations are handled by the software in line with the intuition of the user's perceptions. Hence, data input is simple and easy. The software can be used to analyse numerous design alternatives and to identify the most appropriate design. DDC has undergone several tests using different typical sample data and hence its accuracy and reliability are more. Demonstrations were conducted for designers to assess the user friendliness of the drip simulation software, and we received favourable feedback from them. In summary, Drip Design Check is a useful and reliable tool for the irrigation industry to check the goodness of lateral design.

KEYWORDS: Drip irrigation, Frictional loss, Python, Relative pressure head variation, Simulation

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INTRODUCTION

Drip irrigation is an effective method of delivering water to crops, particularly in areas where water is scarce or expensive. This is a highly efficient and precise method of delivering water to crops, providing significant benefits over traditional irrigation techniques (Battikhi & Abu-Hammad, 1994; FAO, 2011; Attia *et al.*, 2019; Nikolaou *et al.*, 2020). This method can save up to 60% of water compared to traditional irrigation methods and increase crop yields by up to 50% (World Bank, 2006; Kooij *et al.*, 2013; Sidhu *et al.*, 2021).

Drip irrigation pipe designs are characterized by the hydraulic analysis of multiple-outflow pipes. The design of lateral pipes plays a critical role in the efficient operation of drip irrigation systems. A well-designed pipe network can ensure efficient water delivery to the crops, minimizing water wastage and preventing under or over-irrigation, which can result in lower crop yields. Therefore, careful consideration and attention to detail in

pipeline design are crucial to the success of the operation of a drip irrigation system (Keller, 1990; Khan *et al.*, 2006; Wang & Chen, 2019; Ame & Shouhua, 2022).

A simulation is a powerful option that can be used for evaluating the safety and performance of a drip irrigation system (Mirza, 2018; Attia *et al.*, 2019). Simulations can also be used to optimize the layout of the tubing and emitter placement to ensure efficient and uniform water distribution by a trial-and-error process.

In drip irrigation systems, the pressure of water is an important factor that affects the performance of the system. If the pressure head varies significantly along the pipeline, it can lead to uneven water distribution, resulting in under or over-irrigation of crops (Christiansen, 1942; Keller & Karmeli, 1974). To assess the pressure head variation in drip irrigation systems, one common approach is to calculate the pressure head at each outlet of the drip laterals. The pressure head at each outlet takes into

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account frictional head losses and head loss/gain due to elevation (Wu & Gitlin, 1974; Wu *et al.*, 1983; Wu & Barragan, 2000; Ravikumar, 2022a).

The pressure head available at the multi-outlet of each lateral can be calculated by solving analytical equations, but this can be a laborious and time-consuming process as it involves a large number of calculations. Using software can significantly reduce the time required and minimize manual errors in calculations (Narayanan *et al.*, 2002; Pedras *et al.*, 2009; Patel *et al.*, 2018; Palau *et al.*, 2020; Sharu & Ab Razak, 2020). Simulation software developed in this work simulates flow through lateral and relative pressure head variation is estimated for lateral. Satisfactory design of the lateral is done by a trial-and-error process.

Programming languages are powerful tools for software development, with different languages offering unique advantages and disadvantages. Since Python programming is a more popular and has a rich ecosystem of built-in libraries for data analysis and visualization (Johansson, 2019), developing software programs is much easier and hence Python is used in the present work.

MATERIALS AND METHODS

In this section, the methodology for simulating pressure head variation along the lateral is discussed in detail. In addition, details regarding finding the dripper discharge rate and emitter connection loss are also provided.

Simulation of Pressure Head Distribution Along the Lateral

The design procedures presented by Ravikumar (2022a, b) were used in this study. When a lateral is placed on an upslope, friction and elevation loss along the pipe length cause a continuous decrease in pressure head, as depicted in Figure 1. Conversely, when a lateral is installed on a downslope, the pressure head at each location is determined by the elevation gain and friction loss, as illustrated in Figure 2.

The Darcy-Weisbach equation (Equation 1) is generally recommended for drip irrigation systems to determine friction loss through the laterals as their pipe diameters are typically less than 125 mm (Keller, 1990; Ravikumar, 2022a).

$$\Delta h_f = 789000 \times \frac{Q^{1.75}}{D^{4.75}} \times L \quad [1]$$

Where Δh_f is the total frictional head loss (m), Q is the discharge rate through the lateral (l/s), D is the diameter of the lateral (mm), and L is the total length of the lateral (m).

In order to find out the friction loss in any dripper locations, l measured from the lateral inlet (Δh_f), Equation 2 is used (Ravikumar, 2022a).

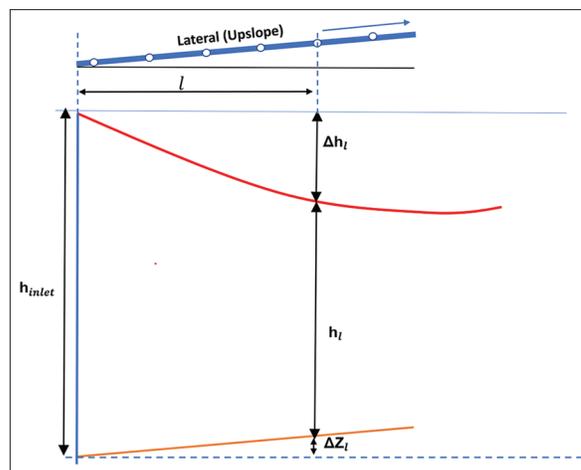


Figure 1: Pressure head distribution along Lateral installed on Upslope

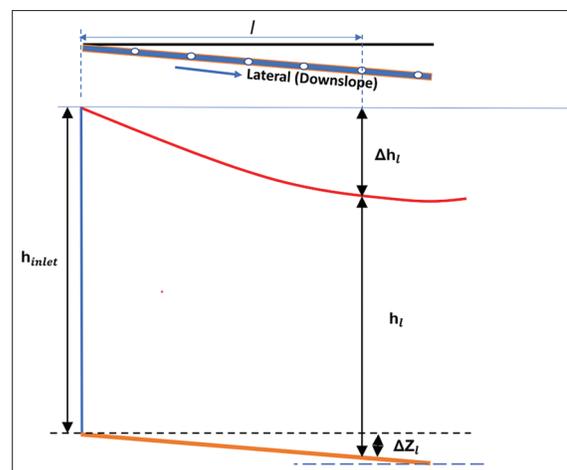


Figure 2: Pressure head distribution along Lateral installed on downslope

$$\Delta h_f = \frac{789000}{2.75 \times D^{4.75} \times \left(\frac{q}{s}\right)} \left(Q^{2.75} - \left(Q - \frac{ql}{s} \right)^{2.75} \right) \quad [2]$$

Where

Q : Discharge rate through the laterals, l/s

q : Dripper discharge rate, l/s

s : spacing between drippers, m

D : Diameter of the lateral, mm

l : length from lateral inlet, m

When a lateral is laid on any slope situation, the resultant pressure head is obtained as Equation 3.

$$h_l = h_{start} - \Delta h_f + p\Delta Z_l \quad [3]$$

Where

h_l : pressure head at any length l (m)

h_{start} : pressure head at the lateral inlet (m)

Δh_f : Total friction loss till length l (m)

ΔZ_l : Elevation difference at l with reference to inlet (m)

p : 1 for downslope and -1 for upslope

For the simulation of the lateral, dripper configuration along the lateral also needs to be considered. This configuration will vary depending on the type of crop being irrigated. For field crops, drippers are typically placed at regular intervals along the lateral, corresponding to the maximum wetted diameter, regardless of the crop spacing. In contrast, for tree crops, drippers are placed based on plant spacing, with more than one dripper installed per tree in some cases (Figures 3 & 4).

For cases where drippers are placed independent of crop spacing, Equation 2 can be used as such to plot the friction loss curves, where q will be substituted as the discharge rate of emitters, and s is the spacing between the drippers. For the case in Figure 3, the q/s term in Equation 2 is to be substituted as follows (Equation 4):

$$\frac{q}{s} = \frac{\sum_{i=1}^{i=N_p} q_i}{s_p} \quad [4]$$

N_p : number of drippers per tree; s_p : plant spacing (m).

Relative pressure head variation (v_h) is used in this study as an indicator to gauge the goodness of the design of drip irrigation laterals due to its simplicity and robustness (Zhang et al., 2013; Ravikumar, 2022c). The v_h can be defined as the ratio of maximum pressure variation (Δh) to the average of pressure head at each outlet position along the lateral. To calculate pressure head variation (Δh), it is necessary to consider the maximum pressure head (h_{max}) and minimum pressure head (h_{min}) values among all the outlets of laterals. The difference between these two values will give the value of Δh . Once the

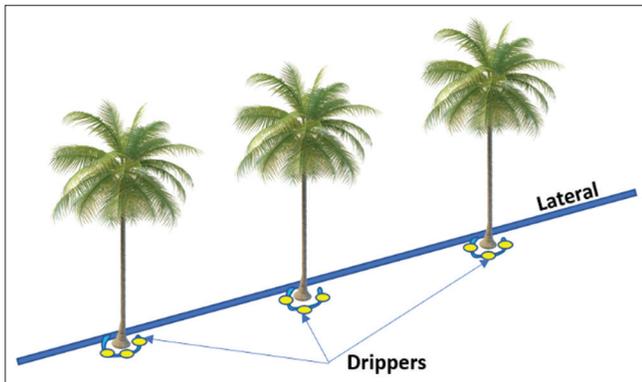


Figure 3: Drippers positioned relative to plant spacing

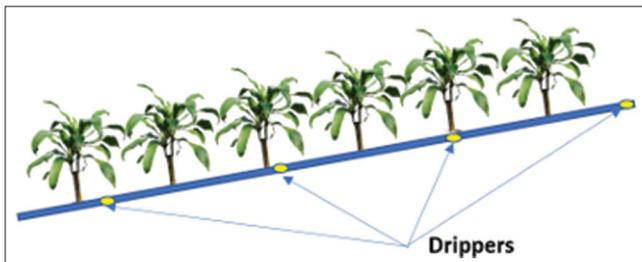


Figure 4: Drippers positioned independent of crop spacing

values of Δh and the average pressure head (h_a) have been obtained, the relative pressure head variation can be calculated using Equation 5.

$$v_h = \frac{\Delta h}{h_a} \quad [5]$$

To ensure that a design is safe, it is essential to keep the relative pressure head variation within a certain allowable limit (v_h^a). The design is considered unsafe if the relative pressure head variation exceeds the allowable limit.

Dripper Discharge Rate (q)

Normally, drippers are designated with discharge rates (q , l/h), such as 2, 6, etc., which are associated with a particular pressure head, such as 10 meters (Ravikumar, 2022d). However, the specified discharge rate for a dripper varies depending on the pressure at the dripper inlet. Therefore, it is essential to consider the pressure head at the inlet when choosing the appropriate dripper for a given application.

To determine q (l/h) at available or designed pressure head (h , m), Equation 6 can be adopted.

$$q = kh^x \quad [6]$$

Where k is the discharge coefficient and x is the dripper flow exponent. One can obtain the values of k and x by referring to the h versus q chart provided by the manufacturers or by conducting field experiments (Ravikumar, 2022d).

Dripper Connection Losses

Protrusions and the subsequent turbulence that result from dripper connections can create additional head losses. To account for this, it is common practice to quantify the head loss caused by dripper connections as an equivalent length of lateral (Keller & Bliesner, 1990; Ravikumar, 2022a). The equivalent length (f_c , in meters) for one dripper connection loss can be determined using the widely used empirical relationship given in Equation 7:

$$f_c = 3.5 \times b \times D^{-1.86} \quad [7]$$

Where b represents the barb size (mm) (Keller, 1990; Ravikumar, 2022a) and D is the lateral diameter (mm). For a lateral with N_p emitters per tree, the total emitter connection losses at each outlet can be calculated as $N_p \times f_c$. The typical range of f_c values for inline drippers is between 0.05 to 0.40 m, with an average value of 0.20 m being frequently used (Ravikumar, 2022a). To account for the dripper connection losses, the obtained losses should be subtracted from the pressure head values at each location.

Development of a Computer Aided Software:

Based on the above-said procedure, a computer-based stand-alone software, “Drip Design Check (DDC)” is developed for

simulating the design and evaluating the design safety, especially for lateral laid on the fields with any kind of slope situations. The software is developed in the Python environment using Python and PyQt Designer.

The development process is initiated by writing Python code and using PyQt Designer to design the graphical user interface. Additional Python libraries are incorporated to automate the drip simulation procedure using Python. For instance, the NumPy library is used for numerical analysis. The values corresponding to the position of drippers, ordinates of friction loss curve, ordinates of elevation curve, slope, diameter, and pressure head, are arranged and stored as lists in Python for easy access and manipulation. These values are also stored as a dictionary, allowing quick access to data corresponding to each position by key-value pairs.

To enhance the software's user interface, a table widget in PyQt Designer is used to display tabular representations of the data. The Matplotlib library was used to visualize pressure head variations in a user-friendly and intuitive way. A Python package called Auto-py-to-exe is used to convert the Python scripts into a stand-alone executable file. Finally, the software is tested with different test cases to ensure that the software is working as intended before deployment to end-users. The technical steps involved in the development of DDC are summarized as shown in Figure 5.

Testing the application: The application, DDC, has been tested for all types of slopes, emitter configurations, and other relevant variables to verify its functionality. A comprehensive dataset is created, which contains all possible test cases, including input

validation. The software is then executed for each test case and the results are recorded. Finally, a live demonstration is conducted for the designers and their feedback is collected.

RESULTS

As previously mentioned, the 'Drip Design Check' software has been developed with an intuitive and user-friendly interface. The subsequent sections detail the features of the application.

Overview of Drip Design Check

The user interface of the developed drip simulation software was designed to provide an easy and intuitive experience for users to input the required data and obtain accurate results. The interface consists of different text boxes for inputting the various parameters required for the simulation. Users can input data by typing the values or using dropdown menus, depending on the data required. However, users must only enter the data in the specified units.

The interface provides real-time feedback to the user, displaying the results of each input parameter as they are entered. This feedback enables the user to quickly identify any potential errors or inconsistencies in their data and make the necessary adjustments. Once all the required parameters have been entered, the software will provide the value of pressure head variation, relative pressure head variation, and safety notes. The window of DDC for lateral simulation is shown in Figure 6.

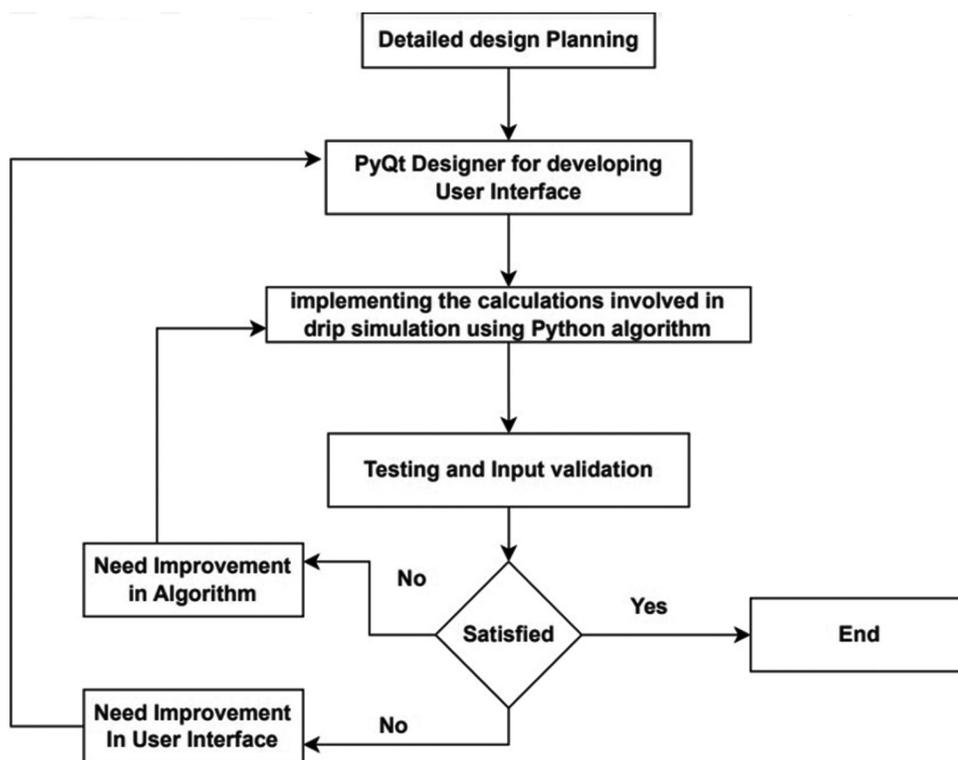


Figure 5: Technical flow chart of DDC

Figure 6: User interface of the DDC for lateral simulation

Drip Design Check Window for Lateral Simulation

User interface and functionality: To begin, the user must first select the emitter placement details, such as whether emitters are placed with respect to crops (for tree crops) or independent of crops (vegetable crops or inline emitters). Next, the user needs to enter the length of the field up to which the lateral has to be laid. Once the lateral length is entered, the user can click on the “add details” button corresponding to the lateral diameter data. The user must then enter the number of diameter segments, diameter values, and the length up to which each diameter segment is intended to be laid. After entering the details of each segment, the user needs to add the details to the table using the “add” option. If any errors are encountered, there is an option to remove any added details (Figures 7 & 8).

To add slope details, the user must click on the “add details” option corresponding to the slope details in the window. Clicking on this option will display a dialog box (Figures 7 & 8). The user must enter the number of slope segments, which will determine whether the field topography is uniform or not. Next, the user can enter the details for each segment, including the slope percentage, slope type (upslope, downslope, or horizontal), and the length of each segment. The total length of each segment should be equal to the length of the lateral entered. If the total length is not equal, an alert message will appear, prompting the user to enter data for the entire length of the lateral. Furthermore, the user is required to input the value of allowable relative pressure head variation into the respective text box.

Emitter Details: Once the add details button against the emitter details option is clicked, two different types of dialog boxes will pop up depending on whether emitters are placed with respect to plants or not. If emitters are placed with respect to the plant, the dialog box, as shown in Figure 9, will pop up where the user must enter the details regarding the barb size of the dripper,

plant spacing (m), number of drippers per plant and the k and x values of each dripper.

The application is designed to estimate the discharge rate of drippers at the designed pressure head. To do so, users can click the calculate discharge rate button. A set of different head versus discharge rate values is required to calculate discharge rate values if the designers do not know the x and k values. In situations with tree crops, many drippers with the same/different discharge rates and flow exponent values for each tree, can also be accounted. Figure 9 shows the dialog boxes developed to calculate the dripper discharge rate at the designed pressure head for the emitter placed with respect to the plants.

For the emitters placed independent of crop spacing, the dialog box in Figure 9 will pop up, where the user must enter the values regarding emitter spacing and f_c . If the user does not know the value of f_c , the default value of 0.2 will be taken for further calculations (Ravikumar, 2022a).

In addition to the above-said details, the user is required to input the average design pressure head, the pressure head available at the inlet of the lateral and v_h^a . Once all the required data has been entered, the user should click the “calculate” button to activate the software’s functionality. The software will then process the data, perform necessary computations, and provide the user with the results of their input, including pressure head variation, v_h , and a design note indicating whether the design is acceptable or not based on v_h^a . This information will help the users to decide on their design.

Users can access and download tabulated results. Additionally, the software also allows users to download the graphical representation of their results. By providing this feature, the software enables users to easily share and store their results in a visually appealing manner.

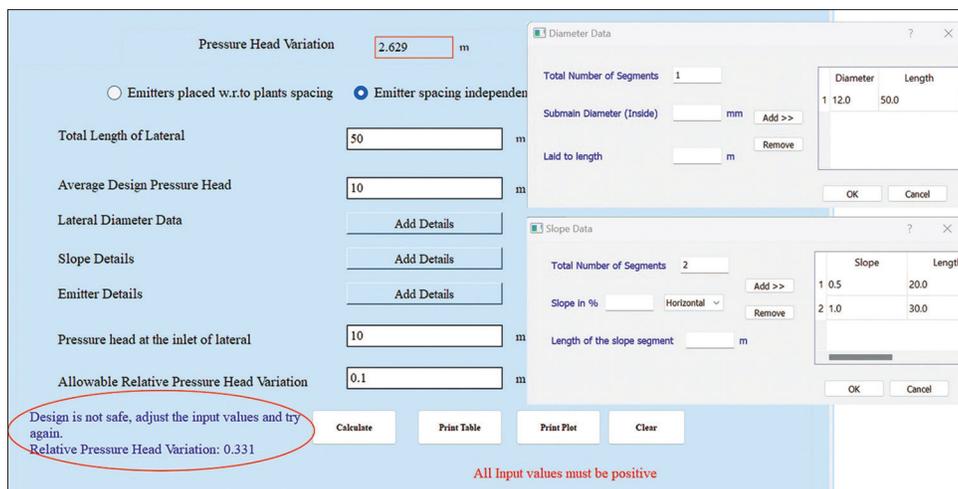


Figure 7: Working of DDC with user-entered data (with uniform lateral)

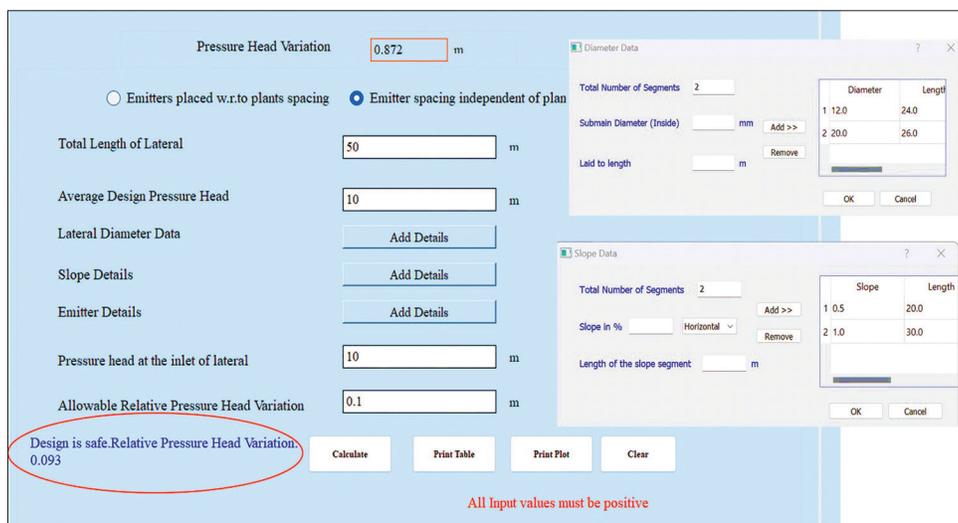


Figure 8: Working of DDC with user-entered Data data (with telescopic lateral)

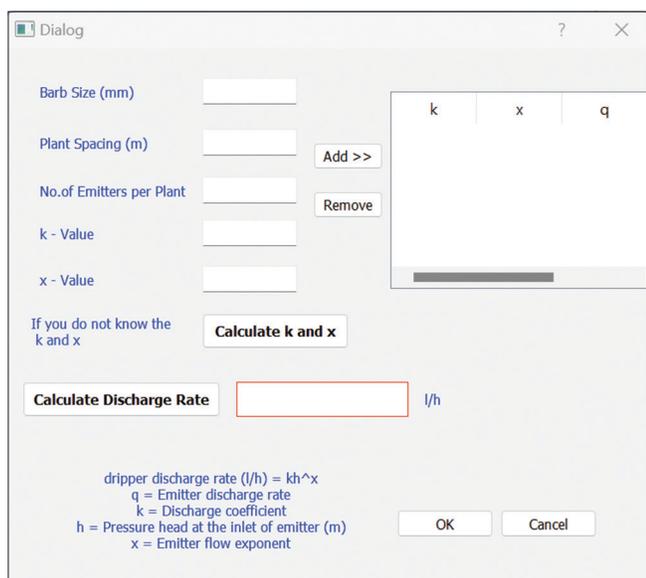


Figure 9: Dialog box for finding discharge rate of online drippers

Testing and Validating the Developed Software

The software was tested using several test data sets prepared for valid and invalid, consistent, and inconsistent data to improve the quality of the software by identifying any errors or issues that may exist. In addition, the results were compared with the output obtained through manual calculations to check the accuracy and reliability of the simulation performed by the DDC. A sample set of data used for software testing for each simulation scenario are shown in Tables 1 and 2.

The DDC can be used to test different sets of sample data for designing the diameter of the lateral. For instance, consider the case where the lateral has a length of 50 m and runs on an upslope of 0.5% for the first 20 m and 1% for the remaining 30 m. Inline drippers are placed at 0.5 m intervals with a discharge rate of 4 L/h. The h_{inlet} of the lateral is 10 m, and the v_h^a is 0.1. The equivalent length of emitter connection loss is 0.2. Two different design choices were tested, as shown in Figures 7 and 8. In the first case, a uniform diameter of 12 mm was used, and

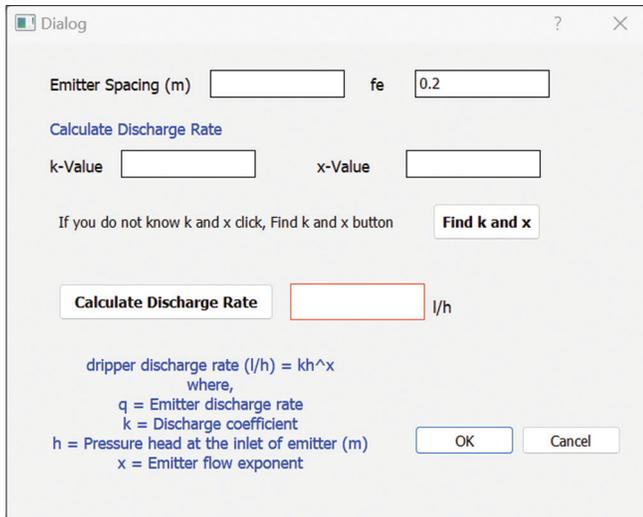


Figure 10: Dialog box for finding discharge rate of inline drippers

the software returned the values of Δh , v_h^a and the acceptability of the design, as shown in Figure 7. Similarly, in the second case, a telescopic pipe design was used, and the results were recorded (Figure 8). Based on the outcomes obtained from these two sample cases, the user can arrive at a proper conclusion. In this particular case, the telescopic design is recommended compared to the uniform diameter of 12 mm for the given field conditions. Likewise, various sets of data were tested using the DDC, and the outputs were recorded. A few examples are given in Tables 1 and 2.

The DDC produced output results that exactly matched the expected return. Sample test cases for upslope and downslope conditions for laying lateral pipes were provided in this paper. Each test case included different design requirements and various-sized pipes were considered based on the given field conditions. Representative data for uniform and telescopic pipes were used. In Sample Case 1, out of the four sample options, Options 2, 3 and 4 provided satisfactory designs. Option 4 was found to be economically feasible compared to Option 2 and 3. Similarly, by examining Sample Cases 1-4, it is possible to notice variations in the v_h values with different sets of diameter data. Therefore, recording the output from the DDC and calculating the pipe cost for each option can enable users to improve drip irrigation design. Furthermore, the software provides alerts and messages for invalid or inconsistent input values, ensuring that it functions properly and provides valuable insights to users.

DISCUSSION

The DDC for designing irrigation pipelines has several benefits. Firstly, the developed application automates many calculations in drip design, reducing the manual effort required to make complex calculations, thereby saving time. Additionally, this application is designed with user-friendly interfaces that are easy to navigate, even for non-technical users. The tabular and graphical representation of results can provide users with a visual

Table 1: A set of sample data used for simulating lateral laid on different slope types for orchard crops (Emitters placed independent of plant spacing)

Inputs to software		Output from Software		
		Δh , m	v_h	Safety Note
Sample case 1: L=50 m,				
Slope=0.5% (upslope) for the first 20 m and 1% (upslope) for the remaining 30 m, $s=0.5$ m,				
$q=4$ L/h, $h_{start}=10$ m, $v_h^a = 0.1$, $f_e=0.2$				
S. No	D, mm			
1	12	2.629	0.331	Not Safe
2	20	0.595	0.063	Safe
3	12: 18 m; 20: 32 m	0.721	0.076	Safe
4	12: 24 m; 20: 26 m	0.872	0.093	Safe
Sample case 2: L=40 m,				
Slope=0.5% (Downslope)				
for the first 20 m and 1% (Downslope) for the remaining 20 m, $s=0.8$ m,				
$q=8$ L/h, $h_{start}=10$ m, $v_h^a = 0.1$, $f_e=0.2$				
S. No	D, mm			
1	10	3.868	0.579	Not Safe
2	14	0.63	0.068	Safe
3	10: 12 m; 12: 28 m	1.569	0.183	Not safe
4	12: 24 m; 14: 16 m	0.833	0.091	Safe

Table 2: A set of sample data used for simulating lateral laid on different slope types for plantation crops (Emitters placed with respect to plant spacing)

Inputs to software		Output from Software		
		Δh , m	v_h	Safety Note
Sample case 3: L=90 m,				
Slope=0.25% (upslope) for the first 60 m and 0.5% (upslope) for the remaining 30 m, $s_p=6$ m,				
$q=8$ L/h, $NDP=2$, $h_{start}=10$ m, $v_h^a = 0.1$, barb size=5 mm				
S. No	D, mm			
1	12	1.68	0.20	Not Safe
2	16	0.641	0.069	Safe
3	12: 60 m; 16: 30 m	1.196	0.133	Not Safe
4	14: 60 m; 16: 30 m	0.823	0.089	Safe
Sample case 4: L=90 m,				
Slope=0.25% (Downslope) for the first 60 m and 0.5% (Downslope) for the remaining 30 m, $s_p=6$ m,				
$q=8$ L/h, $NDP=2$, $h_{start}=10$ m, $v_h^a = 0.1$, barb size=5 mm				
S. No	D, mm			
1	12	1.187	0.140	Not Safe
2	14	0.497	0.054	Safe
3	12: 72 m; 14: 18 m	1.02	0.115	Not safe (boundary)
4	12: 60 m; 14: 30 m	0.835	0.092	Safe

and comprehensive understanding of the performance of the drip system. The setup file of the software can be downloaded freely from www.dripdesigncheck.in. Its web version is also under development.

The functionality of the DDC software was compared to other freely available software programs popular in this domain. For example, HydroCalc, developed by Netafim, is one of the leading software programs in drip simulation and is available online and offline (Darwish *et al.*, 2022). As part of the simulation, HydroCalc checks the goodness of the design based on flow variation instead of relative pressure head variation. Compared to the simulation results provided by HydroCalc, DDC provides more precise results along with a tabular representation of details containing friction loss, elevation gain/loss, and pressure head at each outlet location. Furthermore, emitter connection losses are also encountered while simulating the pressure head distribution along the lateral, adding to the benefits of the DDC software.

Similar to HydroCalc, AquaFlow software also gives various products and models for the user to select, based on which it will give the product details regarding discharge rate, flow exponents, spacing of inline drippers, etc. (TORO, 2014). However, this software is not user-friendly compared to DDC. Another software program used for simulation is DSSP, which provides pressure head values at each location (Krishnan & Ravikumar, 2002). The pressure head values obtained by DDC exactly match those obtained from DSSP, but DSSP does not provide graphical results or information about friction losses or elevation gain/loss at each location as DDC.

Demonstration of the Software

Obtaining feedback and recommendations from designers can be extremely beneficial for evaluating the performance of DDC. In this regard, a live demo of DDC software was conducted to the designers. After the demo, the participants were requested to provide feedback on the software and recommend ways of improving it. The participants generally gave positive feedback, with most of them commending the software's ease of use and how it caters to the user's needs. Additionally, some participants offered suggestions on how to improve the software's functionality, incorporating unit conversion of inputs used in the design. We will factor in these recommendations when developing future versions of the software.

CONCLUSION

Drip Design Check is a computer-aided application developed for simulating and optimizing the design of drip irrigation lateral. Based on the simulated results, it checks the goodness of the design with particular sets of input values. The goodness of the design of laterals is determined based on the v_h value computed by solving the analytical equations.

The DDC is characterized by several features, which include:

- Simulation of drip irrigation systems under various slope conditions, including uniform, non-uniform, and mixed slope situations.
- Simulation lateral that uses uniform or telescopic pipes
- The software also accounts for emitter connection losses, which are significant in drip irrigation.

- Variations in dripper configurations can be handled by the software in line with the intuition of the user perceptions.
- Multiple alternative designs can be evaluated for any input data set, and the most satisfactory design can be selected.

In addition, the recommendation obtained during the software demonstration may be added in the future version. In summary, Drip Design Check is a powerful tool that can simulate and optimize the design of drip lateral under various scenarios, providing reliable results for irrigation system designers.

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