Irrigation volume calculation based on soil wetting pattern in trickle irrigation

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Abstract. The application trickle irrigation system is getting more intensive in Indonesia due to its high efficiency in recent time when water becomes increasing scarcely. The objective of this paper was to draw wetting pattern and to calculate the irrigation volume of trickle irrigation. Soil wetting pattern was observed by taking picture and measure the depth and width of water movement. Moisture content was measured using 26 sensors scattered in the observed soil column. Irrigation volume was calculated based on wetting pattern which containing soil moisture information. Soil texture used in this research was sandy clay soil with bulk density, particle density, and porosity were 1.3 gr/cm³, 2.41 gr/cm³, and 15.47% volume-based respectively. Research results showed that 25.56 cm³/minute irrigation discharge produced wetting pattern with dominant horizontal water movement. The 90-minute operation of trickle irrigation provide 3711 cm³ water in soil column.

1. Introduction

Water is an essential factor for agriculture. Main water source for crops is rainfall. Irrigation is defined as the supply of water to soil to fulfil fluid requirement for crop growth [1]. There are three main methods of irrigation namely surface, sprinkler, and drip or trickle irrigation [2]. Trickle irrigation is an irrigation method to supply irrigation water continuously directly to root zone to fulfil crop water requirement [3]. In trickle irrigation system, water is distributed through pipe network to emitter to discharge water to soil.

Trickle irrigation has a very high efficiency because it minimizes losses by reducing percolation, runoff, evaporation from soil surface. Trickle irrigation supply water with low discharge in a right duration to preserve soil moisture in the root zone [3]. Trickle irrigation may fulfil water requirement without wet all land. Water will flow from emitter through empty pores among soil particles and produce a pattern in soil called wetting pattern. Wetting pattern has a close relationship with irrigation discharge and volume as well as soil characteristics such as texture, structure, and soil moisture. Sandy soil transmits water faster than clay soil does. The lower soil moisture, the faster water disperses in it.

Wetting pattern is part of soil which is wetted with different soil moisture. The soil moisture defines irrigation volume used to define irrigation duration based on soil characteristics. The
objectives of this paper were to draw wetting pattern and to calculate the irrigation volume of trickle irrigation. The study on wetting pattern and irrigation volume was important to determine the discharge of trickle irrigation and the duration of water application.

2. Materials and Methods

2.1. Samples

Soil sample were taken from Bangka District, Bangka Belitung Province, Indonesia. The soil was transported to Universitas Gadjah Mada, Yogyakarta and analyzed in the Laboratory of Land and Water Engineering, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology.

2.2. Soil characteristics

Soil characteristics measured were bulk density, particle density, and texture. Bulk density shows the ratio between soil particle weight to total soil volume. It was determined by ring sample method. Particle density shows the ratio between soil particle weight to soil particle volume. Particle density was measured using pycnometer. Soil texture which shown distribution of particle size was measured using pipetting.

2.3. Experiment devices

Experiment devices in this research consisted of irrigation system and soil tank. The irrigation system consisted of pump, tank, pipe, and emitter. Design of irrigation system was shown in Fig 1. Water level in the tank was maintained constant during experiment to produce constant emitter discharge.

![Figure 1. Design of the irrigation network](image)

Soil placed in a transparent box sized 40 cm x 40 cm x 10 cm. A set of 3 cm x 3 cm gridlines were drawn on the front surface of the box to assist the inspection of wetting pattern. Soil box and its installment is shown in Fig. 2. There were 26 soil moisture sensors placed in
the soil to detect distribution of soil moisture content every 6 minutes. Placement of soil sensors were shown in Fig 3.

Figure 2. Soil box and its instalment with irrigation network

Figure 3. Placement of soil moisture sensors in soil box
2.4. Procedures
First step of the research was calibration of soil sensor by the comparing sensor read with the gravimetry moisture content. In the meanwhile, the irrigation system was set in 25 ml/minute by adjusting emitter opening and keep water level in the tank. Preparation of soil consisted of shifting and drying of sample soil. The soil was then placed in the box while installing sensors as shown in Fig. 3.

The irrigation was turned on and observation of wetting pattern was made every 6 minutes by taking picture of the box. The sensors were also read moisture content every 6 minutes and saved it in the data logger. One observation was made from 0 to 90 minutes. Replication was made by re-drying the soil, placing it again in the box, and running the irrigation supply.

2.5. Analysis
Analysis of wetting pattern were made by drawing the wetting pattern as shown in the picture. Descriptive analysis was made to relate shape of wetting pattern and soil characteristics. Sensor reads were used to draw contour line of soil moisture. From the contour lines, depth and radius of each contour were measured. Recorded measurements of contour lines were used to compute the irrigation volume using the formula of half-ellipse volume.

3. Results and discussion
3.1. Soil characteristics
Soil sample used in this research was categorized as sandy clay soil with composition of clay, silt, and sand particles were 39%, 13%, and 48%, respectively. Bulk density and particle density were 1.3 gram/cm$^3$ and 2.41 gram/cm$^3$, respectively. These characteristics indicated that soil had good ability to absorb water but poor ability to store water.

3.2. Soil wetting pattern
Soil wetting pattern of the sample soil were revealed in Fig 4 for three replications. The figure told that wetting pattern has a half-ellipse shape. In the beginning, water front move fast while at the end water front grow more slowly. The horizontal movement of water fronts were generally faster than the vertical movement. The rate movement of water front were affected by soil texture. The soil was sandy clay which have more micro pores and higher water holding capacity. Water moved slowly through micro pores with more contact area for water to stick. This reduce the vertical movement.

The wetting pattern as shown in Fig. 4 in general formed half-sphere shapes. Fig. 4 also shows that the form rate of wetting front was fast in early process and was getting slow later of the process. The later the process the denser wetting front in accordance with the wider area wetted.
3.3. Irrigation volume

The irrigation volume was calculated from wetting volume in the wetting distribution from the application of trickle irrigation. The wetting volume value was then multiplied by the average moisture content to obtain the volume of irrigation application. Results from measurements of the depth and width of wetting that have been included in the equation of the half-ellipse volume and wetting water volume were shown in Table 1, Table 2, and Table 3.

Table 1. Irrigation volume calculation for replication 1

| Minutes | Average moisture content (%) | Wetting volume (ml) | Irrigation volume (ml) |
|---------|-----------------------------|---------------------|------------------------|
| 6       | 0                           | 0                   | 0                      |
| 12      | 23.35                       | 521                 | 293                    |
| 18      | 22.58                       | 597                 | 325                    |
| 24      | 19.55                       | 884                 | 416                    |
| 30      | 21.48                       | 1856                | 961                    |
| 36      | 20.40                       | 2056                | 1011                   |
| 42      | 18.72                       | 2523                | 1138                   |
| 48      | 18.90                       | 3531                | 1608                   |
| 54      | 22.04                       | 2554                | 1357                   |
| 60      | 22.33                       | 3176                | 1709                   |
| 66      | 20.42                       | 3995                | 1966                   |
| 72      | 18.89                       | 6017                | 2739                   |
| 78      | 21.63                       | 5706                | 2974                   |
| 84      | 21.24                       | 7191                | 3681                   |
| 90      | 19.78                       | 9481                | 4520                   |
Table 2. Irrigation volume calculation for replication 2

| Minutes | Average moisture content (%) | Wetting volume (ml) | Irrigation volume (ml) |
|---------|-----------------------------|---------------------|-----------------------|
| 6       | 0                           | 0                   | 0                     |
| 12      | 40.77                       | 476                 | 467                   |
| 18      | 21.55                       | 1044                | 542                   |
| 24      | 20.46                       | 1139                | 561                   |
| 30      | 23.59                       | 1413                | 804                   |
| 36      | 24.55                       | 1719                | 1017                  |
| 42      | 22.59                       | 1899                | 1034                  |
| 48      | 24.20                       | 2583                | 1506                  |
| 54      | 24.86                       | 2949                | 1767                  |
| 60      | 24.01                       | 3346                | 1936                  |
| 66      | 26.42                       | 3118                | 1985                  |
| 72      | 23.50                       | 3555                | 2013                  |
| 78      | 23.75                       | 4602                | 2634                  |
| 84      | 22.90                       | 5470                | 3019                  |
| 90      | 22.45                       | 5549                | 3002                  |

Table 3. Irrigation volume calculation for replication 3

| Minutes | Average moisture content (%) | Wetting volume (ml) | Irrigation volume (ml) |
|---------|-----------------------------|---------------------|-----------------------|
| 6       | 27.29                       | 411                 | 270                   |
| 12      | 22.92                       | 625                 | 345                   |
| 18      | 20.75                       | 910                 | 455                   |
| 24      | 22.15                       | 1235                | 659                   |
| 30      | 19.66                       | 1662                | 787                   |
| 36      | 23.28                       | 2356                | 1322                  |
| 42      | 22.68                       | 2899                | 1584                  |
| 48      | 22.76                       | 3016                | 1654                  |
| 54      | 23.54                       | 3046                | 1728                  |
| 60      | 22.38                       | 3796                | 2047                  |
| 66      | 23.34                       | 4543                | 2556                  |
| 72      | 22.71                       | 5305                | 2904                  |
| 78      | 22.69                       | 5425                | 2966                  |
| 84      | 22.92                       | 5367                | 2965                  |
| 90      | 22.10                       | 5536                | 2949                  |

Irrigation volume depended on the discharge of emitter which was regulated by adjusting emitter and head of water reservoir. The wetted volume was increasing with the time of irrigation operation. In this research, the emitter discharge was set fix at 25.56 cm$^3$/minute.

The volume calculation used half of sphere volume based on wetted width and depth as parameters to calculate sphere volume. The wetted volume occurred in layers. The total volume was calculated as total of all layer volume. Irrigation supplied water in the volume to achieve field capacity. Table 1, Table 2, and Table 3 shows that average irrigation volume for 90-minute operation were 3711 cm$^3$. This information is important for the automation irrigation to determine the setting point of automation in trickle irrigation operation [4].

4. Conclusion

Based on discussion it was concluded that characteristics of soil shown by texture was sandy clay soil with bulk density, particle density, and porosity were 1.3 gr/cm$^3$, 2.41 gr/cm$^3$, and 15.47% volume-based respectively. Research results showed that 25.56 cm$^3$/minute
irrigation discharge produced wetting pattern with dominant horizontal water movement. The 90-minute operations of trickle irrigation provide 3711 cm$^3$ water in soil column.

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