Application of Logistic Model to Root Growth of Vegetables under Drip and Mist Irrigation

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ABSTRACT

Mathematical model uses a set of mathematical equation to represent of a system. In agriculture, one of the functions of mathematical models is to predict crop growth. The objective of this paper was to apply the logistic model to root growth of three types of vegetables, namely water spinach, mustard, and spinach. The vegetables were cultivated in a screen house and irrigated with drip and mist irrigation. The vegetables were grown in rhizobox-type root windows to observe the root depth every other day. The logistic model was then applied to root depth to determine model parameter μ to characterize each root growth. The analysis resulted that the model parameter μ were -0.087, -0.116, -0.166 for water spinach, mustard, and spinach under drip irrigation, respectively. Meanwhile, the model parameter μ for water spinach, mustard, and spinach under mist irrigation were -0.107, -0.144, and -0.141, respectively. Graphically, the logistic model performed better for spinach then that of other vegetables. However, the results of calibration with t-test indicated that the logistic model was accepted for all crops and all types of irrigation shown by the predicted root growth were not significantly different from the observation root growth.

***Keywords**: Logistic Model, Root Growth, Drip Irrigation, Mist Irrigation, Vegetables.*

1. BACKGROUND

A model imitates behaviour of a system systematically. A mathematical model uses an equation or a set of equation to represent the behaviour of a system (1). There is a relationship among variables of the model and the observable quantities.

Mathematical model can be categorized in several ways. Considering whether the processed is included or not in model development, the model may be empirical or mechanistic. An empirical model aims to describe the respond of the system due to inputs without any explanation of the mechanism of the process while mechanistic model provides explanation of the phenomena being modelled. According to its association with probability, models can be categorized into deterministic and stochastic. A stochastic model takes random element into account while a deterministic model makes definite prediction without any association with probability distribution. Considering the time component in the model, it is known dynamic and static models. A dynamic model predicts how quantities vary with time while a static model does not contain time as a variable and does not make time-dependent predictions.

In agriculture, modelling is useful for prediction, understanding process, and effective management. Agriculture as a system consists of interrelated subsystems of domesticated plants and animals, natural resources, flora and fauna, as well as human sub-system. Mathematical model may represent a system or a subsystem in agriculture.

Modelling in agriculture usually employs dynamic model, which describe the time course of events over periods from a few days or a growing season to many years. Sometimes the model is presented as a set of difference equations relating with time as one of independent variables. There are numerous types of models in agriculture. One of them is crop growth model.

Crop growth modelling is a quantitative approach to predict plant growth, development, and yield as well as variables related to environmental factors. Valid models can help make agronomic decisions such as planting time, planting density, nitrogen fertilization rate, risk analysis and irrigation. The development of this crop growth model can be used on several types of plant variables such as biomass, seed production, root growth, leaf area index and plant nitrogen (2). There are several types of crop growth models that can be used to predict plant growth including, Quadratic Fit, Gompertz Model, Logistic Model and others (3).

Vegetables are essential crops to produce food. They contain several nutrition necessary for human body. Therefore, production of vegetables is interesting to be explored. Recent research mostly focused on the upper part of plants. However, roots have also an important function to plant growth. Roots function to support plant body, absorb water, nutrients, and respiration.

Different irrigation methods result in different plant growth, including root. The plant response to touch, stimulation or mechanical pressure from outside the plant which affects the growth and development of plants is called thigmomorphogenesis (4). This research objective was to apply logistic model on the root growth of vegetable crops under drip and mist irrigation.

2. METHOD

The research was conducted at a screen house located in Depok, Sleman, Yogyakarta Special Region and the Laboratory of Land and Water Resources Engineering Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology UGM. The stages in this research included preparation of the screen house and root window, instalment of irrigation system, cultivation, data collection, and data analysis. Root length measurements were carried out for 25 days from February 1 - 25, 2021.

Vegetables cultivated were water spinach, mustard, and spinach. Observation of crop roots using root window media and measurement of growth parameters using a ruler, scales, and oven.

The research used a screen house with a size of 4.5 m x 3.5 m x 2.5 m as shown in Figure 1. The screenhouse building is divided into two parts for drip irrigation and mist irrigation treatment areas.

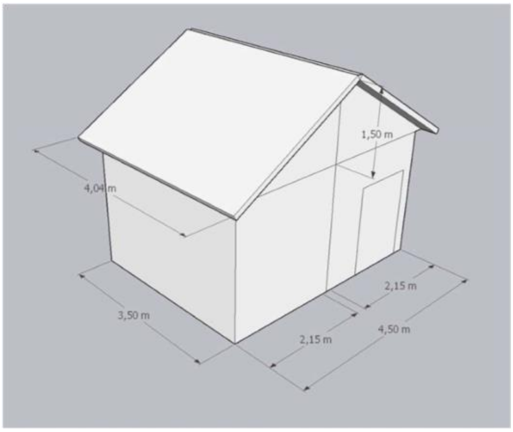


Figure 1. Screenhouse scheme

After the screen house was built, the root window is prepared to observe the growth of plant roots. The type of root window used in this research was a rhizobox made of plastic containers. The root window had dimensions of 46 cm x 34 cm x 25.6 cm as shown in Figure 2. At the bottom of the root window, there is a hole for drainage of irrigation water

Figure 2. Root window setup scheme

The next stage, the installation of irrigation in each treatment, namely drip irrigation and mist irrigation, were used. All irrigation components installed are then calibrated irrigation. Calibration carried out included crop water requirements, discharge, irrigation duration, and coefficient of uniformity (CU).

The discharge measurement was carried out by collecting water using the root window cover that falls on the top surface of the root window. Each discharge measurement was carried out for 120 seconds and 3 repetitions. The discharge calculation is carried out using Equation (1).

$$\text{discharge (Q)} = \frac{Volume\ (liter)}{Time\ (second)} \quad (1)$$

Then, the calculation of the irrigation water supply duration used Equation (2).

$$Duration = \frac{crop\ water\ requirement\ (ml)}{Time(\frac{ml}{second})x60(\frac{detik}{second})} \quad (2)$$

Coefficient of uniformity is a method to measure the degree of uniformity of irrigation. The calculation of the irrigation uniformity value uses Christiansen Uniformity (CU) as shown in Equation (3).

$$CU = \left[1 - \left(\frac{\sum|xi - \underline{x}|}{\sum xi}\right) x100\%\right] \quad (4)$$

Description:

CU = coefficient of uniformity (%)

xi = volume of irrigation water (ml)

$\underline{x}$ = average volume of irrigation water (ml)

$\sum|xi - \underline{x}|$ = total absolute deviation from the mean of measurement (ml)

After calibration, seed preparation in the screenhouse. Seed preparation was carried out in a container that was given a soil medium with a composition of cocopeat, husk charcoal, sand, and manure. Seeds were spread evenly into containers containing planting media and given using planting media. Irrigation was applied twice a day. Seeds were transferred to the root window after 14 days. Each root window planted 6 plants of the same kind right on the wall of the root window and the spacing was adjusted. The crop layout scheme was shown in Figure 3.

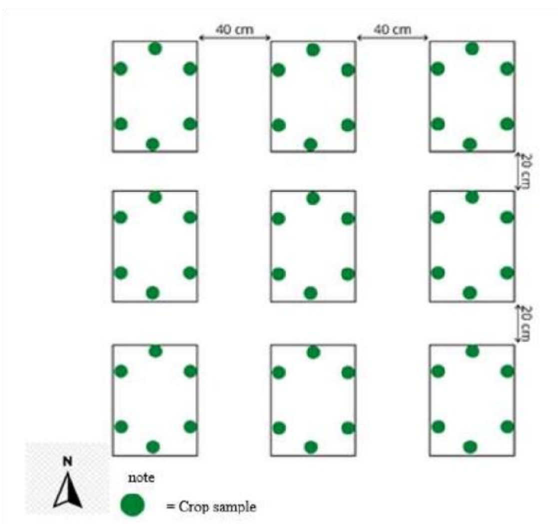


Figure 3. Crop layout scheme

Depth of root (L) was measured daily. The root depth was analysed using the logistic model (1) as shown in equation (5).

$$\frac{dL}{dt} = \mu L(1 - \frac{L}{Lf}) \quad (5)$$

Equation (5) was then integrated from initial condition at planting day t = 0 with initial root length L = L0 until final condition t = t and root length was in its final condition L = Lf as shown in equation (6).

$$\int_{L0}^{Lf}(\frac{1}{Lf-} + \frac{1}{L})dL = \int_0^t \mu dt \quad (6)$$

The solution from equation (6) was shown in equation (7) to determine the parameter μ or the growth coefficient.

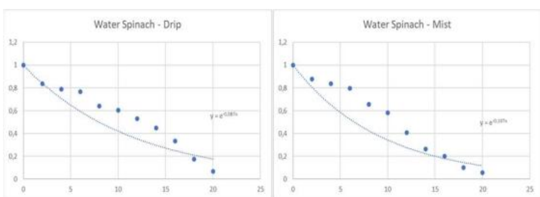
$$e^{-\mu.t} = \frac{L0(Lf-)}{L(Lf-)} \quad (7)$$

The graph regression was employed in each to determine model parameter μ. The model of each crop and irrigation method was the calibrated by comparing the model prediction to observation.

3. RESULT AND DISCUSSION

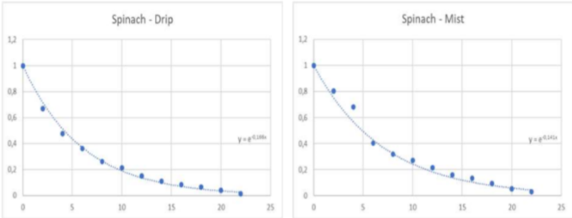
Logistic model was chosen to describe the cop growth because it has S-shape which is similar to the growth rate of plant in general. In the early-stage crop grows slowly. In the middle, the growth rate of plant increase as the middle stage is vegetative stage. At the end of plant growth rate getting slow because it was in generative stage when plant tends to produce flower and fruit rather than getting bigger or taller.

Model parameters of three crops and two irrigation methods were determined using graph in Figure 4, Figure 5 and Figure 6.



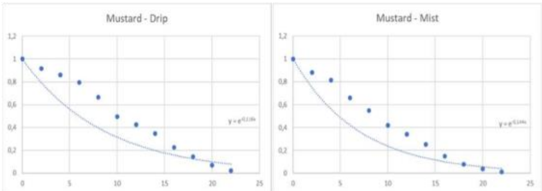
(a) (b)

Figure 4. Parameter determination of water spinach under drip (a) and mist (b) irrigation



(a) (b)

Figure 5. Parameter determination of mustard under drip (a) and mist (b) irrigation



(a) (b)

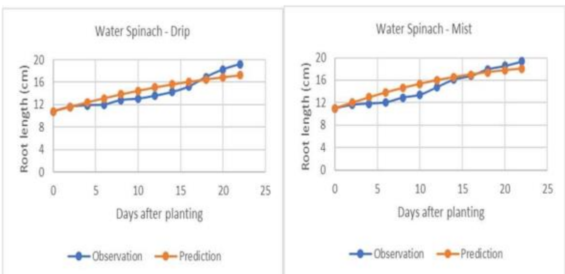
Figure 6. Parameter determination of spinach under drip (a) and mist (b) irrigation

From Figure 4, Figure 5, and Figure 6 the model parameter µ has been found as shown in Table 1

Table 1. Model Parameter of Logistic Model Crop Growth

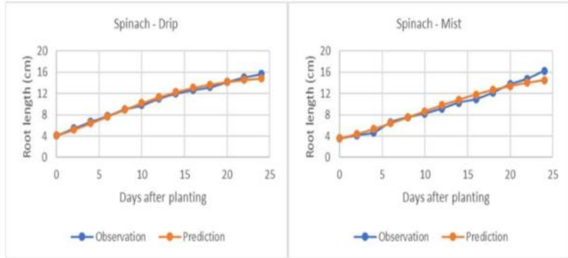
Vegetable	Irrigation	µ
Water spinach	Drip	-0.087
Water spinach	Mist	-0.107
Mustard	Drip	-0.116
Mustard	Mist	-0.144
Spinach	Drip	-0.166
Spinach	Mist	-0.141

The logistic model parameter µ as shown in Table 1 was used t determine root depth every day t. The predictions obtained from model was then plotted in a graph together with observed root depth. Figure 7, Figure 8, and Figure 9 showed the comparison of root length between observation and prediction of the water spinach, mustard, and spinach, respectively.



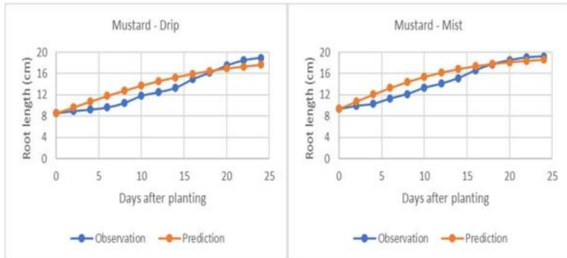
(a) (b)

Figure 7. Calibration of logistic model of water spinach root growth under drip (a) and mist (b) irrigation



(a) (b)

Figure 8. Calibration of logistic model of mustard root growth under drip (a) and mist (b) irrigation



(a) (b)

Figure 9. Calibration of logistic model of water spinach root growth under drip (a) and mist (b) irrigation

Figure 7 and Figure 8 showed that the root growth predictions were not similar to the observation. The prediction tended to be overestimate in the middle stage of crop growth. On the other hand, Figure 9 shows that for spinach prediction could fit better.

Statistical analysis t-test was then employed to compare the prediction and observation of root length. Table 2 showed the t-test result which compare observation and prediction of root length data. The table was obtained from each pair with number of samples 12 and degree of freedom 11.

Table 2. Statistical t-test result

Treatment	No. of samples	DF	t-value	t-table
Water spinach Drip	12	11	0.1647	2.2010
Water spinach Mist	12	11	0.0619	2.2010
Mustard Drip	13	12	0.0182	2.1788
Mustard Mist	13	12	0.0060	2.1788
Spinach Drip	13	12	0.4384	2.1788
Spinach Mist	13	12	0.4228	2.1788

Based on Table 2, it is concluded that all the prediction values does not significantly different from

4. CONCLUSION

The logistic model applied to root depth to determine model parameter µ to characterize each root growth. The analysis resulted that the model parameter µ were -0.087, -0.116, -0.166 for water spinach, mustard, and spinach under drip irrigation, respectively. Meanwhile, the model parameter µ for water spinach, mustard, and spinach under mist irrigation were -0.107, -0.144, and -0.141, respectively. Graphically, the logistic model performed better for spinach then that of other vegetables. However, the results of calibration with t-test indicated that the logistic model was accepted for all crops and all types of irrigation shown by the predicted root growth were not significantly different from the observation root growth.

AUTHORS' CONTRIBUTIONS

All of he authors actively contributed during experimental design and data collection. Murtiningrum was the leader and coordinator while Ngadisih designed the root windows. Ilham Nawan Rasyid, Lia Christyaningrum, and Erlina Fahrunisa were responsible for analysis of spinach, mustard, and water spinach, respectively

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