Positioning of soil moisture sensors for actual conditions of crop water requirement in the controlled drip irrigation system

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Abstract. Controlled drip irrigation systems are one of the most efficient irrigation systems. The soil moisture sensor has a problem with positioning in the soil which causes errors in reading the actual moisture levels and failure to meet the actual crop water requirements. This research aims to determine the optimum position of the soil moisture sensor that represents the actual condition of the root crop water requirements. Knowledge of soil wetted arising from the infiltration of an efficient controlled irrigation system, determines the position of the sensor. The experiment used 26 soil moisture sensor and approached the ratio comparison between the observation of the volume wetting and the volume of the wetting sensor moisture in each segment with an interval of 6 minutes. Indicated the sensor at that location represented actual wetted these occurred in a controlled drip irrigation system. The results showed, the sensors of soil moisture numbers 16, 17 and 18 have the best R² average value of 0.973, 0.953 and 0.931. These values showed that optimal position of the soil moisture sensor, which represents the actual condition of the crop water requirements. Thus, in the application of drip irrigation the position of the optimal soil moisture sensor is controlled at a depth of 10 cm at a radius of 5 cm from the emitter.

1. Introduction
In dryland agriculture, the characteristics of the porous soil (quartz sand) and high surface temperature make the value of evapotranspiration [1]. Encouraging the need to use water-saving irrigation technology [2]. Drip irrigation is an option because water is only applied to the root zone of plants, thereby minimizing percolation and evaporation [3].

Drip irrigation which generally works based on scheduling the time of giving water has a weakness in operation, because the provision of water is often not in accordance with the actual water requirements of the plant. According [4], this weakness can be overcome through the application of a control system in the form of a soil moisture sensor to measure the level of crop water needs based on the availability of water in the soil. The application of controlled drip irrigation in the field is often constrained by actual soil moisture readings. According [5], the error of the sensor reading is due to the inaccuracy of the sensor. This will reduce the operational capability of controlled drip irrigation in meeting plant water needs.

Based on these problems, it is necessary to simulate the sensor placement using a soil wetting approach. Based on soil wetting, information will be obtained about the depth and width of the spread
and the amount of moisture content. The results will be a material consideration for optimizing the placement of moisture sensors. The right placement of the sensor is expected to represent the actual condition of the plant root system in reading moisture content. Provision of irrigation water in controlled drip irrigation systems is expected to be more accurate, economical and in accordance with the conditions of water availability in the roots of plants. Consider, the condition of podzolic and sandy soils having low water binding capacity (water sensitive soil)

The study aims to overcome the problem of the accuracy of the operation of controlled drip irrigation systems, in the form of the ability to maintain water levels at available water levels from actual plant water requirements. So that plant growth can be optimal with good water supply amid high evapotranspiration values, porous soil conditions and limited water availability.

2. Material and Method

In this study, soil samples were taken from pepper plantations in Bangka Regency, Bangka Belitung Islands. Soil samples were analysis at the Laboratory of Soil BPTP Yogyakarta. Research on determining the position of sensors was carried out in the Land and Water Resources Engineering Laboratory of the Department of Agricultural Engineering and Biosystems of the Faculty of Agricultural Technology, Universitas Gadjah Mada. The materials used are: the soil with sandy loam structure (18% of clays, sand 61% and 21% silt); glass box (40 cm x 40 cm x 10 cm); and a set of soil moisture sensor (26 sensors) completed with appropriate data acquisition device (consists of microcontroller Arduino, data logger and timer).

This study was conducted in a series of stages, procedure of this research is shown on Figure 1. The research begins with literature study, followed by designing of the experimental setup Figure 2, namely drip irrigation system, a set of capacitive soil moisture sensor and glass box observation. After the hardware has functioned properly, the study continued drip irrigation application on glass box observation (filled with soil samples and moisture sensors) Figure 3.

![Figure 1. Research procedure](image-url)
Determining the placement of soil moisture sensors, using an approach in the form of a comparison of the correlation of the volume of wetting observation and the volume of wetting sensor moisture. Calculations are carried out by looking at the volume of each segment at 6 minutes intervals for 1.5 hours. Correlation is carried out on each ground sensor (26 sensors) against the volume of discussion for each segment.

The wetting volume comes from the moisture content detected by the soil moisture sensor while the irrigation volume is obtained from the sum of the wetting volume of each contour (segment) in the wetting pattern in the available water range. The wetting volume is described as an ellipse so that the wetting volume considered to be equal to half of the ellipse volume with Equation 1:

\[ V = \frac{4}{3} \pi a d z \]  

\( a = \) wetting thickness (cm)  
\( d = \) wetting width (cm)  
\( z = \) wetting depth (cm)

Determination of volumetric water content is derived from the wetting volume based on the moisture content detected by the soil moisture sensor. Given the soil moisture sensor used is capacitance based is the percent mass of water (\( \theta_m \)) from the gravimetric method. So, determine the volume of water (\( \theta_v \)) Equation 2 is needed:

\[ \theta_v = \theta_m \frac{BJ_{\text{soil}}}{BJ_{\text{air}}} \]  

Where: \( \theta_m \) =% mass of water; \( \theta_v \) = volume of water, soil = soil density and BJair = water density
The sensor placement decision is based on the magnitude of the average value of $R^2$ (Willmut, 1982) generated by each sensor in 3 replications in the interval of data collection every 6 minutes for a period of 1.5 hours.

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(C_{si} - C_{oi})^2}{\sum_{i=1}^{N}(C_{si} - C_{o})^2}$$

where N = total number data; Csi = simulated data; Coi = observed data; and Co = mean of observed data. The greater the average value of $R^2$, the better the correlation value between wetting volume the simulation data from the sensor and the observation data. This correlation indicates that the sensor can represent actual wetting readings that occur in a controlled drip irrigation system.

3. Result and Discussion

Observation In the controlled application of drip irrigation, the position of the sensor in the soil is important because the sensor represents the actual condition of the water needs of the plant roots. In a controlled drip irrigation system, soil moisture sensors will be used as feedback in determining the application of drip irrigation. Determining the position of the soil moisture sensor, the approach taken is a comparison of the correlation of the observation wetting volume ($V_{\text{observation}}$) and the wetting volume of the reading soil moisture sensor ($V_{\text{sensor}}$). Calculations are carried out on the wetting volume of each segment in a time interval of 6 minutes for 90 minutes. Correlation is carried out on each sensor (26 pieces) against the volume of discussion for each segment. The value of volume produced by each sensor is considered to represent the overall volume of wetting.

The wetting volume of drip irrigation is a combination of readings of the moisture content of the sensor by measuring the pattern of width and depth of wetting. Results from measurements of the depth and width of wetting that have been included in the half ellipsoidal volume equation (Equation 1) and volume of water (Equation 2). Generally, overall replication in the application of drip irrigation showed good performance. The value of the volume of drip irrigation produced is good enough to show the performance of drip irrigation and reading by the soil moisture sensor as a control system. Likewise, a surge in the volume of drip irrigation is possible because of parallel reading of the moisture so that the performance of the sensor is weak. The results of observations of wetting from the application of drip irrigation were used as an approach in determining the volume of irrigation.

The decision on the location of the right ground sensor is based on the amount of $R^2$ produced by each sensor in 3 replications. The bigger or close to 1 of the value $R^2$, the better the correlation value. This shows that the location of the sensor can represent actual wetting readings that occur in a controlled drip irrigation system. The location of the sensor both in terms of width and depth, is based on the configuration of the sensor position listed in Figure 3.

| Sensor Number | Replication 1 | Replication 2 | Replication 3 | Average |
|---------------|---------------|---------------|---------------|---------|
| 1             | -1.661        | -3.139        | -2.905        | -2.568  |
| 2             | -1.535        | -1.793        | -1.960        | -1.763  |
| 3             | 0.153         | -0.552        | 0.035         | -0.115  |
| 4             | 0.360         | -0.510        | 0.107         | -0.014  |
| 5             | -0.568        | -0.939        | -0.276        | -0.594  |
| 6             | -1.661        | -2.978        | 0.84          | -1.266  |
| 7             | -1.661        | -3.139        | 0.555         | -1.415  |
| 8             | 0.266         | -0.112        | -1.281        | -0.376  |
| 9             | 0.576         | 0.653         | -2.801        | -0.524  |
| 10            | 0.807         | 0.686         | 0.851         | 0.781   |
| 11            | 0.693         | 0.692         | 0.839         | 0.742   |
| 12            | 0.218         | 0.454         | 0.555         | 0.409   |
| 13            | -1.052        | -1.278        | -1.28         | -1.204  |
| 14            | -1.595        | -0.672        | -2.8          | -1.689  |
Based on the analysis of the volume of wetting observation ($V_{\text{observation}}$) and wetting volume from the sensor reading ($V_{\text{sensor}}$) of each segment. The results obtained are the $R^2$ value of each humidity sensor to the accuracy of the actual moisture readings shown in Table 1. Each $R^2$ value is displayed is a value that represents the performance of soil moisture sensors during drip irrigation applications. Based on the value of $R^2$, there is information that the closer the sensor is to the emitter, the better the ability of the sensor to represent the sensor readings. But the trend will change when the sensor is located too close to the surface and the location of the drip emitter dripping with irrigation water.

| Sensor | $V_{\text{observation}}$ | $V_{\text{sensor}}$ | $R^2$  |
|--------|--------------------------|---------------------|--------|
| 15     | 0.876                    | 0.862               | 0.851  | 0.863 |
| 16     | 0.969                    | 0.972               | 0.978  | 0.973 |
| 17     | 0.967                    | 0.946               | 0.946  | 0.953 |
| 18     | 0.875                    | 0.946               | 0.973  | 0.931 |
| 19     | 0.786                    | 0.846               | 0.810  | 0.814 |
| 20     | -0.293                   | -0.217              | -2.543 | -1.018|
| 21     | -0.211                   | 0.121               | 0.214  | 0.041 |
| 22     | 0.988                    | 0.929               | 0.939  | 0.952 |
| 23     | 0.376                    | 0.963               | 0.979  | 0.773 |
| 24     | 0.987                    | -9.920              | -0.792 | -3.241|
| 25     | 0.940                    | 0.949               | 0.980  | 0.957 |
| 26     | -0.192                   | 0.912               | 0.914  | 0.544 |

**Figure 4. Optimum position of soil moisture sensor**

Determining the location of the sensor is based on the value of $R^2$ of each sensor in Table 1. adjusted to its location on the wetting observation plot. Figure 4. is the result of analysed the location of the optimum sensor after adjusting between the location of the sensor and the value of $R^2$. The results show that sensors with numbers 15, 16, 17, 18, 19 or second row from the ground have the best $R^2$ value (0.81-0.97) because the value is close to 1 among the other sensors (26 sensors). Based on this value, the laying of the soil moisture sensor in this line is considered to provide a better actual condition of soil moisture. Among the humidity sensors in the row, the best sensor location is sensor number 16, 17, 18 with $R^2$ values (0.93-0.97).

Sensor number 24, the worst reading condition (error) occurs with $R^2$ value of -3.24. This indicates that the sensor worked improperly because it is not represented the actual moisture conditions, when located too close to the emitter. This can be seen also in the visual observation of wetting and irrigation volume readings carried out in this study. Regarding the position of placement of soil moisture sensors, both in terms of depth and width from the location of sensors number 16, 17 and 18 based on Figure 4. The recommended sensor depth is 10 cm from the ground surface with a width of 5 cm right and 5 cm left from the centre of the emitter.
4. Conclusion

The optimum position for soil moisture sensors that represent the actual conditions of water requirements in plant roots can be determined by the correlation value ($R^2$). Sensors number 16, 17 and 18 have the value $R^2$ (0.93-0.97) which best shows the optimal location of the sensor in the reading of soil moisture that is at a depth of 10 cm and a width of 5 cm right and 5 cm left from the emitter.

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