

Application of Numerical Newton-Raphson Method in Calculation of Emitter Water Discharge of Drip Irrigation System in “Mutis Cemerlang” Coffee Plantation

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ABSTRACT

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Based on the slope class, the shape of the area and the elevation of dry land in Nusa Tenggara, agricultural land in Noepesu Village is suitable for planting coffee plants with an agroforestry scheme. To overcome the problem of limited water, drip irrigation system technology can be applied. The use of drip irrigation as an agricultural technology in Noepesu village has been carried out by many farmer groups. Still, the installation process does not consider the pipe specifications (pipe length and pipe diameter) and the condition of agricultural land. This causes the service life of drip irrigation to be not long. If this continues, of course, it will increase system installation costs. To optimize service life, a hydraulics analysis method is needed for drip irrigation pipe network systems that take into account pipe specifications and agricultural land conditions. The hydraulics analysis of the drip irrigation network system determines the emitter's water flow rate. The emitter flow rate forms a nonlinear equation known as the closed pipe equation. In the process of solving these equations, numerical methods can be used, specifically the Newton-Raphson method. This study focuses on applying the Newton-Raphson method to calculate the amount of water discharge from each emitter of the drip irrigation network system on the farmland of the Mutis Cemerlang Farmer Group in Noepesu Village. The drip irrigation system is designed with 250 nodes, 275 pipes, 26 loops, and 86 outlets divided into two sides, with the left side containing 84 outlets with one emitter and the right side containing 102 outlets with two emitters. The amount of water discharge for each emitter is $0,0008 \text{ ml/second} \leq Q \leq 2,6 \text{ ml/second}$ for the left side and $0,001 \text{ ml/second} \leq Q \leq 1,1 \text{ ml/second}$ for the right side, as determined by simulation calculations utilizing the Newton-Raphson method and Matlab software. The simulation results show that the amount of water discharge at each emitter is ideal in the first iteration because it has a discharge correction value (ΔQ) ≈ 0 .



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A. INTRODUCTION

Conditions of agricultural land such as the shape of the area, slope and elevation affect the quality of the soil which will greatly determine the level of quality of agricultural production (Khalil et al., 2015), (Nabiollahi et al., 2018), (Magdić et al., 2022), (Javed et al., 2022). Geographically, North Central Timor Regency comprises 2,669.70 Km² or approximately 5.48% of East Nusa Tenggara Province's land area. The topography of North Central Timor Regency is

generally undulating and hilly with varying heights: 1) 177.60 Km² (6.63%) with an altitude of fewer than 100 meters above sea level (masl); 2) 1,499.45 Km² (56.17%) with an altitude of 100-500 masl; and 3) 993.19 Km² (37.20%) has a height of more than 500 masl. According to data from Agroclimate and Hydrology Research Institute in 2003, out of a total of 4.6 million ha in the East Nusa Tenggara region, approximately 1 million ha has an arid climate (semiarid) with annual rainfall <1000 mm, 7-10 dry months (<100 mm), and <2 wet months (> 200 mm).

Noepesu Village is one of 160 villages in the North Central Timor Regency with altitudes between 600 and 1200 meters above sea level and an average temperature of 18° C. With an average altitude of 1,000 meters above sea level and an average temperature of 18° C, Noepesu village has a moderate climate. Based on the division of climate zones and the types of plants that can grow in Indonesia, as stated by Frans Wilhelm Junghun, coffee can be successfully cultivated in Noepesu Village.

The entire area of Noepesu village is dry land with a hilly topography; most of the land has a ±45° slope and is cultivated as fields that are only planted once a year during the rainy season with corn, rice, cassava, string beans, and peanuts, among others. Typically, the rainy season lasts only a few weeks (4 months). Due to dry land conditions and associated constraints, a community's farming activities are restricted to land preparation before the rainy season and the rainy season itself. During the dry season, almost no farming occurs, with the exception of those who raise livestock.

Based on slope class, shape of the area and elevation, dry land in Nusa Tenggara can be grouped into three clusters (Mokarram & Hojati, 2016). Cluster A (<slopes 15%, <200 masl) is suitable for food crops, cluster B (slopes 15-40%, 200-700 masl) is ideal for food crops, forage for livestock, and plantations, while cluster C (slope > 40%, > 700 masl) is suitable for agroforestry. The selection of commodities and soil conservation efforts based on clusters is highly recommended for sustainability, and environmental sustainability, particularly clusters B and C. Highly recommended for cluster C region like Noepesu Village is a combination of annual and food crops; the steeper the land, the more annual crops should dominate (Derlukiewicz et al., 2020).

According to the 2014 numerical database book North Central Timor Regency, there are 26 farmer groups in the West Miomaffo District, including the Mutis Cemerlang farmer group. This group of farmers has 42 members and owns 11 hectares of farmland. This land is used to cultivate various crops, including garlic, red beans, carrots, potatoes, candlenuts, and coffee. The agricultural land of the farmer group has never been irrigated and relies solely on rainwater infiltration into the soil, so crop yields are highly dependent on rainfall. If rainfall is adequate, crop yields are satisfactory, and vice versa. Based on this water constraint, agricultural technologies such as drip irrigation supplying water continuously with low water discharge and high frequency (nearly continuously) around plant roots are required (Assis et al., 2014).

Numerous farmer groups have implemented drip irrigation as an agricultural technology in Noepesu Village, but the installation process did not account for pipe specifications (pipe length and diameter) and the condition of the agricultural land. This results in a short service life for drip irrigation. If this continues, farmer groups will be required to incur additional costs for installing a new system, resulting in higher installation costs. To optimize service life, drip

irrigation pipe network systems require a hydraulics analysis method that considers pipe specifications and agricultural land conditions (Karim & Sahib, 2019).

The emitter is one of the most vital components of a drip irrigation system. The emitter or dropper is a component that continuously distributes water from the lateral pipe to the soil surrounding the plant with a low discharge and pressure close to the atmosphere (Hussain & Gupta, 2017). There is a component in the emitter that functions as a regulator for the amount of water discharged.

The hydraulics analysis of the drip irrigation network system is an analysis to determine the value of the water flow rate at the emitter (Abduraimova et al., 2022), (Ates, 2016). The flow rate at the emitter is represented by a nonlinear equation known as the closed pipe equation (Moosavian & Jaefarzadeh, 2014). Several numerical methods can be used to solve these equations, including Newton-Raphson, Hardy Croos (Brkić & Praks, 2019), Gradient (Teixeira et al., 2021) and the Linear Theory (Moosavian, 2017). The Newton-Raphson method has several advantages over other methods, including simultaneous network analysis, which makes the iteration process shorter and faster, and a low probability of discharge error correction (Saad et al., 2017). Based on pipe specifications, this study aims to apply the Newton-Raphson method to determine the optimal amount of water discharge at each emitter of a drip irrigation system. This study's findings can be used as a guide for utilizing sloping and arid land as agricultural land with the aid of drip irrigation.

B. METHODS

This quantitative study employs the Newton-Raphson method to determine the amount of water discharged by each emitter in a drip irrigation network system. From July to November 2021, this research was conducted at the Mutis Cemerlang Farmers Group coffee plantation in Noepesu Village, West Miomaffo District, North Central Timor Regency, East Nusa Tenggara Province. In addition to the direct collection of research-related data, several relevant journals and books were also consulted for additional references. This study employs the Newton-Raphson method and Matlab R2021 software for data processing.

1. Research Stages

The research stages are as follows:

- a. Looking for sources regarding the use of dry land for agriculture, and the application of the Newton-Raphson method in agriculture.
- b. Preparing land and pipe installation for drip irrigation.
- c. Numbering of all nodes, pipes and loop points.
- d. Construct nodal equations and pressure drop equations in the loop based on the drip irrigation network system that has been built.
- e. Constructing Jacobian matrices from the equations formed.
- f. Applying Newton-Raphson method iterations to obtain optimal solutions with the help of Matlab R2021 software.

2. Data Processing Stages

Pipeline analysis using the Newton-Raphson method is different from other analytical methods, since this method analyzes the entire network simultaneously (Ifiemi et al., 2020). The Newton-Raphson method is a reliable numerical method for solving systems of nonlinear equations. Suppose there are three nonlinear equations such as $F_1(Q_1, Q_2, Q_3) = 0$, $F_2(Q_1, Q_2, Q_3) = 0$, and $F_3(Q_1, Q_2, Q_3) = 0$, to calculate Q_1 , Q_2 dan Q_3 . The discharge correction values for each flow discharge are ΔQ_1 , ΔQ_2 , and ΔQ_3 , which are the solutions of the set such that:

$$\begin{aligned} F_1(\Delta Q_1, \Delta Q_2, \Delta Q_3) &= 0 \\ F_2(\Delta Q_1, \Delta Q_2, \Delta Q_3) &= 0 \\ F_3(\Delta Q_1, \Delta Q_2, \Delta Q_3) &= 0 \end{aligned} \quad (1)$$

Equation (1) is expanded into a Taylor series, as follows:

$$\begin{aligned} F_1 + [\partial F_1 / \partial Q_1] \Delta Q_1 + [\partial F_1 / \partial Q_2] \Delta Q_2 + [\partial F_1 / \partial Q_3] \Delta Q_3 &= 0 \\ F_2 + [\partial F_2 / \partial Q_1] \Delta Q_1 + [\partial F_2 / \partial Q_2] \Delta Q_2 + [\partial F_2 / \partial Q_3] \Delta Q_3 &= 0 \\ F_3 + [\partial F_3 / \partial Q_1] \Delta Q_1 + [\partial F_3 / \partial Q_2] \Delta Q_2 + [\partial F_3 / \partial Q_3] \Delta Q_3 &= 0 \end{aligned} \quad (2)$$

Equation (3) is then presented in matrix form, as follows:

$$\begin{bmatrix} \partial F_1 / \partial Q_1 & \partial F_1 / \partial Q_2 & \partial F_1 / \partial Q_3 \\ \partial F_2 / \partial Q_1 & \partial F_2 / \partial Q_2 & \partial F_2 / \partial Q_3 \\ \partial F_3 / \partial Q_1 & \partial F_3 / \partial Q_2 & \partial F_3 / \partial Q_3 \end{bmatrix} \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \Delta Q_3 \end{bmatrix} = - \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} \quad (3)$$

The solution to equation (4) is:

$$\begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \Delta Q_3 \end{bmatrix} = - \begin{bmatrix} \partial F_1 / \partial Q_1 & \partial F_1 / \partial Q_2 & \partial F_1 / \partial Q_3 \\ \partial F_2 / \partial Q_1 & \partial F_2 / \partial Q_2 & \partial F_2 / \partial Q_3 \\ \partial F_3 / \partial Q_1 & \partial F_3 / \partial Q_2 & \partial F_3 / \partial Q_3 \end{bmatrix}^{-1} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} \quad (4)$$

Thus, the flow rate of Q_1 , Q_2 , and Q_3 can be calculated as follows:

$$\begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix} = \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix} + \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \Delta Q_3 \end{bmatrix} \quad (5)$$

The procedure for network analysis using the Newton-Raphson method begins in several stages, namely:

- a. Numbering of all nodes, pipes and loop points.
- b. Presenting the nodal equation as follows:

$$F_j = \sum_{n=1}^{j_n} Q_{jn} - q_j = 0 \text{ for all nodes } -1 \quad (6)$$

where Q_{jn} is the discharge in n th at node j , q_j is the nodal withdrawal, and j_n is the total number of pipes at node j .

- c. Presenting the pressure drop equation as follows:

$$F_k = \sum_{n=1}^{k_n} K_n Q_{kn} |Q_{kn}| = 0 \text{ for all loops } (n = 1, 2, \dots, k_n) \quad (7)$$

Where k_n is total pipes in k th loop, and K_n is the algebraic sum of the head loss in k th loop which can be expressed as

$$K_i = \frac{8f_i L_i}{\pi^2 g D_i^5},$$

i is pipe link number to be summed up in the loop k .

- d. Assume the initial discharge Q_1, Q_2, Q_3, \dots satisfy the continuous equation.
- e. Assume a friction coefficient is $f_i = 0,02$ for all pipes.
- f. Determine the value of the partial derivative $\frac{\partial F_n}{\partial Q_i}$ and F_n function using the initial discharge pipe Q_i and K_i .
- g. Determine ΔQ_i with the form $Ax = b$ Matrix.
- h. Using the obtained of ΔQ_i values, the pipe discharges are modified and the process is repeated again until the calculated ΔQ_i values are very small.

C. RESULT AND DISCUSSION

The results and discussion are divided into two parts, land preparation and installation of drip irrigation networks, and calculation of emitter water discharge.

1. Land Preparation and Installation of Drip Irrigation Networks

The plantation land of the Mutis Cemerlang Farmer Group is agricultural land with a $\pm 45^\circ$ slope cultivated as fields that are only planted once a year during the rainy season with corn, rice, cassava, string beans, and peanuts. The following illustrates the state of the land, as shown in Figure 1.



Figure 1. Agricultural Land before Processing

Furthermore, the sloped land is transformed into terraces. This is done to shorten the slope and restrict or minimize runoff so water can percolate into the ground (Pramudo et al., 2016). The process of land preparation lasted three weeks. Researchers assisted members of the Mutis Cemerlang Farmers Group in the process of preparing the land. There are five terraces, each measuring 45 meters in length and varying in width from 3 to 5 meters in accordance with the terrain. This terrace serves as a stretch of HDPE pipelines with emitters for each planting hole containing coffee and tamarind plants. In addition, terraces are constructed so that water flow is distributed uniformly to all emitters in the row. The five constructed terraces are of varying heights, so the pipe requirements can be tailored to the existing conditions. The drip irrigation pipeline network installation phases occurred on 31 October 2021 and 7 November 2021, respectively. Researchers were assisted in the installation of the pipes by members of the Mutis Cemerlang Farmers Group. The drip irrigation system is composed of several parts (Jarwar et al., 2019):

- a. An emitter or dropper is a component that distributes water from the lateral pipe to the soil around the plants with a low discharge and a pressure close to atmospheric pressure. Discharge control components support the emitter used.
- b. Lateral pipe, is where the emitter is installed. The pipe used as the lateral pipe is HDPE pipe with a diameter of 0.5 inch (22 mm). The reason for using HDPE pipes as lateral pipes is that HDPE pipes are flexible so they can be adapted to land surface conditions and do not require pipe joints.
- c. The main manifold or sub pipe, is a pipe that distributes water to the lateral pipe. This pipe is designed using a 2-inch (60 mm) diameter PVC pipe.
- d. A component that distributes water to the manifold pipe is the main pipe. This pipe is constructed from 1 inch-diameter PVC pipe (32 mm). PVC (Polyvinyl Chloride) pipes are used as manifold and main pipes because they are commonly referred to as paralon pipes. The formation is made entirely of plastic or a combination of plastic and vinyl so that the pipe is stronger, lighter, more durable, and will not rust.
- e. Other supporting components consist of reservoirs, faucet stops, and valves.

The designed irrigation network system consists of 250 emitters arranged in 13 rows of combination for tamarind and coffee tillers. Each row of each type of tiller is connected to a two-way HDPE pipe faucet with a half-inch diameter. As the main pipe, a 2-inch-diameter PVC pipe is utilized so that the water volume and pressure can increase while distributing water to each row of HDPE pipes equipped with emitters. The land preparation and pipe installation

process are described in (Delvion et al., 2021). Figure 2 depicts the visual appearance of the installed drip irrigation network.



Figure 2. Display of Drip Irrigation Network

The land area used in this study is ± 1,594.6 m² or 0.1594 ha. The pipeline network consists of 26 loops, 186 outlets with 84 outlets with 1 emitter and 102 outlets with 2 emitters. The agricultural land is planted with coffee and tamarind plants. The distance between coffee plants and coffee plants is 2 meters and between coffee plants and tamarind plants is 4 meters while the distance between each tamarind plant is adjusted. The appearance of the drip irrigation network in Figure 2 is illustrated in Figure 3.

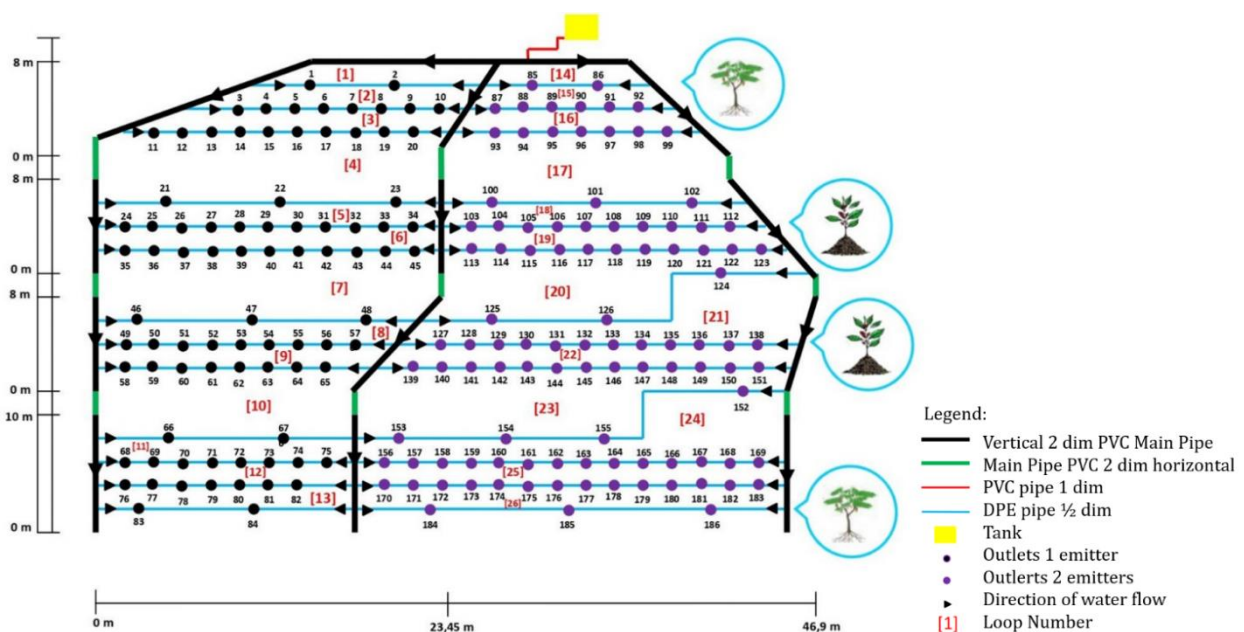
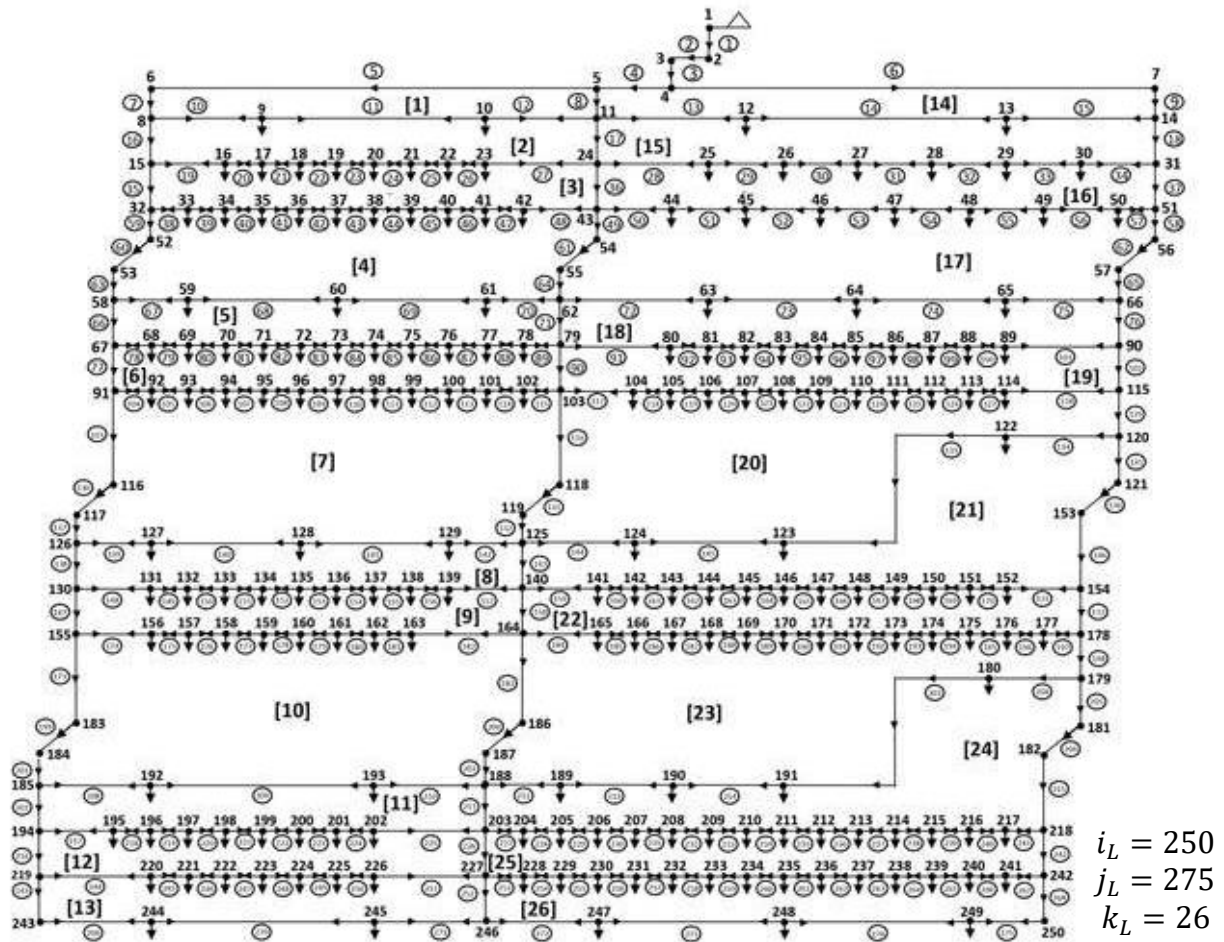


Figure 3. Drip Irrigation Network System

2. Emitter Water Debit Calculation

Figure 3 demonstrates that the constructed drip irrigation network is divided into two sections: the left section contains outlets with a single emitter for each outlet, while the right section contains outlets with two emitters for each outlet. To make it easier to determine the water flow equation for each pipe node, Figure 3 drip irrigation network is depicted in Figure 4 format.



$i_L = 250$
 $j_L = 275$
 $k_L = 26$

Figure 4. Schematic of the Drip Irrigation System Water Distribution Network

Based on Figure 4, the scheme of the water distribution network formed is a mixed scheme between a branched network and a network with loops. Using Equation (6) and Equation (7), 275 equations are obtained, divided into 249 node equations and 26 pressure reduction equations in the loop. For pipeline networks without loops (branched networks), the node equation is as follows:

$$f_1 = Q_1 - Q_2 = 0 \dots \dots \dots \text{node 2}$$

$$f_2 = Q_2 - Q_3 = 0 \dots \dots \dots \text{node 3}$$

Meanwhile, for a looped pipeline network, the node equation is as follows:

$$f_3 = Q_3 - Q_4 - Q_6 = 0 \dots \dots \dots \text{node 4}$$

$$f_{12} = Q_{14} - Q_{15} - 0,4 = 0 \dots \dots \dots \text{node 13}$$

$$f_4 = Q_4 - Q_8 - Q_5 = 0 \dots \dots \dots \text{node 5}$$

$$f_{13} = Q_9 - Q_{15} - Q_{18} = 0 \dots \dots \dots \text{node 14}$$

$$f_5 = Q_5 - Q_7 = 0 \dots \dots \dots \text{node 6}$$

$$f_{14} = Q_{16} - Q_{19} - Q_{35} = 0 \dots \dots \dots \text{node 15}$$

$$f_6 = Q_6 - Q_9 = 0 \dots \dots \dots \text{node 7}$$

$$f_{15} = -Q_{19} + Q_{20} - 0,2 = 0 \dots \dots \dots \text{node 16}$$

$$f_7 = Q_7 - Q_{10} - Q_{16} = 0 \dots \dots \dots \text{node 8}$$

$$f_{16} = -Q_{20} + Q_{21} - 0,2 = 0 \dots \dots \dots \text{node 17}$$

$$f_8 = -Q_{10} + Q_{11} - 0,2 = 0 \dots \dots \dots \text{node 9}$$

$$f_{17} = -Q_{21} + Q_{22} - 0,2 = 0 \dots \dots \dots \text{node 18}$$

$$f_9 = -Q_{11} + Q_{12} - 0,2 = 0 \dots \dots \dots \text{node 10}$$

$$f_{18} = -Q_{22} + Q_{23} - 0,2 = 0 \dots \dots \dots \text{node 19}$$

$$f_{10} = Q_8 - Q_{12} - Q_{13} - Q_{17} = 0 \dots \dots \dots \text{node 11}$$

$$\vdots$$

$$f_{11} = Q_{13} - Q_{14} - 0,4 = 0 \dots \dots \dots \text{node 12}$$

$$f_{249} = Q_{268} - Q_{275} = 0 \dots \dots \dots \text{node 250}$$

Furthermore, the pressure drop equation in the loop is as follows:

$$f_{250} = -0,0000000150Q_5 |Q_5| - 0,0000000108Q_7 |Q_7| + 0,00000000007Q_8 |Q_8| + 0,0000013121Q_{12} |Q_{12}| + 0,0000013121Q_{11} |Q_{11}| + 0,0000013121Q_{10} |Q_{10}| = 0 \dots \text{loop 1}$$

$$f_{251} = -0,0000013121Q_{12} |Q_{12}| - 0,0000013121Q_{11} |Q_{11}| - 0,0000013121Q_{10} |Q_{10}| - 0,0000000116Q_{16} |Q_{16}| + 0,0000000034Q_{17} |Q_{17}| + 0,0000005927Q_{27} |Q_{27}| + 0,0000005927Q_{26} |Q_{26}| + 0,0000005927Q_{25} |Q_{25}| + 0,0000005927Q_{24} |Q_{24}| + 0,0000005927Q_{23} |Q_{23}| + 0,0000005927Q_{22} |Q_{22}| + 0,0000005927Q_{21} |Q_{21}| + 0,0000005927Q_{20} |Q_{20}| + 0,0000005927Q_{19} |Q_{19}| = 0 \dots \text{loop 2}$$

$$f_{252} = -0,0000005927Q_{27} |Q_{27}| - 0,0000005927Q_{26} |Q_{26}| - 0,0000005927Q_{25} |Q_{25}| - 0,0000005927Q_{24} |Q_{24}| - 0,0000005927Q_{23} |Q_{23}| - 0,0000005927Q_{22} |Q_{22}| - 0,0000005927Q_{21} |Q_{21}| - 0,0000005927Q_{20} |Q_{20}| - 0,0000005927Q_{19} |Q_{19}| - 0,0000000104Q_{35} |Q_{35}| + 0,0000000033Q_{36} |Q_{36}| + 0,0000006543Q_{48} |Q_{48}| + 0,0000006543Q_{47} |Q_{47}| + 0,0000006543Q_{46} |Q_{46}| + 0,0000006543Q_{45} |Q_{45}| + 0,0000006543Q_{44} |Q_{44}| + 0,0000006543Q_{43} |Q_{43}| + 0,0000006543Q_{42} |Q_{42}| + 0,0000006543Q_{41} |Q_{41}| + 0,0000006543Q_{40} |Q_{40}| + 0,0000006543Q_{39} |Q_{39}| + 0,0000006543Q_{38} |Q_{38}| = 0 \dots \text{loop 3}$$

$$f_{253} = -0,0000006543Q_{48} |Q_{48}| - 0,0000006543Q_{47} |Q_{47}| - 0,0000006543Q_{46} |Q_{46}| - 0,0000006543Q_{45} |Q_{45}| - 0,0000006543Q_{44} |Q_{44}| - 0,0000006543Q_{43} |Q_{43}| - 0,0000006543Q_{42} |Q_{42}| - 0,0000006543Q_{41} |Q_{41}| - 0,0000006543Q_{40} |Q_{40}| - 0,0000006543Q_{39} |Q_{39}| - 0,0000006543Q_{38} |Q_{38}| - 0,0000000029Q_{59} |Q_{59}| - 0,0000000016Q_{60} |Q_{60}| - 0,0000000029Q_{63} |Q_{63}| + 0,0000000031Q_{49} |Q_{49}| + 0,0000000013Q_{61} |Q_{61}| + 0,0000000031Q_{64} |Q_{64}| + 0,0000017914Q_{70} |Q_{70}| + 0,0000017914Q_{69} |Q_{69}| + 0,0000017914Q_{68} |Q_{68}| + 0,0000017914Q_{67} |Q_{67}| = 0 \dots \text{loop 4}$$

⋮

$$f_{275} = 0,0000006212Q_{253} |Q_{253}| + 0,0000006212Q_{254} |Q_{254}| + 0,0000006212Q_{255} |Q_{255}| + 0,0000006212Q_{256} |Q_{256}| + 0,0000006212Q_{257} |Q_{257}| + 0,0000006212Q_{258} |Q_{258}| + 0,0000006212Q_{259} |Q_{259}| + 0,0000006212Q_{260} |Q_{260}| + 0,0000006212Q_{261} |Q_{261}| + 0,0000006212Q_{262} |Q_{262}| + 0,0000006212Q_{263} |Q_{263}| + 0,0000006212Q_{264} |Q_{264}| + 0,0000006212Q_{264} |Q_{264}| + 0,0000006212Q_{265} |Q_{265}| + 0,0000006212Q_{265} |Q_{265}| + 0,0000006212Q_{266} |Q_{266}| + 0,0000006212Q_{267} |Q_{267}| + 0,0000000064Q_{268} |Q_{268}| - 0,0000000046Q_{252} |Q_{252}| - 0,0000024702Q_{272} |Q_{272}| - 0,0000024702Q_{273} |Q_{273}| - 0,0000024702Q_{274} |Q_{274}| - 0,0000024702Q_{275} |Q_{275}| = 0 \dots \text{loop 26}$$

Next, by substituting the initial debit of the pipe water flow (Q_1), which is 0.41 ml/sec into each node equation, the initial discharge for each node is obtained, as shown in Table 1.

Table 1. Initial Discharge (Q) Value

No.	Q (ml/s)	No.	Q (ml/s)	No.	Q (ml/s)	No.	Q (ml/s)	No.	Q (ml/s)	No.	Q (ml/s)
1	0,41	47	1,8125	93	0,211	139	0,0008	185	0,012	231	0,388
2	0,41	48	0,242	94	0,189	140	0,2008	186	0,388	232	0,012
3	0,41	49	0,242	95	0,211	141	0,4008	187	0,012	233	0,388
4	0,2	50	0,242	96	0,189	142	0,0068	188	0,388	234	0,012
5	0,1	51	0,158	97	0,211	143	0,154	189	0,012	235	0,388
6	0,2	52	0,242	98	0,189	144	1,203	190	0,388	236	0,012
7	0,1	53	0,158	99	0,211	145	0,803	191	0,012	237	0,388
8	0,1	54	0,242	100	0,189	146	0,003	192	0,388	238	0,012
9	0,2	55	0,158	101	0,211	147	0,0038	193	0,012	239	0,388
10	0,05	56	0,242	102	0,101	148	0,0038	194	0,388	240	0,012
11	0,25	57	0,158	103	0,0015	149	0,2038	195	0,012	241	0,388
12	0,45	58	0,108	104	0,0015	150	0,4038	196	0,388	242	0,383
13	0,175	59	0,0125	105	0,2015	151	0,6038	197	0,012	243	0,485
14	0,225	60	0,0125	106	0,4015	152	0,8038	198	0,01	244	0,485
15	0,175	61	0,242	107	0,6015	153	1,0038	199	0,0019	245	0,685
16	0,05	62	0,108	108	0,8015	154	1,2038	200	0,388	246	0,885
17	0,175	63	0,0125	109	1,0015	155	1,4038	201	0,0019	247	1
18	0,025	64	0,242	110	1,2015	156	1,6038	202	0,338	248	1
19	0,025	65	0,108	111	1,4015	157	1,8038	203	0,395	249	1
20	0,225	66	0,006	112	2	158	0,825	204	0,005	250	1,685
21	0,425	67	0,006	113	1,8015	159	0,825	205	0,005	251	1,885
22	0,625	68	0,206	114	2,0015	160	0,425	206	0,005	252	0,3485
23	0,825	69	0,406	115	2,2015	161	0,025	207	0,1931	253	0,3485
24	1	70	0,606	116	0,495	162	0,375	208	0,195	254	0,0515
25	1,225	71	0,182	117	0,495	163	0,025	209	0,205	255	0,3485
26	1,425	72	0,182	118	0,095	164	0,375	210	0,195	256	0,0515
27	1,625	73	0,218	119	0,305	165	0,025	211	0,195	257	0,3485
28	0,725	74	0,182	120	0,095	166	0,375	212	0,005	258	0,3485
29	0,325	75	0,218	121	0,305	167	0,025	213	0,395	259	0,0515
30	0,075	76	0,11	122	0,095	168	0,375	214	0,005	260	0,3485
31	0,0325	77	0,003	123	0,305	169	0,025	215	0,005	261	0,0515
32	0,075	78	0,003	124	0,095	170	0,375	216	0,97	262	0,3485
33	0,325	79	0,203	125	0,305	171	0,025	217	0,97	263	0,0515
34	0,075	80	0,403	126	0,095	172	0,022	218	1,17	264	0,3485
35	0,025	81	0,603	127	0,305	173	0,0019	219	1,37	265	0,0515
36	0,725	82	0,803	128	0,095	174	0,0019	220	1,57	266	0,3485
37	0,05	83	1,003	129	0,006	175	0,2019	221	1,77	267	0,0515
38	0,0125	84	1,203	130	0,0015	176	0,4019	222	1,97	268	0,3315
39	0,2125	85	1,403	131	0,495	177	0,6019	223	2,17	269	0,485
40	0,4125	86	1,603	132	0,495	178	0,8019	224	2,37	270	0,685
41	0,6125	87	1,803	133	0,403	179	1,0019	225	2,57	271	0,885
42	0,8125	88	2,003	134	0,003	180	1,2019	226	1,188	272	0,5365
43	1,0125	89	2,203	135	0,003	181	1,4019	227	1,188	273	0,5365
44	1,2125	90	1,011	136	0,003	182	1,6019	228	0,788	274	0,5365
45	1,4125	91	1,011	137	0,0015	183	0,388	229	0,388	275	0,3315
46	1,6125	92	0,611	138	0,0075	184	0,388	230	0,012		

The next step is to form a Newton-Raphson multivariable iteration matrix as follows:

$$J \times \Delta Q = -F \rightarrow \Delta Q = -J^{-1}F \quad (8)$$

with ΔQ as the column vector, $\{\Delta Q_i\}_{i=1,2,\dots,n}$ is the discharge correction vector for each water flow in the pipe, vector $Q = \{Q_i\}_{i=1,2,\dots,n}$ is the column vector for flow discharge and the matrix J is the Jakobian matrix which is defined as follows:

$$J = [J_{ij}] \text{ with } J_{ij} = \frac{\partial f_i}{\partial Q_j} = \text{elements of the } i\text{th row and } j\text{th column, } i, j = 1, 2, 3, \dots, 275.$$

In the previous step, it is known that there are 275 f equations and 275 Q variables, so the matrix ΔQ has the dimension of 1×275 , the matrix J^{-1} has the dimension of 275×275 and the matrix F has the dimension of 1×275 , as follows:

$$\begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \vdots \\ \Delta Q_{275} \end{bmatrix} = - \begin{bmatrix} \frac{\partial f_1}{\partial Q_1} & \frac{\partial f_1}{\partial Q_2} & \dots & \frac{\partial f_1}{\partial Q_{275}} \\ \frac{\partial f_2}{\partial Q_1} & \frac{\partial f_2}{\partial Q_2} & \dots & \frac{\partial f_2}{\partial Q_{275}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial f_{275}}{\partial Q_1} & \frac{\partial f_{275}}{\partial Q_2} & \dots & \frac{\partial f_{275}}{\partial Q_{275}} \end{bmatrix}^{-1} \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_{275} \end{bmatrix} \tag{9}$$

Replace the initial discharge value in each node equation, loop equation, and their derivatives with the initial discharge value. Due to the large size of the Jacobian matrix, its elements are not presented here, while those of the F matrix are shown in Table 2.

Table 2. Element of The Matrix F

No.	f	No	f
1,2, ... 249	0	263	0,0000223
250	-0,0000071	264	-0,0000118
251	0,0006108	265	0,0000582
252	-0,0006648	266	-0,0000298
253	0,0000477	267	-0,0000014
254	0,0021989	268	-0,0000755
255	-0,0012195	269	-0,0000367
256	0,0001050	270	-0,0000113
257	0,0000163	271	-0,0000601
258	0,0000611	272	0,0000273
259	0,0000549	273	-0,0000155
260	0,0000078	274	-0,0000597
261	0,0000132	275	-0,0000256
262	-0,0000140		

Based on Table 5, it is known that $f_i \approx 0, \forall i = 1, 2, \dots, 275$. The iterative process for determining optimal ΔQ and Q is carried out using Equation (4) and Equation (5) and by using the help of Matlab R2021 software. From the calculation process, the discharge correction value (ΔQ) is obtained as presented in Table 3.

Table 3. Discharge Correction Value (ΔQ)

Node	ΔQ	Node	ΔQ	Node	ΔQ
1, 2, 3, ..., 26	0	40	0,0012	59, 60	0,0055
27	0,0071	41	0,0018	61	0,111
28	0,0142	42	0,0024	62	0
29	0	43	0,003	63, 64	0,0055
30	0,0142	44	0,0037	65	0,111
31	0,0284	45	0,0043	66, 67, 68	0
32	0,0142	46	0,0049	69	0,00006
33, 34, 35	0	47	0,0055	70	0,0012
36	0,9292	48	0,0006	71, 72, 73, ..., 255	0
37	0,00648	49	0,111	256	0,0001
38	0	50, 51, 52, ..., 57	0,0017	257, 258, 259, ..., 274	0
39	0,0006	58	0	275	0,0012

Since $f_i \approx 0, \forall i = 1, 2, \dots, 275, \Delta Q_i \approx 0, \forall i = 1, 2, \dots, 275$ is also obtained as shown in Table 3 so that the iteration is stopped. Then, equation (5) is developed to:

$$\begin{matrix} Q_{recent} \\ \begin{bmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_{275} \end{bmatrix} \end{matrix} = \begin{matrix} Q_{initial} \\ \begin{bmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_{275} \end{bmatrix} \end{matrix} + \begin{matrix} discharge\ correction \\ \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \vdots \\ \Delta Q_{275} \end{bmatrix} \end{matrix} \tag{10}$$

By using equation (10), the final discharge for each node is obtained. Based on the specification description of the drip irrigation network system, there are 84 outlets on the left side with 1 emitter and 102 outlets on the right side with 2 emitters. Table 4 presents the debit data for each emitter outlet on the left side and Table 5 presents the debit data for each emitter outlet on the right side. Since there are 2 emitters on the right side of the outlet, the amount of water discharge resulting from the calculation process needs to be divided by two, as shown in Table 4 and Table 5.

Table 4. Data of Water Debit at Outlet 1 Emitter

No.	Outlet	Debit (ml/sec.)	No.	Outlet	Debit (ml/sec.)	No.	Outlet	Debit (ml/sec.)
1	9	0,2	29	73	0,2	57	139	0,0008
2	10	0,04	30	74	0,2	58	156	1,6
3	16	0,04	31	75	0,2	59	157	1,8
4	17	0,2	32	76	0,1	60	158	0,8
5	18	0,03	33	77	0,003	61	159	0,8
6	19	0,03	34	78	0,003	62	160	0,4
7	20	0,2	35	92	0,6	63	161	0,03
8	21	0,4	36	93	0,2	64	162	0,4
9	22	0,6	37	94	0,2	65	163	0,1
10	23	0,8	38	95	0,2	66	192	0,4
11	33	0,3	39	96	0,2	67	193	0,01
12	34	0,08	40	97	0,2	68	195	0,01
13	35	0,03	41	98	0,2	69	196	0,01

No.	Outlet	Debit (ml/sec.)	No.	Outlet	Debit (ml/sec.)	No.	Outlet	Debit (ml/sec.)
14	36	0,2	42	99	0,2	70	197	0,4
15	37	0,04	43	100	0,2	71	198	0,01
16	38	0,01	44	101	0,2	72	199	0,01
17	39	0,2	45	102	0,2	73	200	0,002
18	40	0,4	46	127	0,3	74	201	0,4
19	41	0,6	47	128	0,1	75	202	0,002
20	42	0,8	48	129	0,006	76	220	0,4
21	59	0,02	49	131	0,5	77	221	1,6
22	60	0,02	50	132	0,5	78	222	1,8
23	61	0,1	51	133	0,4	79	223	2,0
24	68	0,2	52	134	0,003	80	224	2,1
25	69	0,4	53	135	0,003	81	225	2,4
26	70	0,6	54	136	0,003	82	226	2,6
27	71	0,2	55	137	0,002	83	244	1,2
28	72	0,2	56	138	0,008	84	245	0,7

Table 5. Data of Water Debit at Outlet 2 Emitter

No.	Outlet	Outlet Debit (ml/sec.)	Emitter Debit (ml/sec.)	No.	Outlet	Outlet Debit (ml/sec.)	Emitter Debit (ml/sec.)
1	12	0,5	0,2	52	150	0,4	0,2
2	13	0,2	0,1	53	151	0,6	0,3
3	25	1,2	0,6	54	152	0,8	0,4
4	26	1,4	0,7	55	165	0,03	0,01
5	27	1,6	0,8	56	166	0,4	0,2
6	28	0,7	0,4	57	167	0,03	0,01
7	29	0,3	0,2	58	168	0,4	0,2
8	30	0,1	0,0	59	169	0,03	0,01
9	44	1,2	0,6	60	170	0,4	0,2
10	45	1,4	0,7	61	171	0,03	0,01
11	46	1,6	0,8	62	172	0,02	0,01
12	47	1,8	0,9	63	173	0,002	0,001
13	48	0,2	0,1	64	174	0,002	0,001
14	49	0,1	0,1	65	175	0,2	0,1
15	50	0,2	0,1	66	176	0,4	0,2
16	63	0,02	0,01	67	177	0,6	0,3
17	64	0,2	0,1	68	180	1,2	0,6
18	65	0,003	0,002	69	189	0,01	0,01
19	80	0,4	0,2	70	190	0,4	0,2
20	81	0,6	0,3	71	191	0,01	0,01
21	82	0,8	0,4	72	204	0,01	0,003
22	83	1,0	0,5	73	205	0,01	0,003
23	84	1,2	0,6	74	206	0,01	0,003
24	85	1,4	0,7	75	207	0,2	0,1
25	86	1,6	0,8	76	208	0,2	0,1
26	87	1,8	0,9	77	209	0,2	0,1
27	88	2,0	1,0	78	210	0,2	0,1
28	89	2,2	1,1	79	211	0,2	0,1
29	104	0,002	0,001	80	212	0,01	0,003

No.	Outlet	Outlet Debit (ml/sec.)	Emitter Debit (ml/sec.)	No.	Outlet	Outlet Debit (ml/sec.)	Emitter Debit (ml/sec.)
30	105	0,2	0,1	81	213	0,4	0,2
31	106	0,4	0,2	82	214	0,01	0,003
32	107	0,6	0,3	83	215	0,01	0,003
33	108	0,8	0,4	84	216	1,0	0,5
34	109	1,0	0,5	85	217	1,0	0,5
35	110	1,2	0,6	86	228	0,8	0,4
36	111	1,4	0,7	87	229	0,4	0,2
37	112	1,6	0,8	88	230	0,01	0,01
38	113	1,8	0,9	89	231	0,4	0,2
39	114	2,0	1,0	90	232	0,01	0,01
40	122	0,1	0,05	91	233	0,4	0,2
41	123	0,3	0,2	92	234	0,01	0,01
42	124	0,1	0,05	93	235	0,4	0,2
43	141	0,4	0,2	94	236	0,01	0,01
44	142	0,007	0,003	95	237	0,4	0,2
45	143	0,2	0,1	96	238	0,01	0,01
46	144	1,2	0,6	97	239	0,4	0,2
47	145	0,8	0,4	98	240	0,01	0,01
48	146	0,003	0,002	99	241	0,4	0,2
49	147	0,004	0,002	100	247	1,1	0,5
50	148	0,004	0,002	101	248	1,3	0,6
51	149	0,2	0,1	102	249	1,5	0,7

Based on the calculation results, although each outlet's discharge amount is ideal, Table 4 and Table 5 show that the amount of discharge varies. The amount of water discharge at the emitter on the left side is $0,0008 \text{ ml/sec} \leq Q \leq 2,6 \text{ ml/sec}$ while the amount of water discharge at the emitter on the right is $0,001 \text{ ml/sec} \leq Q \leq 1,1 \text{ ml/sec}$. This is due to the following reasons:

- a. The drip irrigation network system is designed with 275 nodes, 184 emitters and the remaining 91 regular nodes. Calculations utilizing the Newton-Raphson method yield a large discharge for every node, not just emitter nodes.
- b. It is known that the designed drip irrigation network system contains three types of pipes: 1 dim PVC pipe, 2 dim PVC pipe, and 0.5 dim HDPE pipe. Additionally, the length of the pipe that connects each node and forms the loop varies. This renders the specifications of each pipeline or loop distinct, so the results of calculating the amount of water discharge for each node will undoubtedly vary. The land contour, which influences the position of the pipes (height, low, and slope) and causes a difference in pressure on each pipe ((Kocyigit et al., 2015) in (Ifiemi et al., 2020)), also influences the variations in the amount of water discharged at the emitter.

From Table 4, it can be seen that the water discharge from each node forms a certain pattern in each loop. For example, in loop 6 with connected nodes 92 to node 102, each node has the same large debit, which is 0.2 ml/second. Furthermore, the nodes in loop 18 (node 80 to node 89) and loop 19 (node 104 to node 114) have a large discharge that continues to

increase by 0.2 ml/sec from left to right. There are loops that experience a change in discharge pattern that increases from the left and when it reaches the middle position, it then decreases to the right side such as loop 15 (node 25 to node 30), loop 16 (node 44 to node 50), and loop 20 (node 122 to node 124), or those with fluctuating debit changes such as loop 2 (node 16 to node 23), loop 3 (node 33 to node 42), loop 5 (node 68 to node 78) and loop 22 (node 165 to node 177). This is due to land conditions (Bachrun et al., 2020) and the flexibility of HDPE pipes to adapt to land conditions (Nguyen et al., 2021). The difference in water discharge at the nodes at the ends of the loop also affects the pipe bends that are formed due to the elbow (Bachrun et al., 2020). The same rationale also applies to Table 5.

By taking into account environmental conditions and pipe specifications, it is expected that the service life of the pipe will be longer, in line with the results of research by (Makris et al., 2020) which show that production, installation, and operation are factors that can affect the lifetime of pipes, as well as research by (Nguyen et al., 2021) which shows that the durability of HDPE and PVC pipes depends on the conditions of each installation area such as service conditions, soil modulus, and the regional and local environmental geology.

D. CONCLUSION AND SUGGESTIONS

Based on the results of research and discussion, it can be concluded that by using the Newton-Raphson method to calculate the water discharge of the drip irrigation network system for the coffee plantations of the Mutis Cemerlang farmer group, which is designed with 250 nodes, 275 pipes, and 26 loops, it is obtained that the amount of water discharge for each emitter is $0,0008 \text{ ml/sec} \leq Q \leq 2,6 \text{ ml/sec}$ for the left side and $0,001 \text{ ml/sec} \leq Q \leq 1,1 \text{ ml/sec}$ for the right side. Although the simulation results show that each outlet's discharge amount is ideal because it has a discharge correction value (ΔQ) ≈ 0 , Variations in water discharge are influenced by factors such as pipe installation itself, such as cross-section (pipe dimensions, bends, joints), surface roughness and flexibility of HDPE pipes as distribution pipes. Meanwhile, for further research, water discharge calculations can be carried out using other methods such as the Hardy-Cross method and the Linear Theory method to determine the difference in discharge values resulting from the three methods.

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