CONTROLLED ELECTRICAL CONDUCTIVITY (EC) OF TOFU WASTEWATER AS A HYDROPONIC NUTRITION

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CONTROLLED ELECTRICAL CONDUCTIVITY (EC) OF TOFU WASTEWATER AS A HYDROPONIC NUTRITION*

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University of Lampung, Department of Agricultural Engineering, Lampung, Indonesia

Abstract

Tofu wastewater has the potential to become an organic fertilizer because of its protein content. The utilization of tofu wastewater into organic fertilizer is an effort to resolve the environmental pollution issue. This study used tofu wastewater obtained from local tofu producer in the city of Bandar Lampung, Indonesia. Tofu wastewater is diluted using clean water in a ratio of 1:5, 1:10, and 1:20. Electrical conductivity (EC) settings are carried out using an automatic control system based on a self-assembled microcontroller. Controlling the EC will be beneficial because a hydroponic system depends on the minerals and ions content of the nutrient solution. EC can deliver electric ions from the nutrient solution to the plant roots. The EC value would affect the photosynthesis speed rate, enzyme activities, and ion absorption of the plant roots. This study applies the design of an automatic control system based on a microcontroller that controls the EC of tofu wastewater to become suitable for plant growth in a hydroponic system. The results showed that the best dilution of distilled water and tofu wastewater for Mustard greens (*Brassica Juncea* L.) in a hydroponic system are using a 1:20 ratio with an EC value of 0.57 mS/cm.

Keywords: Electrical conductivity, microcontroller, tofu wastewater

1. Introduction

In Indonesia, tofu industries have provided employment and economic benefit from their positive value. On the other hand, the negative side of this industry is environmental pollution from residual waste, which has not appropriately managed (Sadzali, 2010). Table 1 shows the value of COD and BOD from tofu and soybean industrial waste.

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** Corresponding author: mareli.telaumbanua@fp.unila.ac.id; marelitelaumbanua@gmail.com

Table 1. Characteristic of tofu and tempe liquid waste

Parameter	*Tofu wastewater*	*Tempe wastewater*
COD (mg/L)	6 374.55	14 459.95
BSD (mg/L)	3 912.27	6 218.42
Source : Said, et.al. (1999)		

In general, the color of industrial waste can reflect the organic content in it. The quality of the waste quality can be predicted by the quality of the composition of the color image of the waste (Yulianti et al., 2016). The tofu wastewater was produced by filtered soybean essence from the protein clumping process. This liquid waste contains organic materials such as protein, fat, and carbohydrate, along with inorganic materials like Ca, Fe, Cu, Na, N, P, K, Cl, and Mg (Tabel 2) (Ernawati, 2014). The protein content from the liquid waste will release N compound if soil microbes decomposed them, then the N compound can be absorbed by the plant roots (Asmoro et al., 2008). This process shows that tofu wastewater has the potential to become an organic fertilizer (Rosalina, 2008).

Table 2. Nutrient content in tofu and commercial fertilizers (Asmoro et al., 2008)

Parameter	*Tofu solid waste*	*Solid compost of Green Valley*	*Tofu Wastewater*	*Commercial liquid fertilizer Tristan*
N (%)	1.24	1.44	0.27	0.42
P2O5 (ppm)	5.54	2.37	2.85	0.28
K2O (%)	1.34	3.03	0.29	0.08
Protein (%)	7.72	-	1.68	-

Organic waste can directly process into useful products (Haryanto et al., 2018; Triyono et al., 2019). The utilization of waste to become organic fertilizer is an effort to resolve the environmental pollution problem. The organic content of this waste can be the organic nutrient for microbes growth. Novita (2009) shows that 25% concentrate of tofu liquid waste provides the best value for all Mustard greens (*Brassica Juncea* L.) growth parameter with once a week sprinkling. The utilization of 20% tofu liquid waste concentration from 1 kg of soil can triple the production of Petsai (*Brassica Chinensis*), but this research was held on soil media (Asmoro et al., 2008).

On the hydroponic system, nutrition and water dissolved for the plant growth. Hydroponic nutrition is vulnerable from EC (Electrical Conductivity) and pH EC changes. EC influenced by the thickness of the nutrient solution. The higher thickness value of nutrients provides the more excellent EC value, and vice versa. Furthermore, the EC changes influenced by environmental factors such as temperature, sunlight intensity, wind, and humidity (Suhardiyanto, 2009; Untung, 2000). However, the temperature factor has the most significant effect of increasing EC value. Uncontrollable EC will interrupt the plant growth, which is needed to be controlled by a system that can adjust EC value according to the plant needs. One of the control system application to control EC is to use a microcontroller. A microcontroller has an output pin and an input pin that can be used as a signal receiver and a voltage supply to other objects (Telaumbanua et al., 2018). The ATmega 328 microcontroller used in this study is a minicomputer inside a chip that can be programmed to control sensors and actuators for EC value control (Telaumbanua et al., 2014).

Using tofu wastewater as hydroponic nutrition can be done by adjusting the EC value contained in the mixture of wastewater and distilled water. Tofu wastewater and distilled water volume variation were carried out to obtain optimal plant yields. This study applies a design of the EC control system of tofu wastewater on hydroponic media. The EC of tofu liquid waste is controlled to be suitable for plant growth. To design this system, sensors that have high accuracy are needed. The effect of the temperature on the conductance value obtained from the calibration process, then this value can determine the sensor validation value and the high accuracy of the sensor control system.

In general, domestic tofu industry in the city of Bandar Lampung will directly stream the wastewater to sewers and rivers without going through the waste processing first. The purpose of this study is to utilize the wastewater produced by domestic tofu industries containing high organic pollutants as hydroponic nutrition.

2. Materials and methods

This research was held at the Agricultural Engineering Department of the University of Lampung. The tools used in this study are:

- The control system component is an Arduino Uno ATmega 328 microcontroller, Arduino Uno shield, EC meter sensor module with a measurement range of 1mS /cm - 20 mS /cm, DS18B20 temperature sensor, Real-Time Clock (RTC) type DS1307, Micro SD card module, 4 channel relay module and 2 channels, 6 single socket, jumper cable, 20 x 4 LCD, laptop, power supply, regulator, transistor, resistor, PCB board, breadboard, EC meter Jenway model 4510.
- Hydroponic components consist of 2 nutrient storage tanks, waste buckets, water buckets, 6 aquarium pumps, aerators, and pipes.
- Mustard greens (*Brassica Juncea* L.), AB mix, distilled water, and tofu liquid waste.

2.1. Design of automatic control system

Arduino Uno microcontroller has connected with supporting components such as EC sensor module, temperature sensor, relay, RTC, micro SD card, LCD, power supply, and pump. Then the command program is entered into the Arduino IDE software which has specially designed for automatic EC control. The EC sensor integrated with a microcontroller (Arduino) (Figure 1). Next, the microcontroller is combined with an actuator pump to control the EC value. In the design, the output pin on the EC module connected to the analog pin A0, and the pump connected with a digital pin three on Arduino UNO 328. Figure 2 shows the block diagram design.

This study was designed to control EC in susceptible 0.4 mS/cm - 1.0 mS/cm. The EC value is obtained from the sensor placed on the surface of the nutrient solution, then the value is sent to the microcontroller. The microcontroller will execute according to the EC sensor output value by giving an order to the actuator, namely the water pump and tofu liquid waste pump. If the EC value is less than vulnerable (<0.4 mS/cm), the tofu liquid waste pump will light up, but if it is more than vulnerable (> 1.0 mS/cm), the water pump will turn on and enter the nutrient storage tub until the EC value returns to vulnerable.

2.2. Calibration and validation procedure of temperature sensor

Temperature sensor calibration is calculated by inserting the sensor and calibrator into the distilled water solution which is heated at 40°C. Then the readable output values on the sensor and temperature calibrator are recorded every one minute for one hour. The calibration results are made relationship graphs and regression analysis to obtain the equation functions that will be included in the Arduino IDE software. Validation is calculated to prove the suitability of the sensor output value and the calibrator. The procedure of the validation process is almost the same as calibration, the difference is that the output value from the sensor is the result of the equation function obtained from the regression analysis.

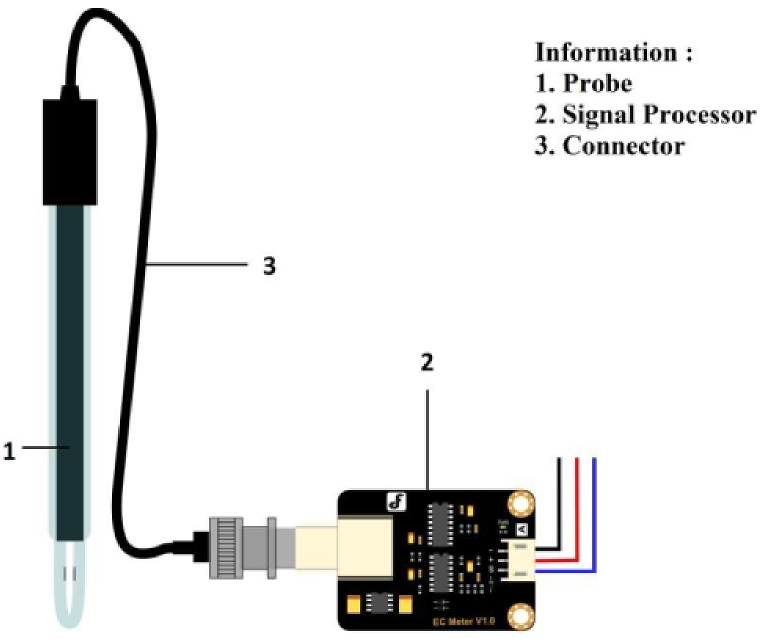

Fig. 1. EC sensors are integrated into the microcontroller

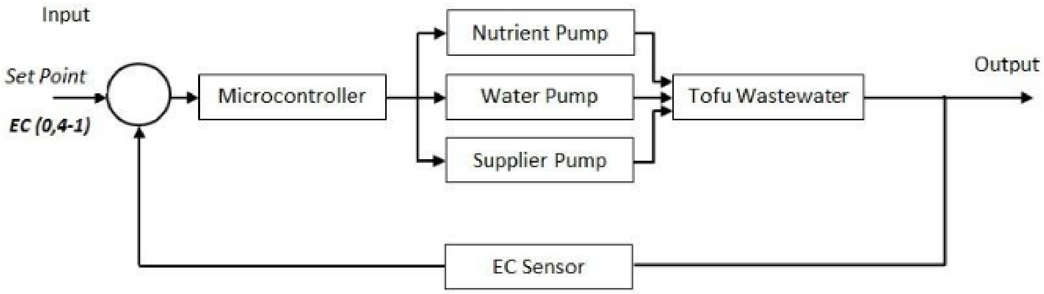

Fig. 2. Block diagram of control system design

2.3. *Calibration and validation procedure of EC sensor*

EC sensor calibration is calculated by the dependent EC variables and independent variable relation (temperature, mV, and pH). Initially, the EC sensor and EC kalibrator are inserted into the same AB mix solution. The calibration process was calculated using 4 samples of EC values, which are 1 mS/cm, 2 mS/cm, 3 mS/cm, and 4 mS/cm, then each sample was heated using a hot plate at 28°C, 31°C, 33°C, and 35°C. After that, the sensor output values and the calibrator are recorded then grouped into variable temperature (°C), EC meter, EC sensor (mV), and pH meter. The calibration results are entered into the regression analysis to find the equation values that will be used in the research into the Arduino IDE program. The validation process is almost the same as the calibration stage, but what distinguishes it is the output value of the sensor is in units of mS / cm ready compared to the calibrator. Afterward, both the RMSE test and the temperature sensor and EC sensor are used to see the sensor error value for the calibrator (Eq. 1).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2} \qquad (1)$$

N = amount of data
O_i = observation data
P_i = prediction data (Sugiyono, 2007).

2.4. Performance test

Performance tests are performed to find the value of accuracy, average control time, system response, and system stability. Accuracy values are sought with equations (2-4).

$$\text{Inaccuracy} = \frac{x}{SP} \times 100\% \qquad (2)$$

$$\overline{X} = \frac{\sum_{i=1}^{n}|SP - NAi|}{n} \qquad (3)$$

$\overline{X}$ = average value
SP = setting point value
NA = actual value
n = amount of data

$$\text{Accuracy} = 100\% - \text{Inaccuracy (in \%)} \qquad (4)$$

The average control time is observed to find out how fast the device can control the value for the desired vulnerability.

2.5. Hydroponic installation

The EC control system has been made to be able to work continuously in hydroponic media. Two sensors placed in a nutrition storage tank, which are DS18B20 temperature sensor and EC sensor. Each sensor will sense the temperature and EC nutrients. The sensor readings are sent to the microcontroller and then displayed on the LCD and stored on a Micro SD card. The value of the EC reading will be the main factor for giving action from the microcontroller to the relay so that the pump is "active" or "turned off."

When the sensor measures the EC value <0.4 mS/cm, the tofu wastewater pump will be activated, if the EC value > 1 mS/cm then the water pump will be activated, then if the EC value is at 0.4-1 mS/cm or in the value range, then the nutrition pump will be active and then sent to the pH control container. The pump on the pH container will send nutrients to the hydroponic installation. After going through the hydroponic installation, the nutrients are fed back into the EC container, and the microcontroller will repeat the process from start to finish.

2.6. Utilizaton of tofu wasterwater

The nutrients used in this study were made from a mixture of fermented tofu wastewater and distillate water with EC value of the nutrient concentration is 0.57 mS/cm. Determination of the concentration of the nutrient solution obtained from trials on Mustard greens plants aged 10 DAP (days after planting). The trial was conducted by preparing three Mustard greens plants and three solution samples with a ratio of tofu and water liquid waste of 1: 5, 1:10, and 1:20 (in liters).

3. Results and discussion

3.1. Characteristics of tofu wastewater

Tofu wastewater is acidic. Therefore, before the waste is processed, it is necessary to check the pH and add a buffer solution to achieve an optimal pH (BPPT, 1997). The initial pH of tofu wastewater is between 4-5, for this purpose fermentation is carried out on the waste in a pre-research trial to increase the pH value to suit the growth requirements of Mustard greens plants, which ranges from 5.5 to 6.5.

3.2. Design of automatic control system

The design of this automatic control device (Fig. 3) uses a variety of components, such as Arduino Uno microcontroller, EC sensor module, temperature sensor, relay, RTC, micro SD card, LCD, power supply, and pump.

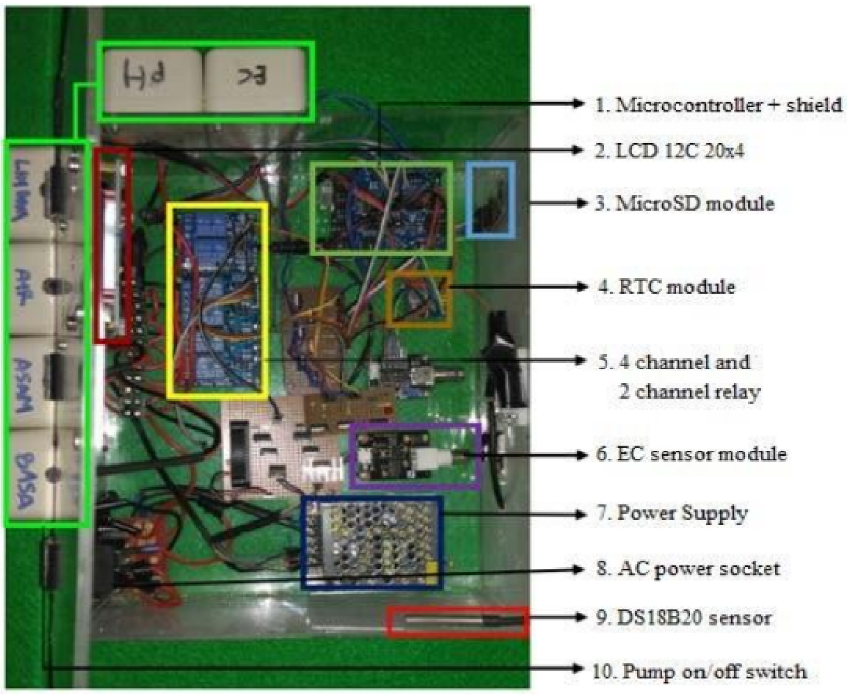

Fig. 3. Set of tools

The microcontroller connected with components that have their respective functions. Arduino Uno microcontroller serves as the brain to process all activities that take place. The Arduino Uno microcontroller can operate at 5V-12V voltage. The function of temperature sensor and EC are to read the temperature and EC value of th solution. RTC is used to record the time (hours, minutes, seconds) of each process that occurs during the process of the microcontroller. The microSD card module stores all data from the process that occurs, both data from sensors and RTC. The function of LCD functions is to display signal output from the sensor and RTC. The power supply has the function to change the AC current from PLN to a 12V voltage DC current as a microcontroller voltage source. Relay has the function as an automatic I/O switch for pumps according to the input signal from sensor readings. The pump has the function as an actuator to drain tofu wastewater according to the command signal from the microcontroller.

3.3. Calibration and validation of temperature sensor

The DS18B20 temperature sensor is a digital sensor so that the output value displayed in Celsius degrees. Temperature calibration result shows a coefficient r-value of 0.9992, which indicates that both relations are strong. From Fig. 4, the y equation is used as a temperature sensor correction factor, i.e.:
T = (0.9446 * temperature sensor) + 2.2498.

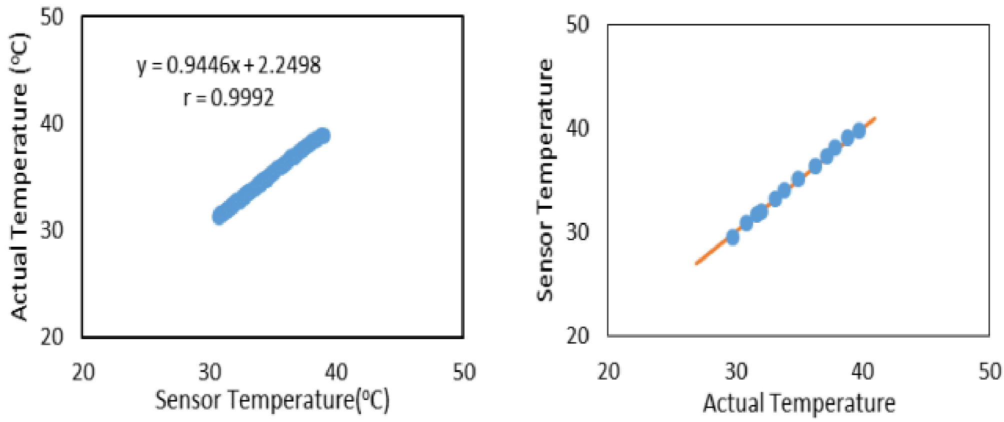

Fig. 4. Calibration and validation of temperature sensor

Next step is the validation process. The temperature sensor validation shows good results because it is in the diagonal line forming a 45 ° angle (Fig. 5 (left)). The error value of the temperature sensor obtained from the RMSE test is 0.16. The EC sensor calibration process with an EC meter calibrator is shown in Fig. 5 (right).

3.4. Calibration and validation of EC sensor

From the EC calibration process, obtained that the influential independent variables are temperature and EC (mV) sensor, seen from the R-value coefficient is close to 1, while the pH shows a weak or has no relationship effect because the R-value coefficient is far from 1. Then the temperature and EC variables (mV) are included in the regression analysis, so that the equation is obtained as a correction factor, i.e.
EC = (0.0015328 * temperature) + (0.0054178 * mV) + 0.024268.

Next step is the validation of EC sensor. The procedure is very close to the calibration of other sensors described above. The error value of the EC sensor obtained from the RMSE test which is 0.028.

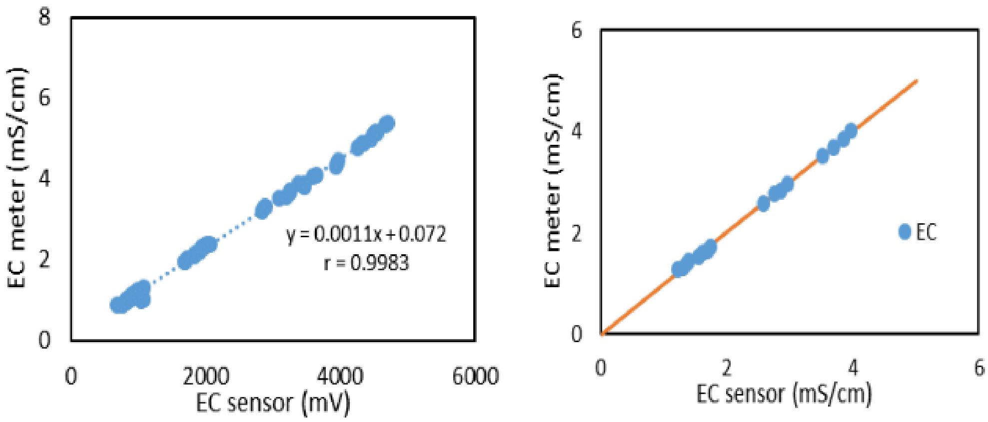

Fig. 5. Calibration of EC sensor with calibrator (left), Validation of EC sensor (right)

3.5. Hydroponic installation

The test setup was developed where all the sensors and Arduino Uno Control device were installed. The general scheme of the experimental rig is shown in the Fig. 6.

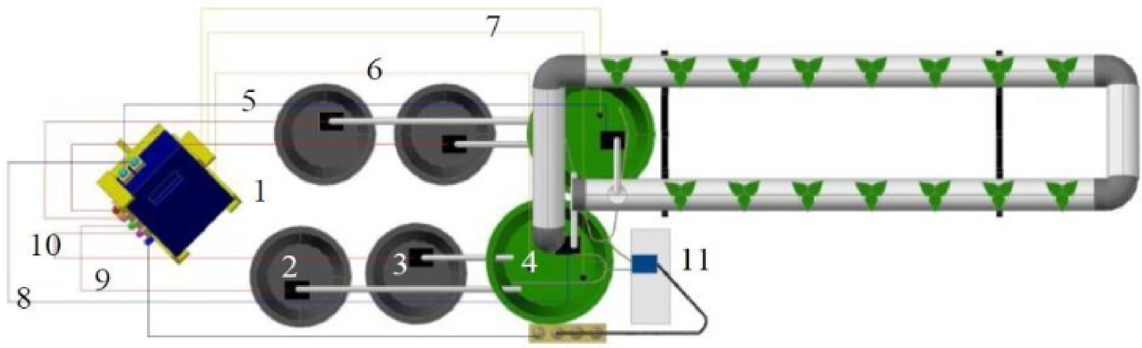

Fig. 6. Hydroponic experimatal rig:
1 – Hydroponic pipe; 2 – Nutrition pump cable; 3 – Water pump cable; 4 – Wastewater pump cable; 5 – Aerator; 6 – Microcontroller; 7 – Water container; 8 – Wastewater container; 9 – Nutrition container; 10 – EC sensor cable; 11 – Temperature sensor cable

The value of the EC setting point used in this hydroponic system was set at 0.57 mS/cm. Hydroponic system testing will be turning on the pump when EC conditions are outside the setting point. When passing the upper limit, the water pump lights up to drain the water from the water bucket to the nutrition container for 2 seconds, while the EC value passes the lower limit, the tofu wastewater pump is lit and fed to the nutrition bath for 2 seconds. Water and tofu wastewater flow through an aquarium hose. For 2 seconds the pump turns on, the amount of water or liquid wastewater that comes out is 21 mL and 9 mL respectively. So, during the 48 hours of research running, the total volume of water added was 3 864 mL, and tofu wastewater was 324 mL.

3.6. Utilization of tofu wastewater

Tofu wastewater diluted with distilled water by turning 1:5, 1:10, and 1:20 then poured into the roots of Mustard greens. After two days, the optimal results produced by the plants that are entitled to a ratio of 1:20 and an EC value of 0.57 mS/cm. Greener leaf color and stem size of Mustard greens plants which are larger than the results of growth in mixed variations of 1:5 and 1:10 are the indicator that in this hydroponic system, the optimal result has been shown by the mixture of 1:20 ratio.

The hydroponic system with a capacity of 200 Mustard greens plants yields 60 kg; each kilogram of plants requires 80% of nutrients per day (in liters) because in 1 kilogram of Mustard greens plants need 0.8 liters of nutrients. For this reason, a hydroponic system requires 48 liters of nutrients, with a contribution of 1:20 so in 1 day this system can use 2.4 liters of tofu liquid wastewater.

4. Conclusions

The hydroponic system in this study uses nutrients consisting of a mixture of tofu wastewater and distilled water by controlling the EC value contained in the solution to fit the growth needs of Mustard greens *(Brassica Juncea* L.).

The best results are shown by Mustard greens plants which were given a mixture of solutions with a 1:20 ratio. By controlling the EC value of 0.57 mS/cm, tofu liquid waste can be used as a nutrient of Mustard greens plants in hydroponic media. The higher the capacity of the hydroponic media used, the higher the use of wastewater from tofu that can be utilized.

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