The Effect of Constant Direct Current Exposure on the Growth of a Vigna Radiata Species

Jaewon Chang and Seyoung Kwon
International School Manila, Taguig, Philippines
Email: {changjaewon0315, sallylovesy}@gmail.com

***Abstract*—Electric currents have been utilised to stimulate growth within plants to a great extent. This technique, known as electroculture, often involves action potentials on soil-based plant systems. Studies that investigate this phenomenon are plenty, however minimal research has been done to investigate electroculture on a hydroponic based system. Furthermore, a constant application of electricity on hydroponics has not been tested before. In this paper, we explore the relationship between the growth of a Vigna Radiata species and the constant application of electricity (5 minutes, 10 minutes, 15 minutes) under a hydroponic based system. To monitor the development of the species, we employed three main growth parameters: Visibility of germination, circumference of stem, and length of shoot system. Daily growth rates were computed using the lengths of the shoot system of a single day and the day before. Results indicate an inversely proportional relationship between direct current application and growth. During primary stages of the experiment, group 5 and group 10 species experienced the highest peak growth rates at values of 139.13% and 113.79% respectively, followed by a sharp decline in subsequent days. Alongside, the control group had a peak growth rate of 64.17% with a gradual decline. However, the group 15 species presented a mortality rate of 100% and measurements were unable to be obtained, due to a lack of germination. Overtime, species receiving less exposure to electricity showed longer lengths of the shoot system near the end of the experiment. Based on the results presented, hydroponic electroculture systems have shown to experience peak growth rates near earlier stages of their development. This however, fails to hold after a certain limit, in which plants fail to germinate due to excessive exposure to electricity. Further research conducted in this field may possibly encourage the usage of electroculture systems in agriculture.**

***Index Terms*—lectroculture, hydroponics, vigna radiata, direct current, action potential**

I. Introduction

There have been various methods of accelerating the process of a plant's growth, one of which is electroculture [1]. When applied, electricity can trigger a response within the phloem cell to stimulate growth within plants [2]. Possibly applications of this technique include enhancements in crop yield. Previous studies have suggested that electroculture has enhanced the growth of plants when cultivated under charged electrodes - based on plants grown atop soil [3]. The study discovers a threshold for electricity exposure within plants, that when surpassed resulted in higher mortality rates. However, with the growing limit in cultivable soil, hydroponics serves as a viable alternative to traditional soil based plant systems [4]. Plants in hydroponic systems have also experienced higher growth rates than conventional soil based systems [5]. Additionally, there have been only a few studies testing the effect of electrical stimulation on a hydroponic system. Conventional methods of electroculture involve the usage of action potentials (electrical impulses induced by polarity changes) or man-made electric fields in the ambiance [6]. As such, this study explores a hydroponic system involving a constant application of electricity - unlike previous studies which involved action potentials. Although methods of creating an electroculture environment varies, the application of electricity has generally shown to enhance the growth of plants [7]. This experiment utilises the *Vigna Radiata* species due to the presence of phloem cells, which allow for electrical signalling [8]. We hypothesized that the Vigna Radiata species exposed to electricity would experience greater growth compared to the controlled species.

To test our hypothesis, we designed an experiment in which the independent variable was the duration of electricity application, and the dependent variables were the visibility of germination, length of shoot system, and diameter of the stem. This study aims to explore the scientific relationship between constant electricity application on a hydroponic based plant system. Following our experiment, we discovered the growth rates of group 5 and group 10 species initially peaked, but eventually had a shoot system of shorter length compared to the controlled group. Additionally, we found a threshold for electricity exposure to the Vigna Radiata species, as the plants pertaining to group 15 presented a mortality rate of 100%.

II. Method and Materials

A. Selection of Vigna Radiata Seeds

We selected mung bean seeds (vernacular for vigna radiata species) for our experiment due to its relatively short growth period in comparison to other plants [9]. Furthermore, the short germination period of 4 to 5 days would allow us to effectively evaluate the suitability of the

Manuscript received June 11, 2021; revised August 27, 2021.

environment in which the experiment is being conducted and adjust if necessary [10]. We obtained 70 mung bean seeds and measured their weights, utilising 20 mung beans that were most similar in mass and size. We then categorized mung beans into 4 groups, establishing a control group, a group receiving 5 minutes of electricity, a group receiving 10 minutes of electricity and a group receiving 15 minutes of electricity. Each group consisted of 5 mung beans.

B. Preparation of the Electroculture System

Prior to the experiment, we created a basic circuit consisting of a power supply, 4 alligator clips, a voltmeter, a power supply and a copper rod. As shown in Fig. 1, the power supply was connected to the copper rod, which was then placed in an opening to the water. The voltage was kept constant, according to a value reported by the voltmeter (3.3V). The voltmeter was connected in parallel, since the voltage across a parallel circuit stays constant. Therefore the recorded value of 3.3 volts is the same amount being travelled across the copper rod. Furthermore, copper is one of the best conductors of electricity among metals [11]. Having a high electrical conductivity value indicates a low resistance value, meaning electricity loss is minimal across the rod [12]. The electroculture system utilises a man-made direct current electricity source.

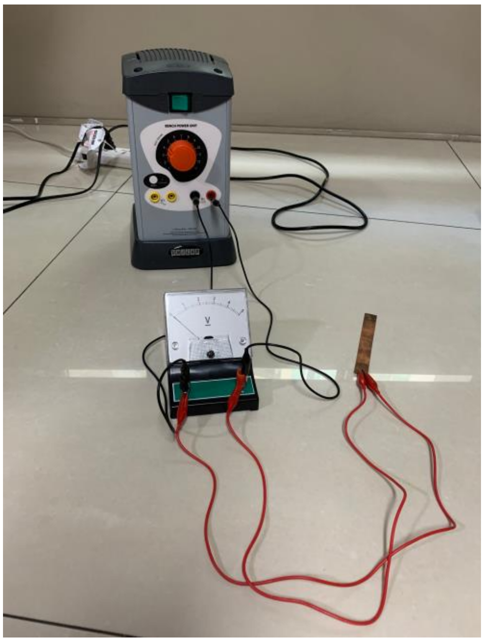

Figure 1. Basic circuit consisting of a power supply, voltmeter, copper rod and alligator clips.

C. Preparation of Hydroponic Environment

We utilised hydroponic planting boxes, which required water set at a temperature of 20°C. Each box was checked on a daily basis to ensure the temperature would stay constant. The planting boxes were also placed in an area concealed from sunlight to achieve a similar environment for each of the groups. Prior to the experimentation, mung beans were soaked in water for 3 hours, and the planting sponges were soaked in water for 2 hours to stabilize. A buoy was used as an indicator to represent the amount of water in the container. An artificial light source was utilised as a substitute for natural sunlight for 6 hours each day.

D. Process of Electroculture

In order to observe the effect of applying a man-made electricity source on the development of a plant, we constructed a basic circuit. As shown in Fig. 2, a copper rod was placed in an opening of the hydroponic box, to be in contact with the water. Electricity was then applied for the desired amount each day (5 minutes for group 5, 10 minutes for group 10, 15 minutes for group 15). After the application of electricity, the length of the shoot system was recorded each day. In the case where germination was not visible, the length of the shoot system was not obtained.

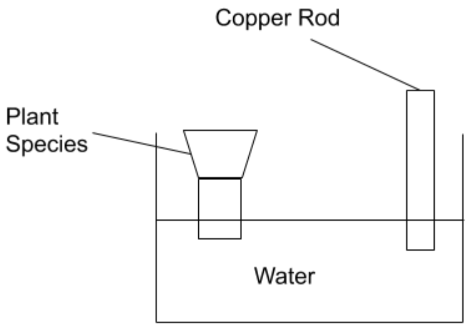

Figure 2. Diagram showing general process of electroculture. Copper rod is assumed to be connected to a power supply.

E. Growth Parameters

To monitor and evaluate the growth of the mung beans, we established three main growth parameters: the circumference of the stem (the longest circumference), the length of the shoot system, and the visibility of germination [13]. Germination is a universal indicator utilised to determine the suitability of conditions for the plant. It is a stage experienced by seedlings when they begin to grow. However, in the case that all the plants were to germinate, we established another parameter to differentiate the growth of plants: the length of the shoot system. The length of the shoot system portrays the development of a plant, and can be employed to evaluate the growth experienced after germination [14]. The shoot system serves as a useful indicator because a plant grows upwards only when a stable base is present. Therefore, a larger value in the length of the shoot system implies the base is stable, and hence a larger growth experienced. Furthermore, a secondary vascular tissue develops after a plant's primary growth, leading to an increase in thickness of the stem [15]. This led us to formulate our final growth parameter: the circumference of the stem. We believed that the circumference of the stem would be a useful indicator along with the length of the shoot system to differentiate mung beans that have experienced germination.

F. Qualitative Observations

We took note of qualitative observations on a daily basis during the experiment. We observed key features of the mung bean, such as the presence of leafs, size of leafs, visibility of germination, and thickness of stem. Throughout the experiment, the leaves were not present and visible for most of the mung beans. Furthermore, the mung beans pertaining to experimental group 15 were not germinated throughout the duration. There was a noticeable increase in the thickness of the stem, increasing throughout the duration of the experiment.

III. Results

We utilised three main growth parameters to evaluate the development of mung beans throughout the experiment: the length of the shoot system, the circumference around the root, and the visibility of germination. To effectively compare the lengths of the shoot system, we decided to compute growth rates for all groups each day of the experiment. Growth rate was calculated using the formula $Growth\ Rate = \left|\frac{initial - final}{initial}\right| * 100\%$, where the final measurement was the value obtained on a single day, and the initial measurement was the value measured on the day before. This process was repeated for all days of the experiment following germination when a shoot system was visible. Growth rates were computed for every mung bean, and the average growth rate was recorded for each group as shown in Table I. These average values were then recorded in a line graph, presenting changes in growth rates. We believed computing a growth rate for the circumference around the root would be negligible (too small to compare), thus we compared the length of the circumference on the final day of the experiment. To apply germination as a growth parameter, we computed a germination percentage for every group, using the equation

$$Germination\ \% = \frac{Successfully\ germinated\ seeds}{Total\ number\ of\ seeds} * 100\%$$

Table II presents the germination percentage of each group, indicating the percentage of seeds that successfully germinated.

TABLE I. Growth Rate Values of Each Group for Days 3, 4, 5, 14, 15 and 16 Were Recorded

Average Growth Rate Values for Days 3, 4, 5, 14, 15, and 16				
	Control	Group 5	Group 10	Group 15
Day 3	43.40	139.13	0	0.00
Day 4	64.17	91.96	113.79	0.00
Day 5	43.16	74.90	86.72	0.00
Day 14	1.51	0.28	1.89	20.00
Day 15	1.42	3.30	1.19	0.00
Day 16	6.58	0.90	2.27	0.00

TABLE II. The Values for Each Group Were Recorded in the Table as a Percentage

Germination Percentage	
Control	100%
Group 5	80%
Group 10	80%
Group 15	0%

As shown in Fig. 3, the peak growth rates of mung beans pertaining to group 5 and group 10 were higher than that of the control group (139.13% for group 5 and 113.79% for group 10 compared to 64.17% for the control group). The average growth rate of mung beans in the control group experienced a gradual decrease, having a growth rate value of 50.02% on day 8. On the other hand, the average growth rates of group 5 and group 10 species experience a steep decline following the peak. After day 9 of the experiment, the growth rate values begin to approach 0 for all groups, as there is no noticeable growth. The group 15 mung bean species did not experience a growth rate due to the lack of germination in all of its species. The growth rate of 20% experienced by group 15 species on day 14 of the experiment was the first presence of a shoot system, however, the growth rate on day 14 returns to 0% on day 15 as the only mung bean germinated withered. When comparing the growth rates of group 5 and group 10, plants pertaining to the group 10 system experienced a growth rate starting from day 4 due to their late germination. The growth rate of the group 5 system peaks at 139.13% on day 3, and the growth rate of the group 10 system peaks at 113.79% on day 4. The germination percentage indicates the final number of seedlings that were able to germinate, without measuring the amount of time it took for germination to occur. Fig. 3 presents a growth rate of 0% for group 10, which alludes to a later germination experienced by the seedlings.

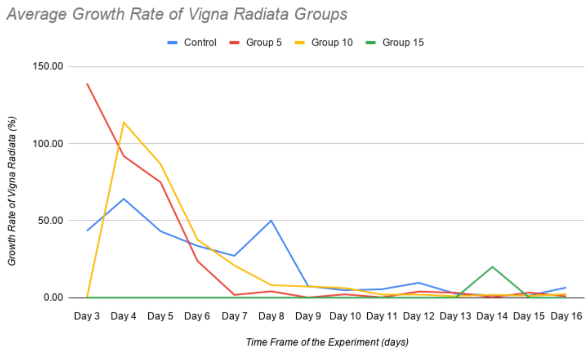

Figure 3. The average growth rates for each experimental group recorded for each day of the experiment.

The lengths of the shoot system were measured on a daily basis, and an average was computed. Near the beginning of the experiment, the group 5 mung bean species experience a longer shoot system length than the control group. This trend continues around time frames of day 3 to day 13 of the experiment. Furthermore, the group 10 mung bean species experiences a similar trend, in which the average length is greater than the control group. This occurs from days 6-8. The control group experiences a relatively steady increasing average length, while the group 5 and group 10 species experience a larger average length near the beginning of the experiment. Furthermore, the group 15 and group 10 species show minimal increase near the end of the experiment, while the control group portrays a constantly increasing line. When germination occurs for one seedling in group 15, the length is measured and recorded on Fig. 4. The average value of the length was simply the value measured of the one seedling that had successfully germinated.

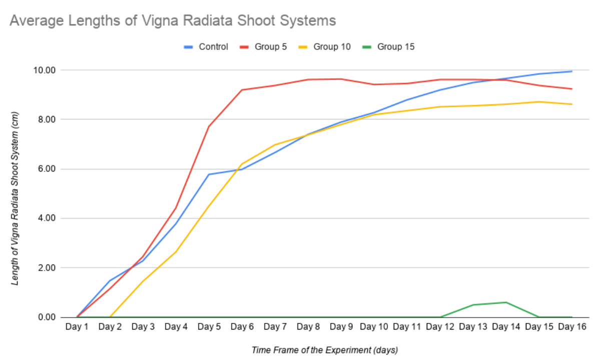

Figure 4. The average lengths of Vigna Radiata Shoot System were recorded for each day of the experiment.

Table III shows the lengths of the circumference pertaining to each group that were recorded on the final day of the experiment. Due to none of the mung beans of group 15 having a visible stem, a measurement was unable to be obtained. The control group had the greatest average circumference of the stem, followed by the circumferences of group 5, group 10 and group 15. The data suggests an inverse relationship between electricity exposure to the length of the circumference.

TABLE III. THE CIRCUMFERENCE OF THE THICKEST PART OF THE STEM OF EACH SPECIES ON THE LAST DAY OF THE EXPERIMENT

Average Circumference of Stem	
Control	1.3
Group 5	0.7
Group 10	0.5
Group 15	0

IV. DISCUSSION

The peak growth rate experienced by mung beans in group 5 and group 10 were higher than that of the control group, which is indicative of a positive response in growth rate when a direct current is applied. This is further supported by the steep decline following the peak in growth rates, alluding to electricity triggering plant growth only in the short term. The sharp decrease in growth rates of the group 5 and group 10 systems justify the longer shoot system length of the control group near the end of the experiment. As shown in Fig. 3, a higher peak is experienced by group 5 (139.13%) than the peak experienced by group 10 (113.79%). This suggests that a threshold is slowly being approached, since the peak growth rate is lower for group 10 which had received more electricity. This may be due to electric current fostering a release of auxin, a plant hormone that promotes cell elongation [16]. In contrast to the growth rates of the former groups, the group 15 growth rate remains constant at 0%, except for the sudden peak experienced on day 14 of the experiment. Following this however, the growth rate returns back to 0% due to the withering of the only mung bean that had germinated. The 100% mortality rate serves as a useful indicator that exposure to electricity for more than 15 minutes is fatal. Long exposure to direct current causes corona discharges from the tips, hindering the growth of plants [17]. When utilising this information with the group 10 growth rate information, we can approach a consensus that the threshold of electricity application on mung beans exists somewhere between 10 to 15 minutes. This is only applicable when the voltage applied is 3.3V. Also, long exposure to the electricity might cause Variation Potentials (VP), which are unique electrical signals occurring in the plants - arising as a result of damaging effects that can potentially be fatal. VP severely reduces the rate of photosynthesis in plants, thereby reducing their productivity. [18]

Additionally, as shown in Fig. 4, the average lengths of the shoot system for groups 5 and 10 were computed to be larger in certain timeframes of the experiment. This further supports the claim that electricity application is helpful in the early stages of development, however ultimately proves to be detrimental, as the average length of the shoot system for the control group is larger. Furthermore, the group 5 and group 10 mung systems experience minimal growth near day 16 of the experiment, which presents electricity as a detriment to the development of a plant. Ultimately, on day 16 of the experiment, the length of the shoot system presents the control group having the largest value, followed by group 5, group 10 and group 15. Although the application of a man-made direct current can accelerate the growth of a plant near its primary stages of development, the final trend indicates that an exposure to electric currents is detrimental in the long run.

The lengths of the circumference have an inverse relationship with electricity exposure. As presented in Table III, less exposure to electric currents resulted in longer circumference lengths. Longer circumference lengths are often a result of a secondary vascular tissue being developed within the organism. Therefore, the longer circumference present within groups receiving less electricity indicates that the plant has experienced more growth.

When comparing the results in this paper to that of previous studies, similar findings can be observed. Though optimal environments vary for different species, electricity exposure has generally accelerated the growth of plants [19]. For the Festuca Arundinacea species in specific, electroculture systems have shown to be beneficial throughout their development [20]. This stands in stark contrast to the electroculture system constructed in this study, as stimulated species ultimately developed less than the controlled species.

In the electroculture field of study, this research defines a clear relationship between electrically stimulated Vigna Radiata species and non-stimulated species under a hydroponic environment.

V. CONCLUSION

From the results obtained in this paper, further research can be conducted to explore the effect of alternating currents on the development of a Vigna Radiata species. Doing so can allow one to compare the effectiveness of a direct current versus an alternating current in stimulating plant growth.

When taking into account germination percentage data (presented in tab. 2), one can assume that a threshold limit for 3.3V of direct current exposure exists between 10 to 15 minutes. Though this data may not apply to other organisms, future research could investigate shorter time intervals, to accurately quantify the threshold exposure limit.

Although this study was restricted to the Vigna Radiata species due to the presence of phloem cells, different plant organisms could be investigated. In specific, electroculture could be investigated for crops like rice and wheat. If discovered to be effective, this technique could be employed to possibly alleviate global hunger issues.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Jaewon Chang has conducted the research, participated in data collection, analyzed the data, and wrote the paper; Seyoung Kwon has conducted the research, collected and verified the data, and wrote the paper; all authors had approved the final version.

References

[1] I. Jorgensen and W. Stiles, "The electroculture of crops," *Science Progress (1916-1919)*, vol. 12, no. 48, pp. 609-621, 1918.

[2] A. G. Volkov, *Plant Electrophysiology: Theory and Methods*, Springer Berlin Heidelberg, 2006.

[3] R. A. Nelson. (May 2014). Electro-culture (the electrical tickle). *Iceagefarmer*. [Online]. Available: http://www.blog.lege.net/content/StimulatingPlantGrowthWithElectricityMagnetismSound.pdf

[4] G. L. Barbosa, *et al.*, "Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods," *International Journal of Environmental Research and Public Health*, vol. 12, no. 6, pp. 6879-6891, 2015.

[5] R. Gashgari, K. Alharbi, K. Mughrbil, A. Jan, and A. Glolam, "Comparison between growing plants in hydroponic system and soil based system," in *Proc. the 4th World Congress on Mechanical, Chemical, and Material Engineering*, Madrid, Spain, 2018.

[6] F. M. Yamaguchi and A. P. Krueger, "Electroculture of tomato plants in a commercial hydroponics greenhouse," *J. Biol. Phys.*, vol. 11, pp. 5-10, 1983.

[7] P. Barman and R. Bhattacharya, "Impact of electric and magnetic field exposure on young plants—A review," *International Journal of Current Research and Academic Review*, vol. 4, pp. 182-192, 2016.

[8] J. R. Edwardson, *CRC Handbook of Viruses Infecting Legumes*, CRC Press, Boca Raton, 2018.

[9] E. C. D. Silva, N. Peixoto, N. Arruda, N. C. D. Ferreira, and L. A. B. D. Oliveira, "Yield and development of mung bean according to the plant density," *Journal of Neotropical Agriculture*, vol. 6, pp. 14-20, 2019.

[10] H. M. Kamrul, M. S. Islam, M. R. Islam, H. N. Ismaan, A. E. L. Sabagh, "Germination and early seedling growth of mungbean (Vigna radiata L.) as influenced by salinity," *Azarian Journal of Agriculture*, vol. 5, no. 2, pp. 49-59, 2018.

[11] L. Lu, Y. F. Shen, X. H. Chen, L. H. Qian, and K. Lu, "Ultrahigh strength and high electrical conductivity in copper," *Science*, vol. 304, pp. 422-426.

[12] B. Wachter, H. D. Keulenaer, F. Nuño, and R. Targosz. (2019). Electrical conductors. [Online]. Available: https://www.researchgate.net/publication/336838620?channel=doi&linkId=5db5d014a6fdccc99da8a1ac&showFulltext=true

[13] S. Gvozdenac, V. Bursic, M. Mezei, J. Ovuka, M. Tatić, and D. Prvulovic, "Germination energy and seed germination of cultivated plants as indicators of water contamination with nickel," in *Proc. 23rd International Symposium on Analytical and Environmental Problems*, 2017, pp. 198-202.

[14] M. Mühlich, D. Truhn, K. Nagel, A. Walter, H. Scharr, and T. Aach, "Measuring plant root growth," in *Pattern Recognition*, vol. 5096, G. Rigoll, Ed., Springer Berlin Heidelberg, 2008, pp. 497-506.

[15] M. Baucher, M. E. Jaziri, and O. Vandeputte, "From primary to secondary growth: Origin and development of the vascular system," *Journal of Experimental Botany*, vol. 58, pp. 3485-3501, 2007.

[16] D. A. Morris, "The influence of small direct electric currents on the transport of auxin in intact plants," *Planta*, vol. 150, pp. 431-434, 1980.

[17] M. F. Diprose, *et al.*, "The effect of externally applied electrostatic fields, microwave radiation and electric currents on plants and other organisms, with special reference to weed control," *The Botanical Review*, vol. 50, no. 2, pp. 171-223, 1984.

[18] EurekAlert. (May 2018). Electrical signals in plants affect photosynthetic activity. [Online]. Available: https://www.eurekalert.org/news-releases/677478

[19] P. Barman and R. Bhattacharya, "Impact of electric and magnetic field exposure on young plants—A review," *Int. J. Curr. Res. Aca. Rev.*, vol. 4, no. 2, pp. 182-192.

[20] N. Ahangarnezhad, "Design and construction of electro-culture system and evaluation of its effect on grass seed (Festuca arandinacea) performance improvement and germination rate," *Journal of Agricultural Engineering*, vol. 40, no. 2, pp. 1-12, 2018.

Jaewon Chang was born in Seoul, South Korea, March 15, 2003. He is currently a high school student at the International School of Manila. He has previously presented scientific and mathematical research papers in international journals, including the Asia Pacific Journal of Multidisciplinary Research vol. 8, no. 3, the International Organization of Scientific Research Journal of Mathematics Series-3 (Mar – Apr 2020), and has a research paper forthcoming in the International Journal of Current Research.