Mathematical modelling of soybean var. anjasmoro plant growth

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Abstract: Thorough understanding of interactions between all factors involved in soybean plant cultivation process is needed to increase the yield. This study is aimed to determine which interaction has the highest correlation according to the Pearson correlation coefficient, to define a certain model for said interaction, and to confirm the identicality of all samples that were observed using destructive sampling method. After being tested using Pearson correlation coefficient, the highest r value is 0.81 which is between plant height and number of leaves, proving they are highly related. Both parameters were simulated in several different ways until it was found that number of leaves variable is best described as function of plant height variable, the equation is \( y_1 = 0.85x_1 + c_1 \) where \( y_1 \) represents number of leaves and \( x_1 \) represents plant height. Identicality between all plants is not confirmed, thus destructive sampling method is not recommended to be applied for similar studies.

Keywords: Identicality, interaction, soybean plant.

1. Introduction
Soybean production in Indonesia still has not reached its full potential yet [1]. This is mostly due to the lack of detailed knowledge about the best cultivation method for soybean, especially in the terms of fulfilling plant’s needs of nutrient, water, sunlight, and other supporting components with the right amount and at the right time in order to produce the optimum yield [2]. To be able to meet the needs of plants in appropriate amount and time, an understanding of the relationship between plant growth supporting components and their effect on the plant’s physical parameters is required, from which a certain model can be defined in order to understand those relationships more easily [3].

This study is conducted to define the interrelationship between soybean plant growth supporting components such as water needs, total nitrogen, nitrogen fixing bacteria population, and soybean plant physical parameters which are plants height, and number of leaves [4]. Pearson correlation coefficient is used in this study due to its ability to show the coefficient of correlation between the two variables [5]. Furthermore, the plant growth pattern is also analyzed through plants height changes, and its interaction with the number of leaves changes using simulations with random numbers.
The study was conducted by planting 39 soybean plants in a greenhouse using polybags by following an established method of soybean plant cultivation stated by Indonesian Legumes and Tuber Crop Research Institute [6]. The parameters being observed are divided into two categories. The first one is the destructive parameter [7], it includes total nitrogen content and nitrogen fixing bacteria population. To obtained the required data for this parameter, three soybean plants are chosen randomly every once in a week for 13 weeks to be destructed. The next one is non-destructive parameter, it includes plant height and number of leaves. the data for this parameter is obtained from all of the remaining plants every once in a week for 13 weeks.

All the average value of all parameters obtained every week for 13 weeks were then being tested using pearson correlation coefficient [8]. Plant height parameter continued to be simulated using logarithmic growth with limit function. Number of leaves parameter continued to be analyzed of its interaction with plant height, and also simulated as several different functions, which are as a function of plant height, as a function of time (week/s after planting), and using a data generated with random numbers.

2. Model
2.1. Schematic of Components Relation
There are five main components in the soybean plant cultivation system considered in this study, which are environment [EV] (sun light intensity), water needs [WN] (evaporation [EP], transpiration [TP]), population of nitrogen fixing bacteria in soil [PNB], total nitrogen content [TN] (of soil [NS] and plant tissue [NP]), and plant’s physiology (plant height [PH], number of leaves [NL]). Several of these components has an inevitable reciprocal relationship, for example the relationship between nitrogen content and nitrogen fixing bacteria population [9].

EV can not be controlled; EP in WN will depend to EV and NL; TP ini WN will depend to EV, NP and NL; PNB will depend to EV, EP and NS; NS will depend to PNB and NP; NP will depend to NS, PH, and NL; PH will depend to EV, WN, TN, and NL; while NL will also depend to EV, WN, TN, and PH.

Figure 1. Interactions between components involved in the soybean cultivation system. The interactions between components involved in the system are illustrated at figure 1 (right), and the diagram is also shown at figure 1 (left).
2.2. Pearson Correlation Coefficient
The data obtained during soybean cultivation process are as follows:

**Figure 2.** Soybean plant height during cultivation process.

**Figure 3.** Soybean plant number of leaves during cultivation process.

**Figure 4.** Soybean plant evaporation, transpiration, and water needs during the cultivation process.

**Figure 5.** Total nitrogen content at soil and soybean plant tissue during cultivation process.

**Figure 6.** Population rate of nitrogen fixing bacteria at soil during cultivation process.
From the figure 2 to 6, it can be seen that the data obtained is quite varied and not always forming a smooth line. The interactions between each of those parameters with all other parameters were then being tested using pearson correlation coefficient \cite{8} and the results are as follows:

**Table 1.** Pearson coefficient correlation value of interactions between all components involved in soybean plant cultivation system.

|                    | Plant Height | Number of Leaves | Evaporation | Transpiration | Plant Water Needs | Total Nitrogen of Plant Tissue | Total Nitrogen of Soil | Nitrogen Fixing Bacteria Population |
|--------------------|--------------|------------------|-------------|---------------|-------------------|-------------------------------|------------------------|-------------------------------------|
| **Plant Height**   | 1.00         | -0.31            | -0.25       | -0.26         | -0.37             | -0.38                         | 0.12                   |                                     |
| **Number of Leaves** | 1.00     | -0.05            | -0.18       | -0.09         | -0.25             | -0.31                         | 0.01                   |                                     |
| **Evaporation**    | 1.00         | 0.67             | 0.46        | 0.55          | 0.55              | -0.40                         | -0.39                  |                                     |
| **Transpiration**  | 1.00         | 0.58             | 0.70        | 0.72          | 0.45              |                               | -0.45                  |                                     |
| **Plant Water Needs** | 1.00   |                  |             |               |                   |                               |                        |                                     |
| **Total Nitrogen of Plant Tissue** | 1.00 |                  |             |               |                   |                               |                        |                                     |
| **Total Nitrogen of Soil** |               |                  |             |               |                   |                               |                        | 1.00                                |
| **Nitrogen Fixing Bacteria Population** |               |                  |             |               |                   |                               |                        |                                     |

2.3. **Plant Height**

Living creature’s growth, including soybean plant growth, as can be seen through its height growth, commonly can be justified using the function of logarithmic growth with limit (equation 1) \cite{10},

\[
H = \frac{H_0}{1 + \left(\frac{H_0}{H_{\text{max}} - H_0}\right)e^{rt}}
\]  

(1)
Thus, it will follow the sigmoid curve as seen in figure 7 below:

![Figure 7. Height of plant over time.](image)

![Figure 8. Comparison between simulated growth curve and original data of plant height.](image)

However, the plant height changes data obtained from the field observation in this study as seen at Figure 2, is scattered randomly and does not form a smooth sigmoid curve. The comparison between the original data obtained and simulated data using the equation of logarithmic growth with limit is as seen at figure 8.

This happened due to the usage of destructive method for the data sampling, in which the plant is being destructed routinely during the cultivation process, and all the plants involved in the study is assumed to be identical, therefore the remaining plants are assumed to be able to represent the already destructed plants until the end of the cultivation period. In fact, according to the previous research reported [3], each individual of plant, although it comes from the same variety and is claimed to have high similarity, has their own way to express their genetic information, and it will very much depend on the conditions they are exposed into.

Hence, to mimic the process of data sampling using destructive method, we simulate the plant height data using equation (1). The two variables are $H_{\text{max}}$ that represents the maximum height possibly reached by the soybean plant, and $r$ that represents the growth rate of soybean plants, both are modified using random numbers to picture the difference of genetic expression of each individual plant. As for $H_0$, it is equated with the value of $H_0$ from the field observation, which is 11.95. The sigmoid curves generated from equation (1) should be able to cover the maximum and minimum value of the original data, and other curves that lie between those two. This process resulted on figure 9 below.

![Figure 9. Simulation of soybean plant height growth considering the difference at genetic information expressed by each individual plant.](image)
The data forming the chart at figure 9 is then eliminated one by one for each week to demonstrate the process of destructive sampling process as follows:

Table 2. Soybean plant height data simulation of destructive data sampling method.

| Week | Original Data | S Data | Average of Data Simulation |
|------|---------------|--------|---------------------------|
| 0    | 0.00          | 11.95  | 11.95                     |
| 1    | 11.95         | 18.99  | 18.95                     |
| 2    | 20.42         | 29.56  | 29.62                     |
| 3    | 31.25         | 44.63  | 45.79                     |
| 4    | 60.75         | 64.59  | 67.73                     |
| 5    | 98.67         | 88.64  | 90.70                     |
| 6    | 111.83        | 114.49 | 113.02                    |
| 7    | 135.67        | 139.09 | 131.76                    |
| 8    | 152.33        | 159.94 | 150.60                    |
| 9    | 181.50        | 175.94 | 167.15                    |
| 10   | 190.83        | 187.30 | 174.98                    |
| 11   | 197.75        | 194.93 | 184.80                    |
| 12   | 202.95        | 199.87 | 196.76                    |
| 13   | 208.14        | 202.99 | 202.99                    |

The yellow box represents the data absent due to destructive sampling activity. The average value is then calculated from the remaining data, and then it is plotted into a graph and is compared with the original data obtained by field observation to see the similarity.

2.4. Number of Leaves

According to pearson correlation coefficient calculation, the r value of plant height interaction to number of leaves is 0.81, which is a strong positive correlation, it means that high score at plant height variable will go with high score of number of leaves [5]. Hence we proposed number of leaves variables as the function of plant height generated from one of simulated data in the previous section, using the following equation:

\[ y_1 = 0.85x_1 + c_1 \]  (2)

With \( y_1 \) represents the number of leaves and \( x_1 \) represents the plant height.

Next we also proposed number of leaves as the function of time, in this case is weeks after planting, using the following equation:

\[ y_2 = 15.45x_2 + c_2 \]  (3)

With \( y_2 \) represents the number of leaves and \( x_2 \) represents the weeks after planting.

Last we proposed number of leaves data generated using random numbers.

The result of these three simulations are then compared to the field observation data of number of leaves and its correlation with the plant height are also tested using pearson correlation coefficient. The result is shown in the following figure.
3. Result and Discussion

From the Pearson correlation coefficient (Table 1), it is known that the highest $r$ value of 0.81 is obtained from the interaction between the plant height variable and the number of leaves variable. This phenomenon corresponds to the previous research that reported the positive interrelationship between plant height and the number of leaves, both having a positive correlation with relative plant maturity [4].

The next highest $r$ value is 0.72 and is obtained from the interaction between total nitrogen content and water needs, which also corresponds with previous research that mentions the positive correlation between precipitation and net nitrogen availability in a cultivation system [11].

The original data of plant height obtained from field observation of this study has a relatively high similarity with the simulated data of plant height generated from logarithmic growth with limit function with the destructive data sampling method being considered. The result as seen at the following figure:

![Figure 11. Comparison between original plant height data and simulated plant height data considering the destructive method of data sampling.](image-url)
It proves that the plants used in the study are not identical, thus assuming that the remaining plants could represent the already destructed plants in the practice of destructive method of data sampling is not recommended.

The highest Pearson coefficient correlation is obtained from the interactions between plant height and number of leaves simulation data generated from the equation (2) with the r value of 0.93. Hence it confirms that number of leaves can be well described as the function of plant height. But this equation has a limitation, that is can not quite describe the declining in the number of leaves towards the end of the cultivation process that is caused by the soybean plant sheds its leaves as a signal telling that it is ready to be harvested.

4. Conclusion
According to Pearson correlation coefficient, interactions between components involved in this study with the highest correlations are interactions between plant height and number of leaves with r value of 0.81, and interaction between total nitrogen rate and transpiration rate with an r value of 0.72.

Data sampling using destructive method with a small number of sample will lead into the collection of less representative data, because the plants are not identical, each plants has their own way of expressing genetic information depends to the condition they are exposed into.

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Data sampling using destructive method with a small number of sample will lead into the collection of less representative data, because the plants are not identical, each plants has their own way of expressing genetic information depends to the condition they are exposed into.

The number of leaves variable is the function of plant height variable, the equation is $y_i = 0.85x_i + c_i$ where $y_i$ represents number of leaves and $x_i$ represents plant height. The disadvantage of this equation is its inability to describe the declining in the number of leaves towards the end of the cultivation period.

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