2014 International Symposium on Nonlinear Theory and its Applications
NOLTA2014, Luzern, Switzerland, September 14-18, 2014

Analysis of bioelectric potential response of plant

Yuki Hasegawa†, Ki Ando‡ and Hidekazu Uchida†

†Graduate School of Science and Engineering, Saitama University
255 Shimo-okubo, Sakura-ku, Saitama 338-8570, Japan
‡Department of Electrical and Electronic Engineering, Tokyo Denki University
5 Senju Asahi-cho, Adachi-ku, Tokyo 120-8551, Japan
Email: yuki@ees.saitama-u.ac.jp

Abstract– We investigated the effects of several light irradiation conditions on the evaluation of plant physiological activities using the plant bioelectric potential. In the experiments, we measured bioelectric potential responses and CO_2 concentration when light irradiation was started or stopped with several blink period. In addition, we investigated the effect of the light interruption time on the evaluation of plant physiological activities using plant bioelectric potential.

1. Introduction

It is known that plants sensitively react to change of growth environment conditions. Thus, Plants have a capability of environment recognition and an environmental adaptability. The effect of these reactions appear on a growth rate of plant, stomatal movements and the photosynthetic characteristics such as CO_2 consumption rate, protein synthesis characteristic and chlorophyll fluorescence. Therefore, various studies have been carried out to measure these phenomena in order to evaluate the plant physiological activity [1]-[3].

In our previous work, we investigated the plant physiological activity of plant using bioelectric potential measurement. The bioelectric potential is generated by ions in the plant cell, and it changes with physiological activities. Measurement of the plant bioelectric potential is one of promising methods of real-time evaluation and monitoring of the plant's state of physiological activity as a physical quantity. We already 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 that the characteristics of the bioelectric potential depend on the illumination period, wavelength and intensity [4]-[7]. Now, we focused on the effect of light interruption time for the behavior of the potential response.

In this paper, it is introduced and discussed about the typical bioelectrical potential responses of plant under several light irradiation condition. We consider that these results indicate the relationship between plant bioelectric potential response and plant physiological activity to light irradiation.

2. Measurement of Bioelectric Potential

2.1. Measurement System

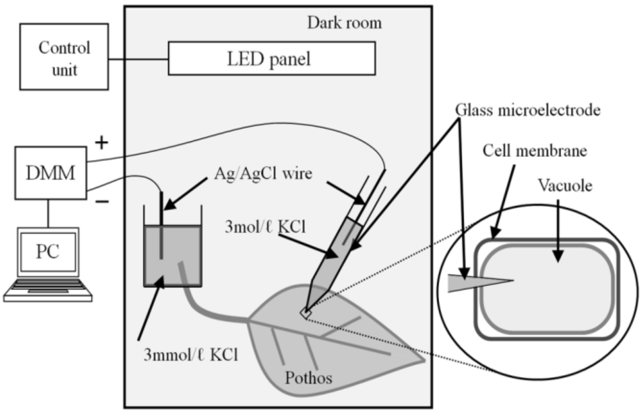
In our experiment, it was used two types of measurement system in order to detect plant bioelectric potential response. Figure 1(a) showed measurement system of the cell bioelectric potential of plant using a glass microelectrode (the tip diameter: 0.5μm, handmade). Cell bioelectric potential is a general method in field of bioelectric physiology, and detects detailed active and passive ion transports on plant cell directly.

Figure 1(b) shows measurement system of the leaf surface bioelectric potential. The leaf surface potential was measured using electroencephalographic (EEG) disk-type electrodes (the diameter: 9mm, NE-155A, Nihon Kohden Corp.) attached to the plant surface with a conductive paste for EEG (Z-401CE, Nihon Kohden Corp.). It is easy to measure and practical to use instead of difficult to detect detail information. To detect the surface potential response induced by photosynthetic reactions, an electrode was attached to the leafstalk as a reference electrode and another electrode was attached to the leaf surface, where photosynthesis takes place.

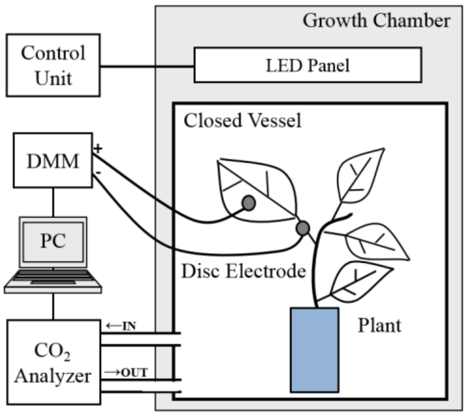
The potential difference between the two electrodes was measured with a high-input-impedance (> 1G ohm) digital multimeter (DMM in Figure 1, R6552A, ADC Corp.) and was recorded by a computer at a sampling interval of 1s.

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.). First, we measured the increase in CO_2 concentration caused by the respiration of the plant in the dark, and defined it as the respiration rate (ppm/h). Then, we found the sum of the observed decrease rate in CO_2 concentration owing to photosynthetic activity under illumination and the respiration rate, and defined it as the photosynthetic rate (ppm/h).

The ambient temperature and humidity were controlled at 25 ºC and 60 to 70 %RH, respectively by the growth chamber (BAC-130H, Espec Corp.) enclosing the vessel. The light source consisted of blue (470 nm), green (525 nm), red (660 nm) and infrared (735 nm) LEDs, and light



(a) plant cell potential



(b) Leaf surface potential

Figure 1. Measurement system of bioelectric potential.

irradiation patterns were controlled by a control unit. The photosynthetically active photon flux density (PPFD) at the leaf surface was 150 μ mol m^2 s^{-1}. The sample plants were some golden pothos plants (Epipremunum aureum) grown in hydroponics in 0.5 L plastic pots and have 2 to 3 leaflets.

2.2. Evaluation Parameters and Conditions

We measured the bioelectric potential response of the sample plant to a stimulus of light irradiation. 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. In a previous study, it was reported that the amplitude of the potential variation V_{on} by starting the illumination has a strong correlation with the photosynthetic rate. The results suggested that this parameter can be used to evaluate the plant physiological activity.

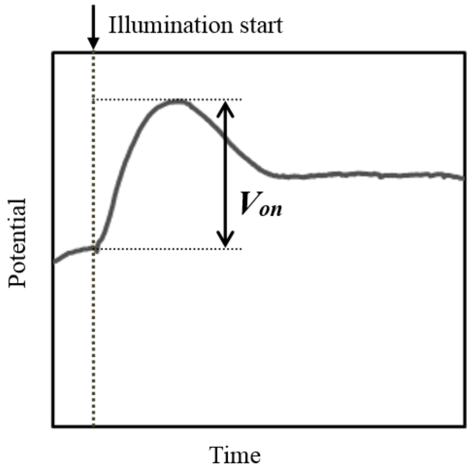


Figure 2. Typical bioelectric potential response (leaf surface) to light irradiation and definition of evaluation parameter, V_{on}.

We observed bioelectric potential under various light irradiation conditions. At first, it has been reported that the photosynthesis acceleration by pulsed light irradiation compared with continuous light irradiation [8]. Therefore, we measured two type of bioelectric potentials under various blinking periods (20, 240, and 600 second).

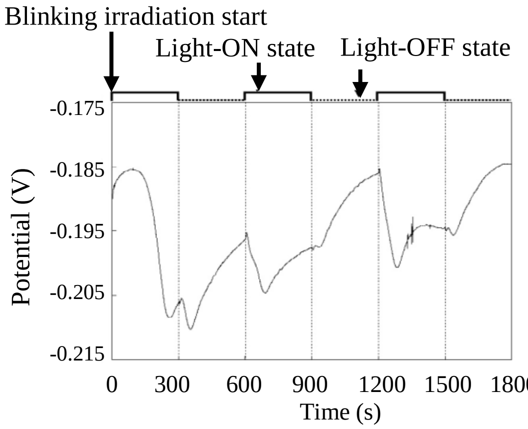
Next, we measured leaf surface potential response when the light interruption time was gradually shortened (1, 3, 5, and 10 min). In this experiment, we aimed to observe the influence of the light interruption time before light irradiation to bioelectric potential response.

3. Results and Discussions

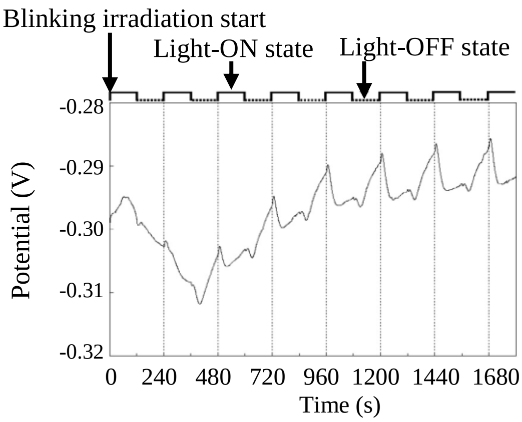
3.1. Bioelectric Potential Responses under Blinking Light Irradiation

Figure 3 shows the cell bioelectric potential response with some blinking periods. The potential level of the cell bioelectric potential was around -200 mV and its amplitude of the response ranged from about 30 mV. In this figure, it is seen that the potential responded at the beginning of the blinking irradiation and increased about 0.5 mV, and then lowered most in around 500 s. The potential after 500 s responded synchronously with blink period of the light.

Figure 4 shows the cell and leaf surface bioelectric potential response when the blink period was set to 20 s. This figure indicated the both types of potential responses vibrated with blink period, and showed similar behavior each other. The potential level of the leaf surface potential was around 20 mV and its amplitude was a little bit smaller than the cell potential. It is suggested that it is difficult to detect rapid and detailed response from the leaf surface bioelectric potential [5]. On the other hand, we consider that the leaf surface potential response has enough resolution in order to obtain the amplitude of the envelope. Thus, in next experiment, we obtained CO_2



(a) Blinking period : 600s



(b) Blinking period : 240s

Figure 3. Cell bioelectric potential responses with blinking light irradiation.

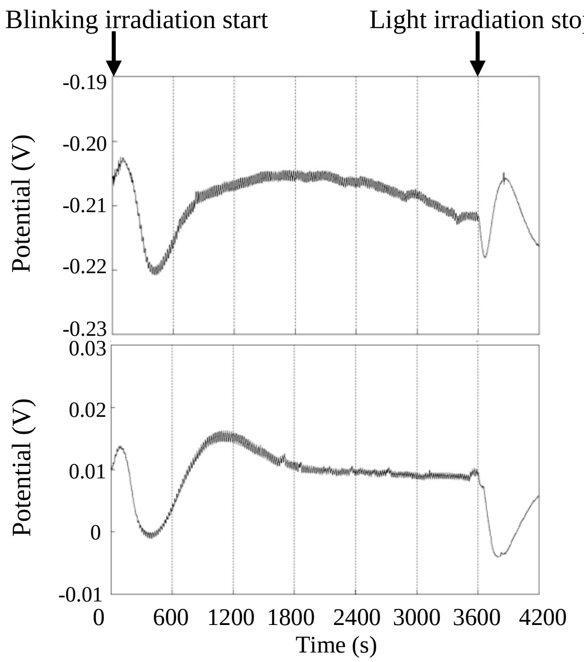


Figure 4. Cell (a) and leaf surface (b) bioelectric potential responses with blinking light irradiation (blink period: 20 s).

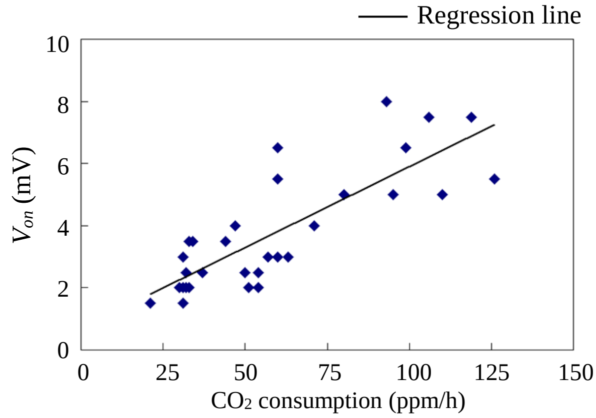


Figure 5. Relationship between V_{on} and CO_2 consumption.

consumption in order to detect the photosynthetic rate and researched relationship between the leaf surface bioelectric potential response and photosynthetic rate.

In Figure 5, each point represents V_{on} and CO_2 consumption when blink period was set to less than 20 s and the solid line shows a regression line. It is showed that V_{on} decreased with the CO_2 consumption, and correlation coefficient was about 0.81. In addition, V_{on} and CO_2 consumption value with blinking light irradiation had a tendency which was larger than these values with continuous light irradiation.

So far, we focused only the potential response when light illumination was started. Although, it was considered that the potential response when light illumination was stopped was relating to other plant physiological activities. Therefore, a more detailed investigation of the relationship between the plant physiological activities and the bioelectric potential responses when light illumination was stopped is required in our future work.

3.2. Light Interruption Time and Bioelectric Potential Responses

Figure 6 shows the bioelectric potential responses at various light interruption times. We observed very simple responses when the interruption time was 1 min. The potential response decreases immediately after light interruption was observed, and then the potential increases rapidly until the initial values after light illumination. The potential responses at the interruption times of 3 and 10 min had similar waveforms. At first, the potential responses decreased and had the first small peak about 1min after the light interruption. Then, the response at 3 min decreased gradually until the light illumination was started, and the response at 10 min also decreased until the second peak and then increased gradually until the light illumination was started. After light illumination was started, the potential slightly increased, and then decreased soon and had a peak. Finally, we observed the

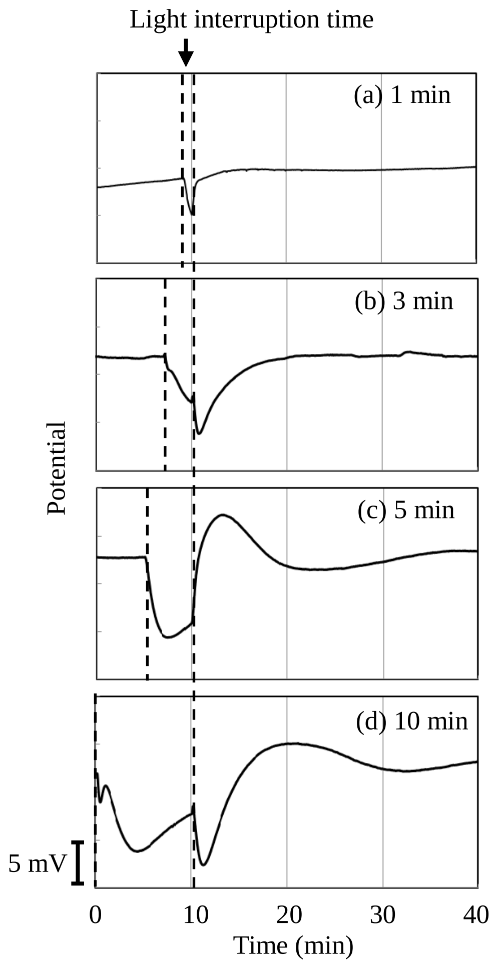


Figure 6. Bioelectric potential responses at various light interruption times.

distinctive potential response when the interruption time was 5 min. The potential response did not include several small peaks; thus, it looks like a sine curve. All trends of the waveforms were observed repeatedly in multiple plants. We obtained the difference in the potential responses depending on the light interruption time [9].

4. Conclusions

In this study, we investigated about the plant bioelectric potential response to several light irradiation conditions. Especially, we observed the effect of blinking light irradiation with several blink periods and the light interruption time. At first, we indicated the amplitude of the bioelectric potential decreased with the CO_2 consumption, and correlation coefficient was about 0.81. Next, we also observed the bioelectric potential response when the light interruption time was gradually shortened.

These results showed that the characteristic behavior in the potential responses depending on the light irradiation conditions was observed.

Acknowledgments

This work was supported by JSPS Grant-in-Aid for Young Scientists (A) Grant Number 24686049.

References

[1] W. Yamori, K. Suzuki, K. Noguchi, M. Nakai and I. Terashima, "Effects of Rubisco kinetics and Rubisco activation state on the temperature dependence of the photosynthetic rate in spinach leaves from contrasting growth temperature, " *Plant, Cell & Environ.*, vol. 29, pp. 11659-1670, 2006.

[2] A. O' Carrigan, E. Hinde, N. Lu, X. Xu, H. Duan, G. Huang, M. Mak, B. Bellotti and Z. Chen, "Effects of light irradiance on stomatal regulation and growth of tomato," *Environmental and Experimental Botany*, vol. 98, pp. 65-73, 2014.

[3] R. Caulet, G. Gradinariu, D. Iurea and A. Morariu, "Influence of furostanol glycosides treatments on strawberry (*Fragaria × ananassa* Duch.) growth and photosynthetic characteristics under drought condition, " *Scientia Horticulturae*, vol. 169, pp. 179-188, 2014.

[4] Y. Hasegawa, S. Asada, T. Katsube and T. Ikeguchi, "An analysis on bioelectrical potential when plant purifies the air pollution," *IEICE Trans. on Electro.*, vol. E87-C, pp. 2093-2098, 2004.

[5] K. Ando, Y. Hasegawa, H. Maekawa and T. Katsube, "Analyzing bioelectric potential response of plants related to photosynthesis under blinking irradiation," *IEICE Trans. on Electro.*, vol.E91-C, pp. 1905-1909, 2008.

[6] K. Ando, Y. Hasegawa, T. Yaji, H. Uchida, "Study of plant bioelectric potential response due to photosynthesis reaction", *Electronics and Communications in Japan*, Vol.95, pp.10-16, 2012.

[7] K. Ando, Y. Hasegawa, T. Yaji and H. Uchida, "Study of plant bioelectric potential response due to photochemical reaction and carbon-fixation reaction in photosynthetic process," *Electronics and Communications in Japan*, Vol.96, pp.85-92, 2013.

[8] D. J. Tennessen, R. J. Bula and T. D. Sharkey, "Efficiency of photosynthesis in continuous and pulsed light emitting diode irradiation," *Photosynthesis Research*, Vol. 44, pp. 261-269, 1995.

[9] Y. Hasegawa, G. Yamanaka, K. Ando and H. Uchida, "Ambient temperature effects on evaluation of plant physiological activity using plant bioelectric potential," *Sensors and Materials* (in press).