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Development of Cultivation Environment Control System Using Plant Bioelectric Potential

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Abstract– The plant bioelectric potential responses are correlated with the physiological activity. Thus, we considered that the cultivation environment operating system will be improved by using the bioelectric potential response as an evaluation index.

In this study, we aimed to develop the light intensity control system using plant bioelectric potential.

1. Introduction

Recently, the artificial plant cultivation facility such as a plant factory has been in practical use for ensuring a stable food supply and cultivating high quality vegetables [1]. However, these facilities have problems with capital and operating expenditures, because it needs to maintain a stable and full environment control system that includes an air conditioner, a feed nutrient solution line, and some sensing devices. Especially, the electricity expense take up around 40 % of the operating expenditure. Therefore, the important issues are cost reduction and productivity of the improvement [2].

On the other hand, the number of people enjoying a kitchen garden has been increasing at an ordinary household. However, most people are said to give up the cultivation within approximately one year, because it needs knowledge and environment for cultivating vegetables. Some systems or devices for a kitchen garden such as an operating system and a hydroponics device with LED light are already commercially available. These systems can automatically control nutrition concentration, sprinkling water, sowing seed.

In our previous work, we focused on the measurement of plant bioelectric potential responses as a low-cost and a high sensitivity technique of real-time evaluating plant physiological activities. We reported that the bioelectric potential varies when the illumination is started or stopped, that the amplitude of this variation is correlated with the photosynthetic rate, and the characteristics of the potential depend on the illumination period, wavelength, and light intensity[3]-[5]. Thus, we considered that the energy saving performance and the usability of the cultivation environment operating system will be improved by using the bioelectric potential response as an evaluation index.

In this study, we aimed to develop the light intensity control system for an indoor kitchen garden using plant bioelectric potential. Generally, the condition of an optimal light intensity varies from kinds of plants and several growing phases. In addition, a photoinhibition caused by too strong light illumination, and the photosynthetic activity is suppressed [6]. The light intensity control system contribute to the improvement of the cultivation environment and the energy saving effect.

2. Materials and Methods

2.1. Typical plant bioelectric potential response

In our previous study, the bioelectric potential difference between the two electroencephalographic (EEG) disk type electrodes (the diameter: 9mm, NE-155A, Nihon Kohden Corp.) was measured with a high-input-impedance (> 1G ohm) digital multimeter (DMM in Figure 1, R6552A, ADC Corp.) and was recorded by a computer.

The plant was placed in a 22.4 L closed vessel, and the change in CO_2 concentration caused by plant metabolism such as photosynthesis and respiration was measured using an NDIR-type CO_2 analyzer (LI-840, Meiwafosis Co., Ltd.). The light source consisted of blue (470 nm), green (525 nm), red (660 nm) and infrared (735 nm) LEDs, and light irradiation patterns were controlled by a control unit.

Figure 2 shows the typical bioelectric potential responses when illumination was started. The potential rose immediately after light irradiation and passed a peak, and slowly returned to approximately the initial value. We defined the difference V_{on} as that between the biggest potential increase and the value before light irradiation.

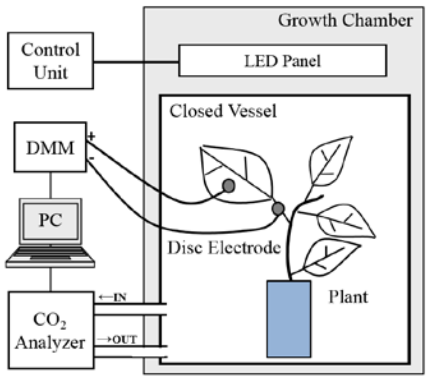

Figure 1. Previous measurement system.

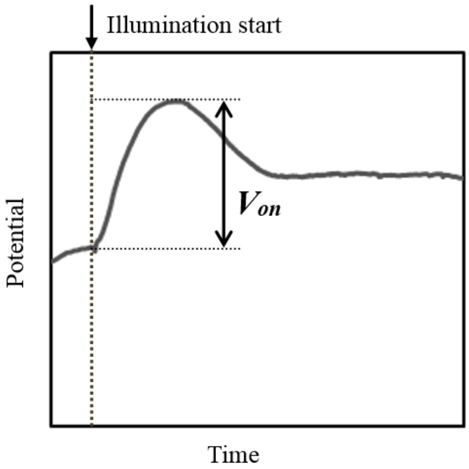

Figure 2. Typical bioelectric potential response to light irradiation and definition of evaluation parameter, V_{on}.

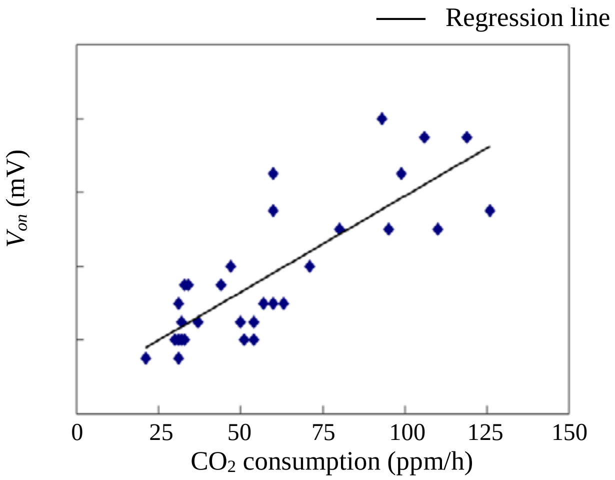

Figure 3. Relationship between V_{on} and CO_2 consumption. (Correlation coefficient: about 0.81)

Figure 4. Photograph of our developed system.

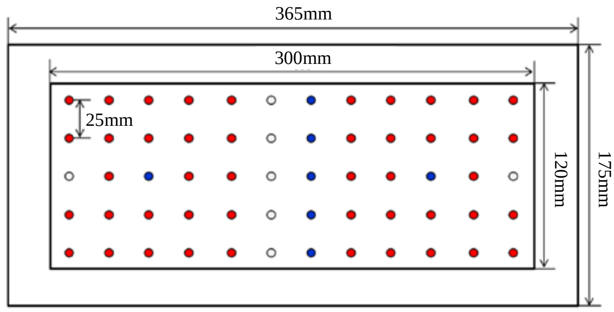

Figure 5. Pattern arrangement of LEDs light source.
(● : blue, ● : red, ○ : white)

We reported that the amplitude of the potential variation V_{on} by starting the illumination has a strong correlation with the photosynthetic rate (Figure 3). The results suggested that this parameter can be used to evaluate the plant physiological activity.

2.2. Light intensity control system

At first, we constructed a new system for detecting bioelectric potential and controlling light intensity (Figure 4). The required conditions for this system are as follows: measurement and feedback functions, compact size and easy to practical use. Therefore, we prepared a microcomputer (H8/3664), small LEDs light source device capable of the light quantity adjustment, hydroponics devices, EEG needle type electrodes (NE-224S, Nihon Kohden Corp.) and sample plant, cabbage (*Brassica oleracea* var. capitata), seedlings. The microcomputer amplified and analyzed the bioelectric potential. Then, a control signal depending on the analyzed result was transmitted to the light source equipped with light intensity controller from the microcomputer.

Figure 5 shows the pattern arrangement of LEDs light source. The light source consisted of blue (470nm), red (660nm) and white LEDs, because the chlorophyll of plants have light absorption peaks in the wavelength of blue and red. Especially, red is the most influential wavelength for the photosynthetic rate. In this study, the photosynthetic photo flux density (PPFD, μ mol m^{-2} s^{-1}), used as an index of the illumination intensity, was measured at the leaf surface. The PPFD of blue, red and white LEDs when 100% light irradiation were 60, 340 and 30 respectively.

To improve the photosynthetic rate and productivity in a cultivation environment, it is desirable that the light interruption time is as short as possible. However, in our previous evaluation method, light has to be interrupted for at least 30 min to observe a significant potential response V_{on}. Therefore, we adopted a weak blue light (25 μ mol m^{-2} s^{-1}) instead of the light interruption in this system.

In the experiment, the temperature and the humidity were not controlled but used an air conditioner in the room, because we assumed this system was used in a kitchen or a living room of an ordinary household. The room temperature is about 22 °C.

3. Results and discussion

3.1. Light intensity control parameters and conditions

Figure 6 shows one of an observed potential response by our system and the definition of the parameters for making a feedback signal. In this figure, the potential responses changed immediately with full lighting (ON) and blue lighting (Blue). We also observed the amplitude of the bioelectric potential variation when the full lighting. From this result, when the system used a weak blue light instead of the light interruption, the amplitude of the potential variation was also observed. As mentioned previously, it is considered that this amplitude has a correlation with the photosynthetic rate.

In this system, the light intensity control parameters and conditions were decided from this correlation and the previous operating condition of the light intensity. The light intensity was controlled from 20 to 100 % at 10 % intervals depending on a feedback signal.

When the system changes the light intensity at time 0 in Figure 6, we defined the potential difference of the last full light illumination as V_{on}, and also defined the difference of the next to the last full light illumination as pre_V_{on}. Specifically, we use the difference between V_{on} and pre_V_{on} as the parameter.

Table 1 shows the automatic light intensity control conditions of this system. This system was controlled by the difference between V_{on} and pre_V_{on} and previous operating conditions of light intensity. These conditions were considered from the point of view of the relation between the photosynthetic rate and the potential response, and the photoinhibition.

For example, if it was not observed the increasing potential when the light intensity changes 10 % UP, it was judged to spend the consuming power and to suppressed the photosynthesis. Therefore, the light intensity will be controlled 10 % DOWN in the next time.

3.2. Execution of light intensity control system

Figure 7 shows the execution example of the light intensity control system using the plant bioelectric potential. This figure include the raw data of the bioelectric potential, auto controlled light intensity and the value of V_{on}. Symbols A to C in this figure indicate the time of the full light irradiation. The light intensity was increased from time A to time B depending on the previous operating condition and the difference of V_{on} and pre_V_{on}. But the variation of V_{on} in time B does not increase at this time. Thus, in time C, the light intensity was decreased again.

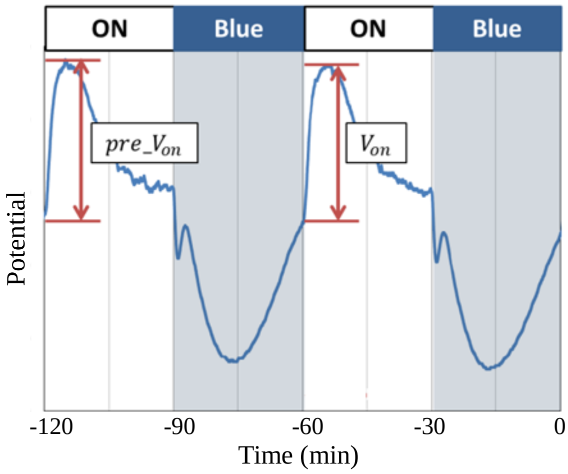

Figure 6. Bioelectric potential response and definition of parameters for making feedback signal.

Table 1. The automatic light intensity control conditions.

		Previous operating conditions of light intensity		
		UP	DOWN	STAY
V_{on} - pre_V_{on}	More than 10mV	UP	STAY	UP
	Less than -10mV	DOWN	UP	DOWN
	Otherwise	DOWN	STAY	STAY

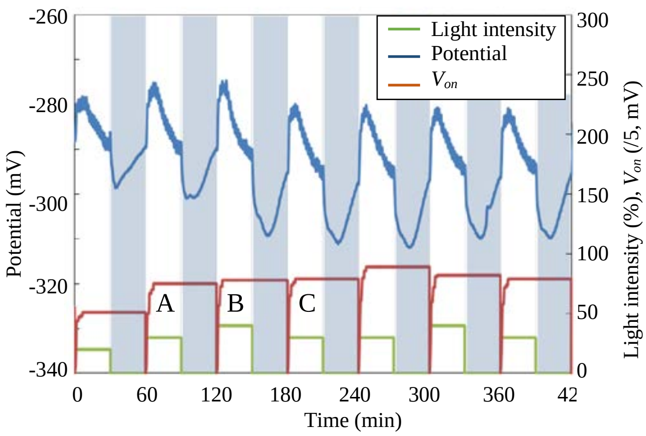

Figure 7. Example of automatic light intensity control

These results showed that our developed system can operate correctly depending on the feedback signal made from the plant bioelectric potential. We suggested that the system contribute to the improvement of the cultivation environment control system and the energy saving effect. A more detailed investigation of the usability and the energy saving performance of this system should be carried out in our future work.

4. Conclusions

In this study, we aimed to develop the light intensity control system for an indoor kitchen garden using the plant bioelectric potential. At first, we constructed a new system for detecting bioelectric potential and controlling light intensity using a microcomputer, small LEDs light source device capable of the light quantity adjustment, hydroponics devices and EEG needle type electrodes. The sample plant were some cabbage grown in hydroponics.

We measured and analyzed the bioelectric potential when the full lighting and the blue lighting instead of the light interruption are started. And then a control signal depending on the analyzed result was transmitted to the light source equipped with light intensity controller from the microcomputer. The light intensity control parameters and conditions were decided from the correlation between the photosynthetic rate and the potential difference V_{on} and the previous operating condition of the light intensity. The light intensity was controlled from 20 to 100 % at 10 % intervals depending on a feedback signal.

These results showed that our developed system can operate correctly depending on the feedback signal made from the plant bioelectric potential. We suggested that the system contribute to the improvement of the cultivation environment control system and the energy saving effect.

Acknowledgments

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