2023 S.T. Yau High School Science Award (Asia)

Research Report

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Title of Research Report

Power Plant in Plant_ By Rhizodeposition

Date

15 August 2023

Power Plant in Plant_ By Rhizodeposition

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Abstract

The advocation of Power Plant in Plant is to mitigate the energy crisis, providing an alternative of efficient, effective and stable renewable energy. During photosynthesis, organic substances, which have not been consumed and released to soil by rhizodeposition, (Kabutey et al, 2019) are decomposed by microorganisms to convert chemical energy into electrical energy (Castresana, Martinez, Freeman, Eslava, & Di Lorenzo, 2019) that could be collected. The experiment is divided into four parts, all of which proved the feasibility of generating electricity by plants, while the highest voltage generated is 6069 mVm^{-2}. Also, the power generation of plants after watering was higher than that of before watering, the longer the period that the plants were not watered, the lower the power generations were. Moreover, wrapping the reserved copper wire by plastic obviously enhances the performance of copper electrodes and electrodes with different shapes remain the power generation. Furthermore, the power generated by plants was stable within the whole day, both with and without sunshine, indicating the high potential and high efficiency of Power Plant in Plant. However, how the power generation rate could be uplifted still requires the study of scientists.

Keywords: Plants, rhizodeposition, new energy source, power

Acknowledgement

We would like to thank Mr Yeung Wai Lok Wesley for the advice for improvements. We would also like to thank Mr Law Yan Ming and Mr So Pak Yeung for providing assistance in programming.

Commitments on Academic Honesty and Integrity

We hereby declare that we

1. are fully committed to the principle of honesty, integrity and fair play throughout the competition.
2. actually perform the research work ourselves and thus truly understand the content of the work.
3. observe the common standard of academic integrity adopted by most journals and degree theses.
4. have declared all the assistance and contribution we have received from any personnel, agency, institution, etc. for the research work.
5. undertake to avoid getting in touch with assessment panel members in a way that may lead to direct or indirect conflict of interest.
6. undertake to avoid any interaction with assessment panel members that would undermine the neutrality of the panel member and fairness of the assessment process.
7. observe the safety regulations of the laboratory(ies) where the we conduct the experiment(s), if applicable.
8. observe all rules and regulations of the competition.
9. agree that the decision of YHSA (Asia) is final in all matters related to the competition.

We understand and agree that failure to honour the above commitments may lead to disqualification from the competition and/or removal of reward, if applicable; that any unethical deeds, if found, will be disclosed to the school principal of team member(s) and relevant parties if deemed necessary; and that the decision of YHSA (Asia) is final and no appeal will be accepted.

(Signatures of full team below)

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Contents

1 Introduction

1.1 Background

As the demand for electricity is increasing drastically, the depletion of fossil fuels is being alarmed. Research shows that in 2015, the reserves of three main fossil fuels in earth, petroleum, natural gas and coal, were only remaining 1697.6, 186.9 and 891,531billion barrels respectively (BP Statistical Review of World Energy 2016), which was expected to be supplied for 56, 55, 119 years only. Therefore, it is essential to overcome this problem.

However, the efficiency of solar power systems, hydroelectricity systems and wind power systems are being constrained by many factors, such that the electricity produced is not enough to afford humans' demand. In 2008, renewable energy only accounted for around 18%. (Renewables 2010 global status report.) This shows that the society relying on unrenewable energy is still very high, which cannot decline the consumption of fossil fuels. Take solar power as an example, although it makes use of the energy of the environment, however the cost of the setup is very expensive, it is unrealistic to have it be used by every family. Moreover, there is not enough land to lay the solar panels. On the other hand, not only is the development of wind power systems costly, the output of energy produced is also affected by the geographical location. Hong Kong, which is full of high-rise buildings, is not conducive to the application of wind power systems. In 2010, 20% of total electrical energy generated was renewable energy, in which the hydroelectricity system occupied 19%, showing that its efficiency was the highest among renewable energy systems. (Energy Information Administration. 2013) However, although the trend of developing renewable energy is rising, water resources on Earth and appropriate regions for setting the system are limited, and thus the hydroelectricity could not replace or reduce the usage of fossil fuels even though the technology is further ameliorated. Therefore, only discovering some new renewable energy with high efficiency could tackle the problem, and the idea of utilising plants, which is universal, as a medium for generating electricity is derived. Not only could this reliable technology aid mitigate the rate of fossil fuels being depleted, but also green the environment and reduce greenhouse gas emissions, to protect the Earth.

1.2 The principle of Power Plant in Plant

The principle of Power Plant in Plant is that during photosynthesis, some organic substances not consumed are released to soil from the roots by rhizodeposition. (Kabutey et al, 2019) Rhizodeposits excreted mainly consist of carbon, such as sugars, amino acids, organic acids, hormones, and vitamins, while ions such as ammonium ions and nitrate ions, are also released to the rhizosphere during rhizodeposition. (Wichern et al, 2008) The decomposition of the organic substances by microorganisms such as electrochemically active bacteria in soil is a series of redox reactions to convert chemical energy into electrical energy. (Castresana, Martinez, Freeman, Eslava, & Di Lorenzo, 2019) The electrode placed nearby the roots and conductive material added in soil act as anode and cathode respectively. The decomposition of organic substances by bacteria adjacent to the anode produces hydrogen ions and high-energy electrons which could be collected by electrodes. Meanwhile, oxygen adjacent to the cathode, as a terminal electron acceptor, reacts with hydrogen ions to produce water, causing a potential difference between electrodes.

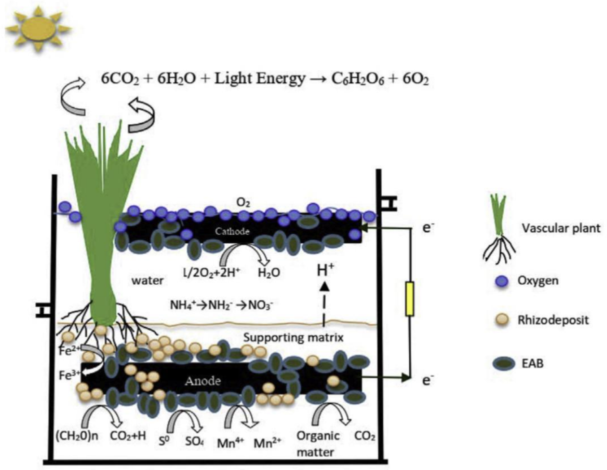

Fig. 1.1 The principle of Power Plant in Plant (Kabutey et al, 2019)

Theoretically, the higher rate of rhizodeposits excretion and high-energy electron production of microorganisms, the larger amount of power is generated. (Kabutey et al, 2019)

1.3 Hypothesis

It was assumed that the products of the process of photosynthesis taken by plants could be used to produce energy carrying electrons by microorganisms, and hence used to generate electricity. The hypothesis was tested by finding whether there was voltage generated during photosynthesis of plants.

1.4 Objectives

There were four objectives in the experiment. First, find out whether the plants in Hong Kong could generate electricity as some foreign papers mentioned. Second, finding out the species which could generate the most electricity among all the prepared plant species. Third, discussing the factors affecting the power generation of plants and the relationship between them. Fourth, finding out with what setup of the same species of plant would electrons be collected most efficiently and stably.

1.5 Impact or significance

The benefits of ultilizing plants to generate electricity is prodigious and mutual dependency. First, a large number of plants is required to implement Power Plant in Plant on a large scale. Forests such as the Amazon Forest no longer need to sell wood to make a living and provide required electricity for the country. If the current tree felling continues, all the trees in the forest will be cut down one day, followed by the disappearance of this habitat which has nourished many precious species and even the extinction of these precious species. The biodiversity of the Earth would hence be seriously affected. However, as long as there are large areas of plants executing photosynthesis continuously, electricity could be generated. Not only could it bring fortune to the country, but also provide perfect habitat for wildlife animals and preserve precious plant species.

Second, more greening projects could be carried out, to bring fresher air and provide electricity to the city. If only every country put their hands together to implement greening and reduce the felling of trees, ample plants could absorb carbon dioxide, the major gas produced by greenhouse effect, during photosynthesis, and so on solve the current grim problem of global warming, including the rising sea-level caused by the glacier meltdown, etc.

Last but not least, the large-scale use of Power Plant in Plant could greatly slow down the depleting rate of fossil fuels . Nowadays, most of the renewable energy sources are not widely used and have low efficiency, while the cost of planting is affordable, a Power Plant in Plant device could be installed in every household to be self-sufficient and charge simple electrical applications. Even if fossil fuels are exhausted one day, the problem of non-renewable energy could be solved by laying the electrodes under vegetation to provide electricity for the world.

2 Methodology

2.1 Testing the feasibility of generating power by different plants in flower pots

In experiment 1, the feasibility of generating power by different plants were tested by three plants, including *Aloe vera*, *Dracaena trifasciata*, and *Catharanthus roseus*.

Materials of experiment 1:

Material	**Amount**
Plants (*Aloe vera*, *Dracaena trifasciata*, *Catharanthus roseus*)	1 per each
Electroconductive carbon fibre	1 kg
Copper wire (1.5 m)	6
Multimeter	1
Photometer	1
Thermometer	1
Soil	3 serving size
Electric wire	3 serving size
Flowerpot	3
Sandpaper	1 piece

2.1.1 Procedure of experiment 1:

1. Prepare a pot whose radius and height are 14 cm and 12.5 cm respectively.
2. Prepare two copper wires and polish them with a piece of sandpaper.
3. Roll the first 135 cm of the copper wire into a spiral shape and reserve the remaining 15 cm. The distance between every circle should be 0.5 cm as shown:

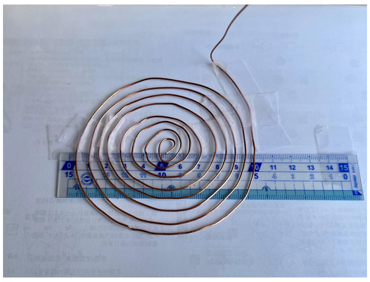

Fig. 2.1 Spiral-shaped copper wire electrode

4. Place a ruler vertically along the edge of the pot.
5. Add some soil into the pot until it meets the marking of 2.5 cm.
6. Place a copper wire electrode on top of the soil as the bottom electrode which acts as the cathode of the device. Leave the reserved copper wire vertically along the pot and hang the remaining 5 cm outside the pot for collecting data.
7. Add some electroconductive fibre into the pot until it meets the marking of 4 cm to increase the contact area of the electrode and hydrogen ions and high-energy electrons.
8. Add some soil into the pot until it meets the marking of 6 cm.
9. Add some electroconductive fibre into the pot until it meets the marking of 7.5 cm.
10. Place a copper wire electrode on top of the electroconductive fibre as the top electrode which acts as the anode of the device. Leave the reserved copper wire vertically along the pot and hang the remaining 5 cm outside the pot for collecting data. Notice that the two copper wires should not contact the copper electrode of the other side.
11. Transplant the plant on top of the above layers of materials and add some soil until the pot is full. The whole device is completed as shown:

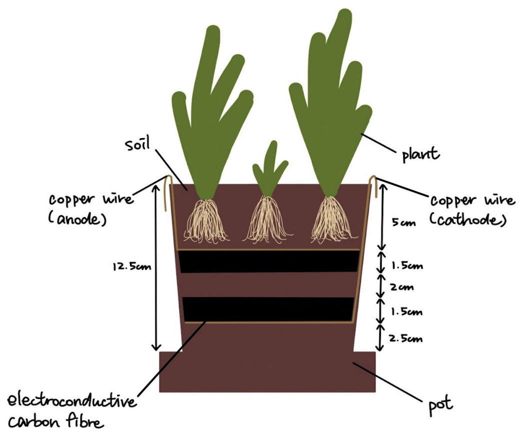

Fig. 2.2 The device diagram of Power Plant in Plant

12. After the device was completed, a multimeter was used to collect the voltage index during the photosynthesis by plants.

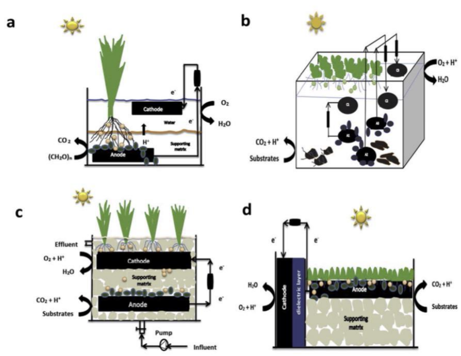

Fig. 2.3 The processes of Power Plant of Plant (Kabutey et al, 2019)

Ensuring fairness of tests:

1. Sandpaper was used to polish the copper wire, to make sure that its best role can be played and the results were not affected by the oxide on the surface of the copper wire.
2. The voltage was measured in the absence of sunlight as a control device, to ensure that the changes in voltage were caused by light intensity and the plant.
3. The three plants were placed in the environment of the same light intensity and temperature. The environment would affect the rate of photosynthesis and thus the voltage generated by the plants. Fairness of the experiment was ensured by placing the plants under identical conditions.
4. The experiment was repeated under different light intensities. The voltages of plants under different light intensity were compared to find out the relationship between the light intensity and the power generation of plants.
5. The experiment was repeated to bolster credibility of the experiment.
6. The length of the copper wire used is unified to be 1.5 m.
7. The size of the flower pots whose radius and height are 14 cm and 12.5 cm respectively are unified.
8. The amount of watering is unified to be 100 mL per week.

Control device:

Fig. 2.4 Control device 1: voltage was 0 mV when there was no sunlight

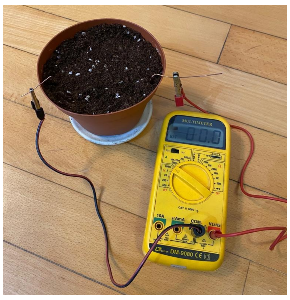

Fig. 2.5 Control device 2: voltage was 0 mV when there was no plant

From the control devices, the voltages measured under both two conditions of no sunlight and no plant were 0 mV. The voltage generated during the experiment could so be deduced to be generated during photosynthesis reasonably.

Details of plants:

	Aloe vera	*Dracaena trifasciata*	*Catharanthus roseus*
Contact area of root (m^2)	0.0133	0.0133	0.0133
Height of the plant (cm)	17.5	11.5	14.5

As the flowerpots and the plants had different volumes, it was essential to have the data compared in the same unit to ensure the fairness to the experiment. In this experiment, the area of the flowerpots, i.e. the contact area of the root, were chosen to be measured, because the microorganisms in the soil would affect the generation rate of the plants.

2.1.2 Result of experiment 1:

Date	**Day**	***Aloe vera*** **(mVm^{-2})**	***Dracaena trifasciata*** **(mVm^{-2})**	***Catharanthus roseus*** **(mVm^{-2})**	**Light intensity (lux)**	**Temperature (℃)**
2021.11.02	2	2788	829	151	2051	16.9
2021.11.04	4	4144	979	151	2460	14.8
2021.11.08	8	6404	603	301	2540	16.7
2021.11.10	10	4445	603	0	2540	17.3
2021.11.15	15	5048	1130	0	2320	18.9
2021.11.18	18	5274	753	75	1940	14.9
2021.11.29	29	6103	3240	151	2090	15.6
2021.12.09	39	12732	2486	1431	2740	17.1
2021.12.15	55	7685	2637	6253	2740	18.9
Average		**6069**	1473	946	2380	16.8
Min. value		2788	603	0	1940	14.8
Max. value		12732	3240	6253	2740	18.9

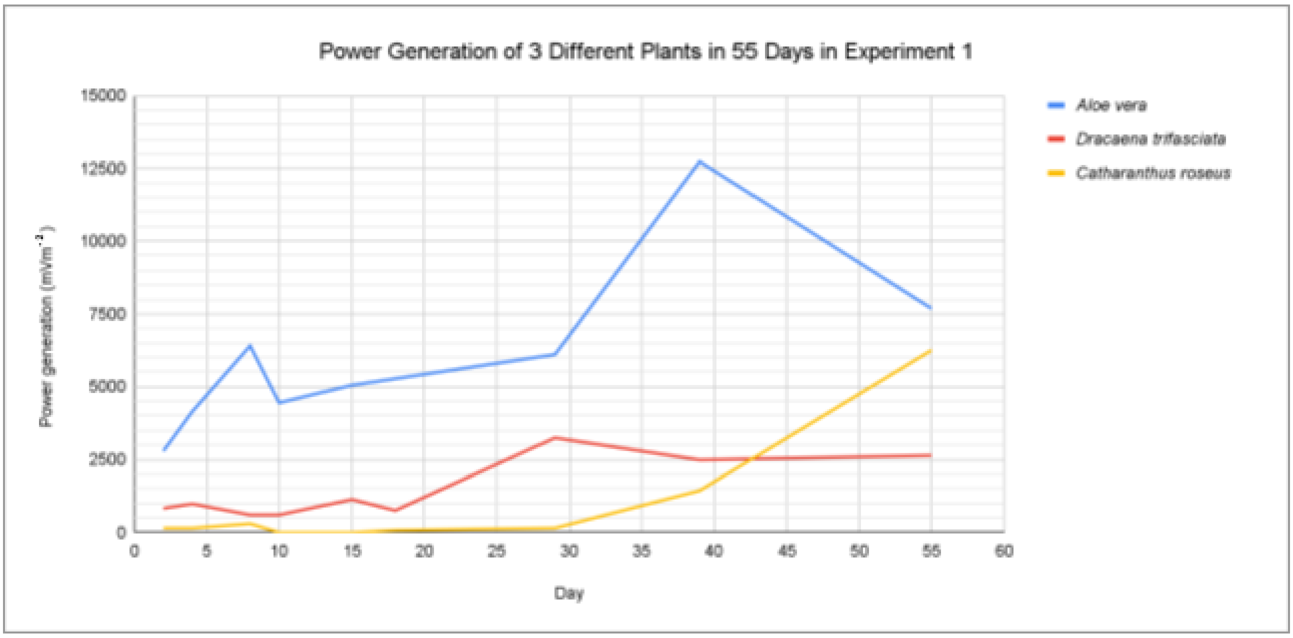

Fig. 2.6 Power generation of 3 different plants in 55 days in experiment 1

Temperature and light intensity of different days:

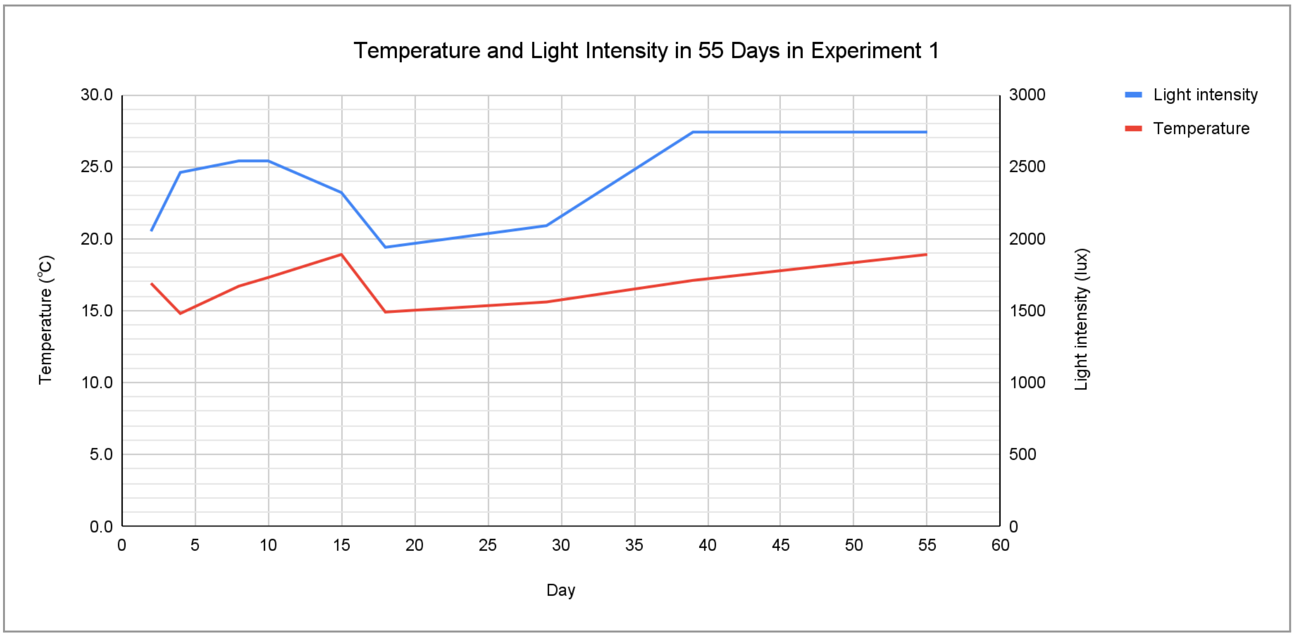

Fig. 2.7 Temperature and light intensity in 55 days in experiment 1

The following conclusions could be drawn by the above data:

First, there was release of electrons, which could be collected and measured, during photosynthesis of plants. It was believed that it was because some nutrients not consumed by the plants were expelled to the soil from the root by rhizodeposition of plants, followed by the decomposition of these nutrients by the microorganisms in the soil. The electrical energy generated by plants could hence be collected if electrodes were placed in the root of the plants and conductive materials were added to the soil.

Second, the average power generation of *Aloe vera* was the highest among the three plants.

Plant	**Average power generation (mVm^{-2})**
Aloe vera	6069
Dracaena trifasciata	1473
Catharanthus roseus	946

Untreated data of result of experiment 1 could be found in appendix 1.

2.2 Finding the factors affecting the power generation of plants

Although the increase in light intensity would increase the rate of photosynthesis of plants, it was shown from experiment 1 that there did not seem to be much correlation between light intensity and power generation of plants, which was quite different from the expectations. Hence, it was perceived that there were other factors that affect the power generation of plants.

In experiment 2, it was hoped that the factor that had the greatest influence on the power generation of plants could be found. After combining and collating the data collected in Experiment 1, the experiment-environment-comparison chart of the power generation was drawn:

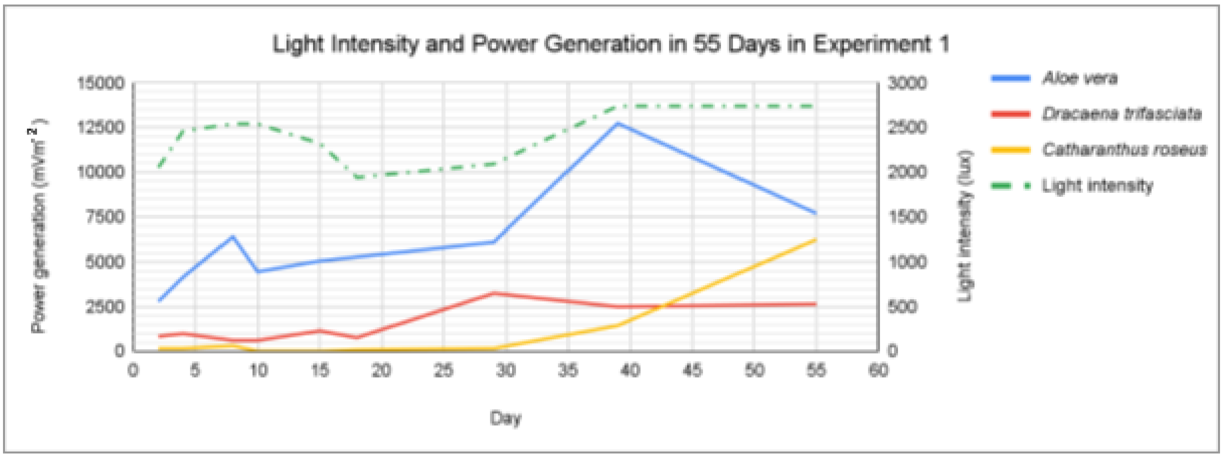

Fig. 2.8 Light intensity and power generation in 55 days in experiment 1

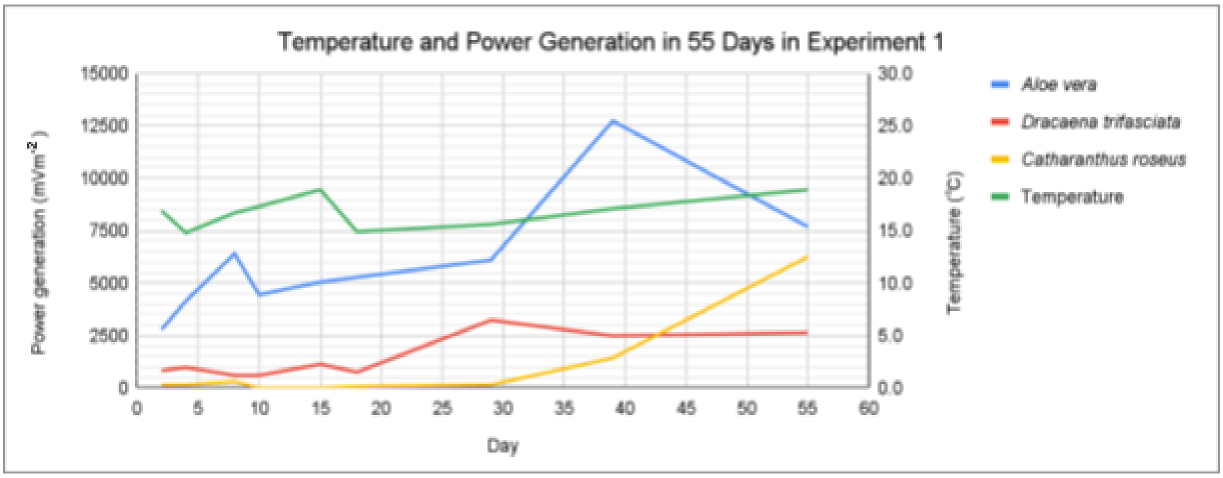

Fig. 2.9 Temperature and power generation in 44 days in experiment 1

Correlation between the amount of power generated by plants and light intensity:

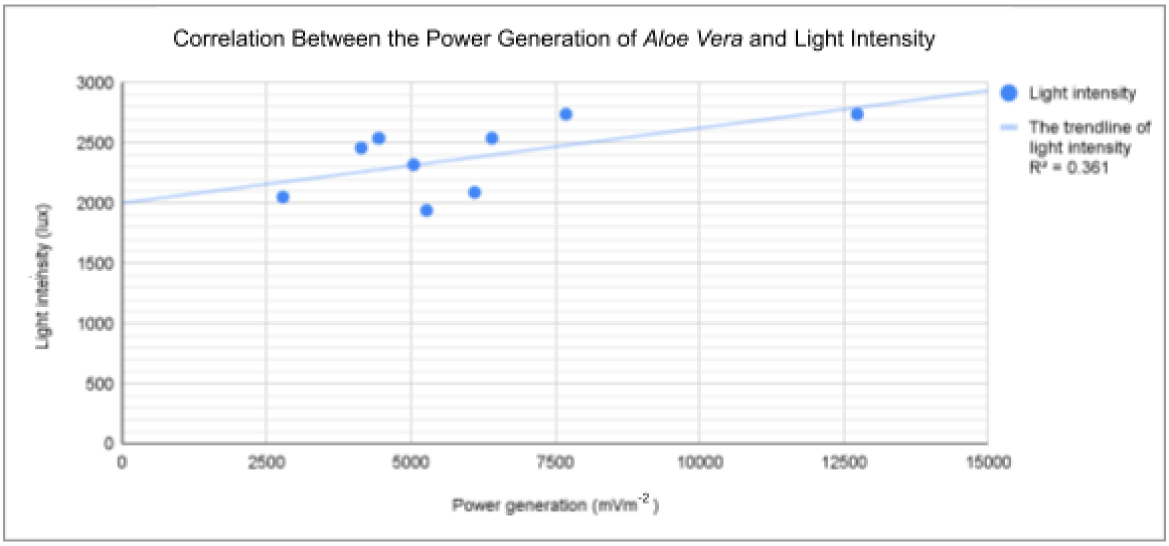

Fig. 2.10 Correlation between the power generation of *Aloe vera* and light intensity

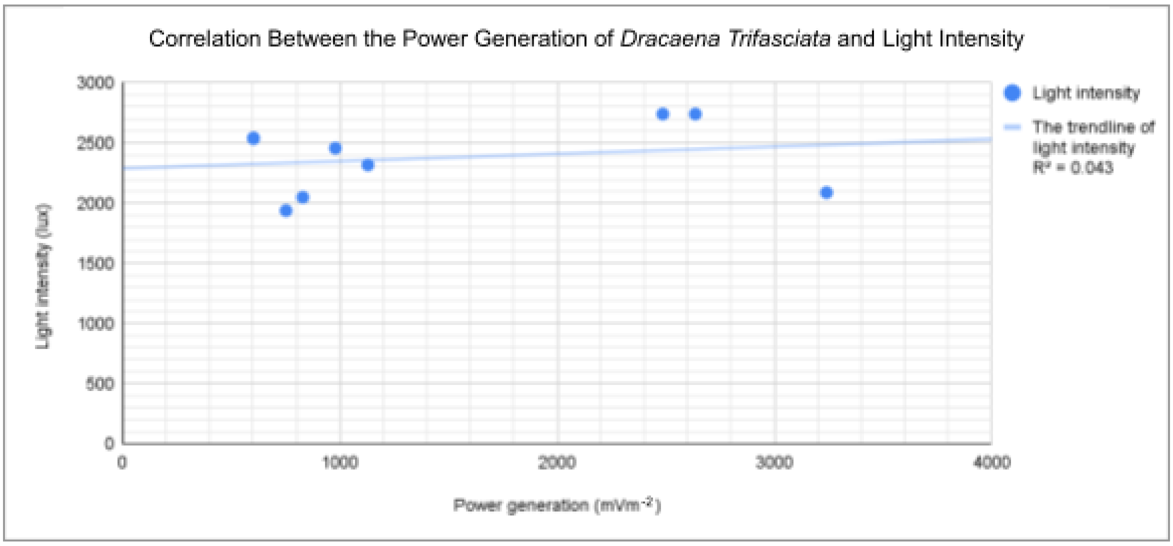

Fig. 2.11 Correlation between the power generation of *Dracaena trifasciata* and light intensity

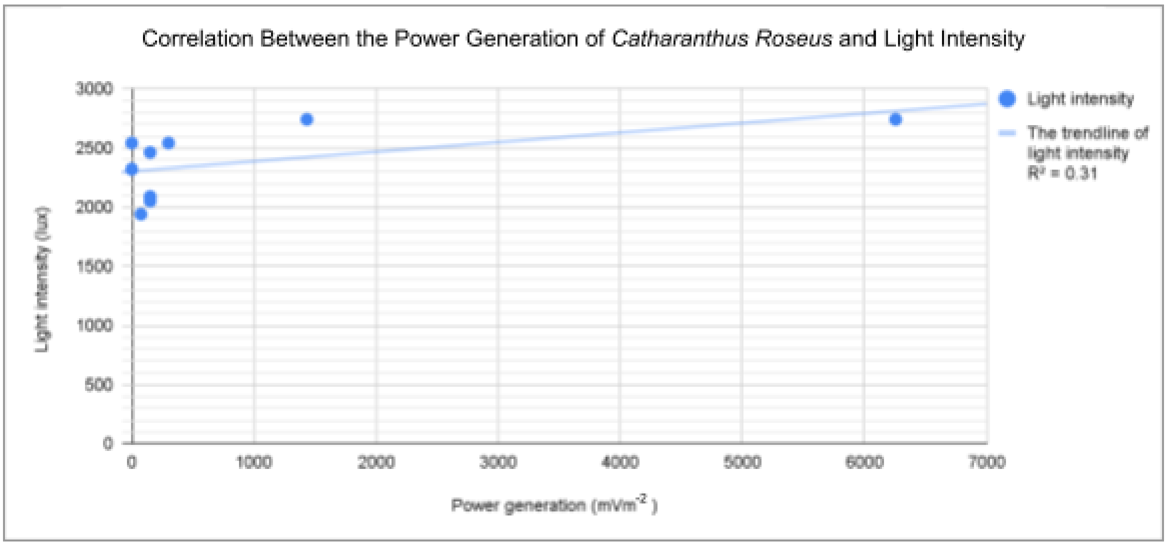

Fig. 2.12 Correlation between the power generation of *Catharanthus roseus* and light intensity

Correlation between the amount of power generated by plants and temperature:

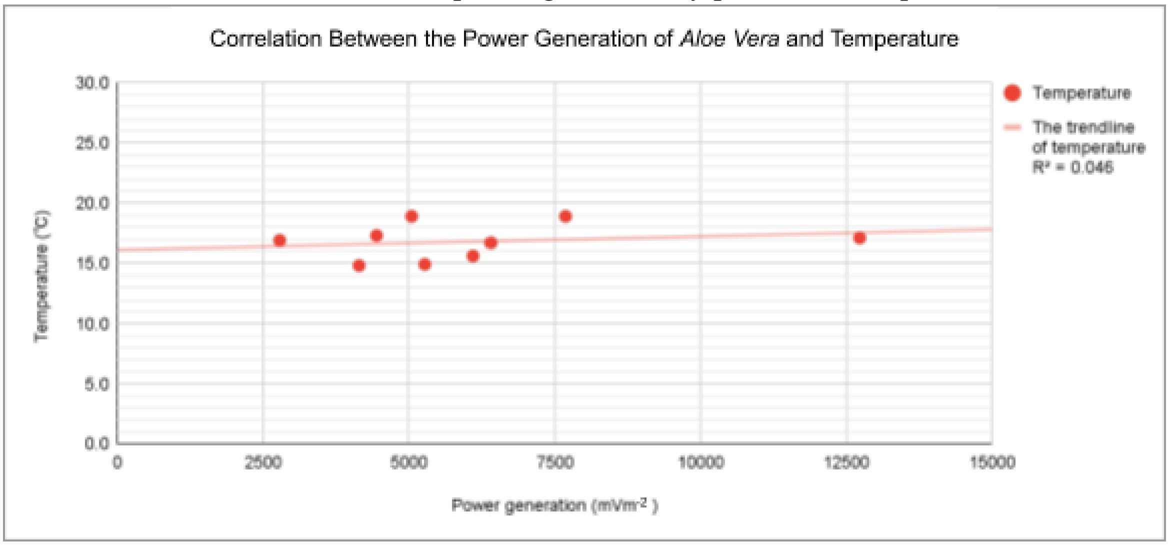

Fig. 2.13 Correlation between the power generation of *Aloe Vera* and temperature

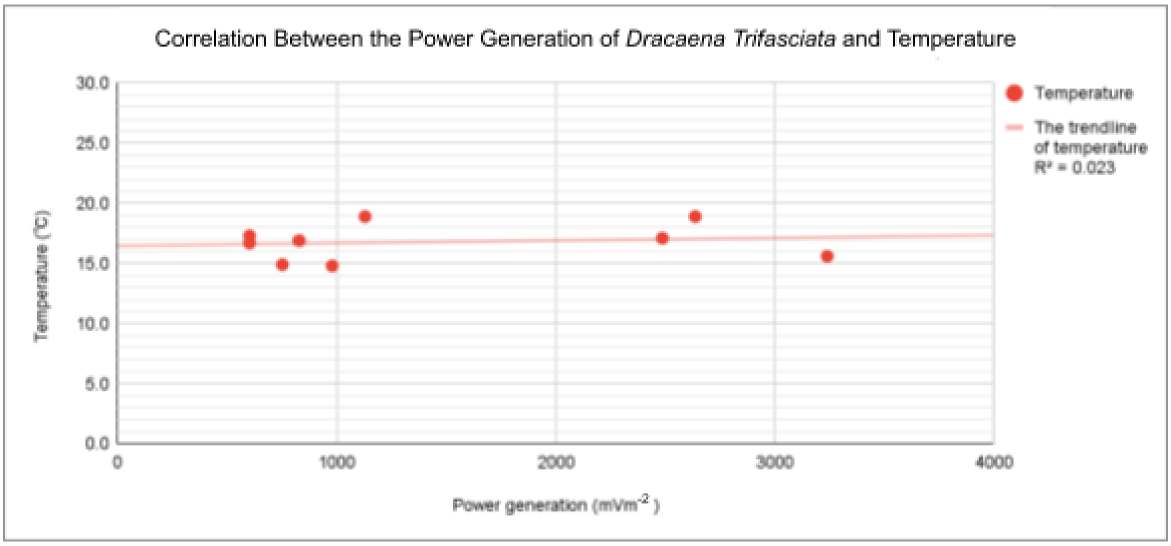

Fig. 2.14 Correlation between the power generation of *Dracaena trifasciata* and light intensity

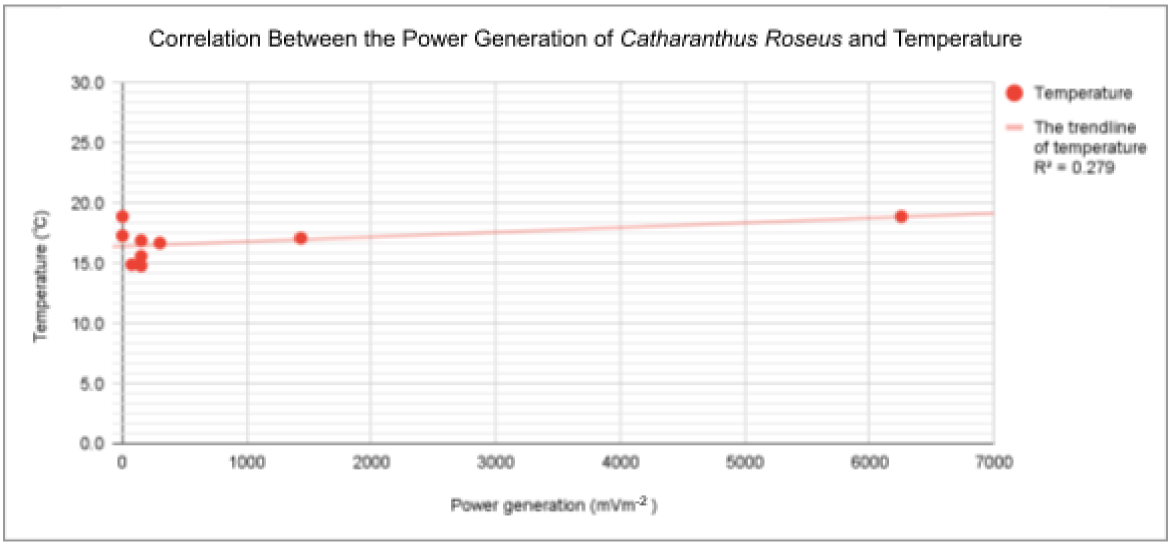

Fig. 2.15 Correlation between the power generation of *Catharanthus roseus* and temperature

Regression analysis was applied to determine the correlation between the amount of power generated by plants and the light intensity and temperature. When R^2 approaches 1, it was indicated that the two variables were correlated. When R^2 approaches 0, it was indicated that the two variables were orthogonal.

Below are the R^2 which show the correlation between the amount of power generated by plants and light intensity:

Plant	$\mathbf{R^2}$
Aloe vera	0.361
Dracaena trifasciata	0.043
Catharanthus roseus	0.31

Below are the R^2 which show the correlation between the amount of power generated by plants and temperature:

Plant	$\mathbf{R^2}$
Aloe vera	0.046
Dracaena trifasciata	0.023
Catharanthus roseus	0.279

In this regard, the amount of power generated by plants and the light intensity and temperature were not correlated.

Hence, it was further estimated that the amount of power generated by plants was correlated with the amount of watering to plants. The activity of microorganisms in soil may be affected by the amount of water, and thus the amount of power generated by plants was affected. Therefore, experiment two, which was divided into two parts, was devised to verify the assumption. First, to determine the difference in the amount of power generated by plants. Second, to find out the effect of not watering in a long period on the power generation.

Materials of experiment 2:

Material	Amount
Power Plant in Plant device	3
Watering can	1
Multimeter	1

2.2.1 Finding the difference of the power generation before and after watering

The power generation before and after showering was measured respectively, so that the effect of watering on Power Plant in Plant could be figured out by comparing the two groups of data.

Result:

	Aloe vera	*Dracaena trifasciata*
Before watering (mVm^{-2})	6041	3633
After watering (mVm^{-2})	15278	8338

(The *Catharanthus roseus* had withered)

In this regard, the amount of power generated by the two plants has obviously increased after watering. It was deduced that because of the increase of activity of microorganisms after watering, the rate of high-energy production was thus increased, causing a larger amount of power generation.

2.2.2 Finding the effect of not watering in a long period on the power generation

Not watering in 5 days and 10 days before measuring the power generation, so that the effect of not watering in a long period on Power Plant in Plant could be figured out.

Result:

Number of days not watering	*Aloe vera* (mVm^{-2})	*Dracaena trifasciata* (mVm^{-2})
5	6041	3633
10	3087	3585

(The *Catharanthus roseus* had withered)

In this regard, after not watering in both 5 days and 10 days, the power generation of plants decreased obviously compared with watering every day. Moreover, the power generation of not watering in 5 days was higher than that of not watering in 10 days. It was deduced that not watering in a long period would decrease the rate of photosynthesis of plants and the rate of the production of energy carrying electrons by microorganisms, and hence decrease the power generation of plants. As the period was expanded, the rate of photosynthesis and hence the power generation of plants were decreased.

2.2.3 Result of experiment 2:

From the above results, the following conclusions were drawn. First, among the three factors, which are light intensity, temperature and amount of water absorption, watering affects the amount of power generation the most. Second, a larger amount of power generated could be measured after watering. Third, The longer the plant was not watered, the lower its power generation.

2.3 Testing the feasibility of the application of Power Plant in Plant

Feasibility of Power Plant in Plant was investigated in experiment 1. More knids or common plants in Hong Kong were then set to relatively larger areas to determine the feasibility of substantial application.

In experiment 3, six plants, which were *Aloe vera*, *Pachira aquatica*, *Hedera helix*, *Epipremnum aureum*, *Mentha canadensis* and *Dracaena sanderiana*, were placed into one pot. Multimeter was used in the investigation to measure the voltage generated when photosynthesis was carried out by different plants simultaneously.

Materials of experiment 3:

Material	**Amount**
Power Plant in Plant device	1
Multimeter	1
Electric wire	2
Plants (*Aloe vera, Malabar chestnut, Hedera helix, Epipremnum aureum, Mentha canadensis, Dracaena sanderiana*)	1 per each

Fig. 2.16 The device diagram of Power Plant in Plant with plants in a relatively larger area

2.3.1 Result and details of experiment 3:

Date	**Day**	**Before watering (mVm^{-2})**	**After watering (mVm^{-2})**	**Light intensity (lux)**	**Temperature (℃)**
2022.04.08	1	67	74	19430	24.5
2022.04.10	3	121	136	6270	25
2022.04.12	5	58	71	19540	24.7
2022.04.16	9	54	108	6400	19.3
2022.04.18	11	125	144	1137	23.8
2022.04.21	14	266	334	379	26.5
2022.04.24	17	232	217	12780	24
2022.04.25	18	104	285	1655	25.1
2022.04.28	21	95	135	8920	28.2
Mean		**125**	167	8501.22	24.57
Min		54	71	379	19.3
Max		266	334	19540	28.2

Considering that flora could generate electricity, plants in a relatively larger area did hold the ability of generating power. Thus, there was potential in applying Power Plant in Plant in life.

Untreated data of result of experiment 3 could be found in appendix 2.

2.3.2 Verification of experiment 2

In experiment 3, voltage is measured before and after watering, to verify whether the deduction in experiment 2 could be applied when setups and conditions such as the size of pot and the amount of plants.

Result of experiment 3.2:

Date	**Day**	**Before watering (mVm^{-2})**	**After watering (mVm^{-2})**
2022.04.08	1	67	74
2022.04.10	3	121	136
2022.04.12	5	58	71
2022.04.16	9	54	108
2022.04.18	11	125	144
2022.04.21	14	266	334
2022.04.24	17	232	217
2022.04.25	18	104	285
2022.04.28	21	95	135
Average		125	167
Min		54	71
Max		266	334

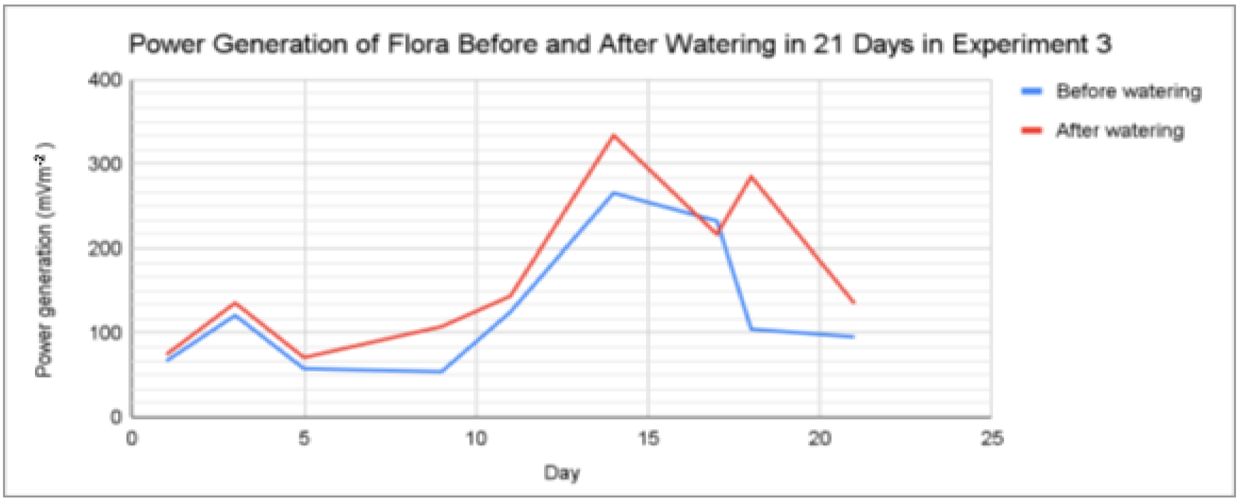

Fig. 2.17 Power generation of flora before and after watering in 21 days in experiment 3

From the graph, most of the voltage generated after watering is higher than that before watering, indicating the deduction was proved.

2.4 Finding setups that enhance the efficiency of Power Plant in Plant

In experiment 1 and 3, the amount of power generated is not stable. It is estimated that different arrangements of conductive materials may affect the stability. Therefore, experiment 4 is implemented to determine setups that enhance the stability and efficiency of Power Plant in Plant and feasibility of substantial application.

Aloe vera was chosen because of its greatest voltage generation in experiment 1, to determine the major affecting factor of the amount and stability of power generated.

2.4.1 Testing the feasibility of different arrangements of conductive materials

In experiment 4.1, the feasibility of different arrangements of conductive materials was tested from eight setups containing four aspects: distance between layers of conductive materials, ratio of soil to electroconductive carbon fibre, shape of copper rope and amount of hydrogel added.

Materials of experiment 4.1:

Material	**Amount**
Plants (Aloe vera)	8
Electroconductive carbon fibre	2 kg
Copper wire (1.5 m)	16
Multimeter	1
Soil	8 serving size
Electric wire	8 serving size
Flowerpot	8
Sandpaper	1 piece

2.4.1.1 Procedure of experiment 4.1:

1. Set eight Power Plant in Plant devices regarding the procedure mentioned in Experiment 1 and the following details.

Details of each setup:

Setup	Distance between layers of conductive materials (cm)	Ratio of electroconductive carbon fibre to soil	Shape of copper wire electrode	Ratio of the amount of hydrogel added to soil
Standard	2	1:3.17	Spiral	No hydrogel
Long distance	**4.5**	1:3.17	Spiral	No hydrogel
Short distance	**1.5**	1:3.17	Spiral	No hydrogel
Electroconductive fibre:soil = 1:4	2	**1:4**	Spiral	No hydrogel
Star	2	1:3.17	**Star**	No hydrogel
Grid	2	1:3.17	**Grid**	No hydrogel
Full hydrogel	2	1:3.17	Spiral	**No soil**
Half hydrogel	2	1:3.17	Spiral	**1:1**

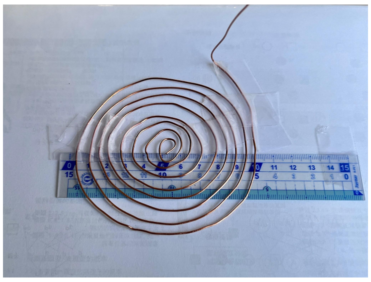

Fig. 2.18 Standard (spiral-shaped) electrode

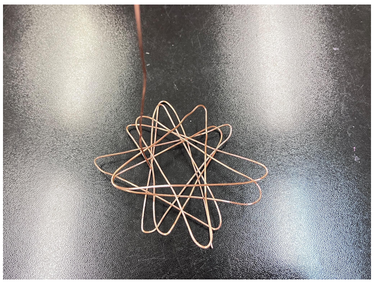

Fig. 2.19 Star-shaped electrode

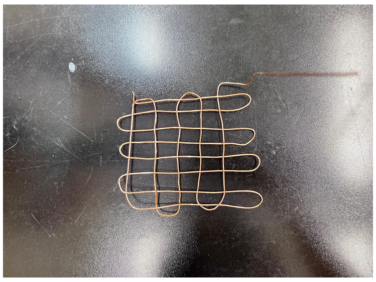

Fig. 2.20 Grid-shaped electrode

2.4.1.2 Result and details of experiment 4.1:

Date	**Day**	**Standard (mVm^{-2})**	**Long distance (mVm^{-2})**	**Short distance (mVm^{-2})**	**Soil:electroconductive fibre (mVm^{-2})**	**Star (mVm^{-2})**	**Grid (mVm^{-2})**	**Full hydrogel (mVm^{-2})**	**Half hydrogel (mVm^{-2})**
6/12/2022	1	1695	8	90	821	75	15	8	475
7/12/2022	2	2464	0	234	671	105	38	0	490
15/12/2022	10	2418	38	362	23	595	241	105	1017
26/1/2023	52	4362	4995	113	309	2132	2494	2870	3420
27/1/2023	53	3451	188	2019	128	4890	3533	2667	2931
1/2/2023	57	5650	897	5598	1605	5251	4679	3322	4777
6/2/2023	62	4739	1831	2976	1183	6298	5598	2720	4377
7/2/2023	63	4430	3903	4498	482	5229	5394	3744	2931
Average		**3651**	1482	1986	653	3072	2749	1930	2552
Min. value		1695	0	90	23	75	15	0	475
Max. value		5650	4995	5598	1605	6298	5598	3744	4777

Untreated data of result of experiment 4.1 could be found in appendix 3.

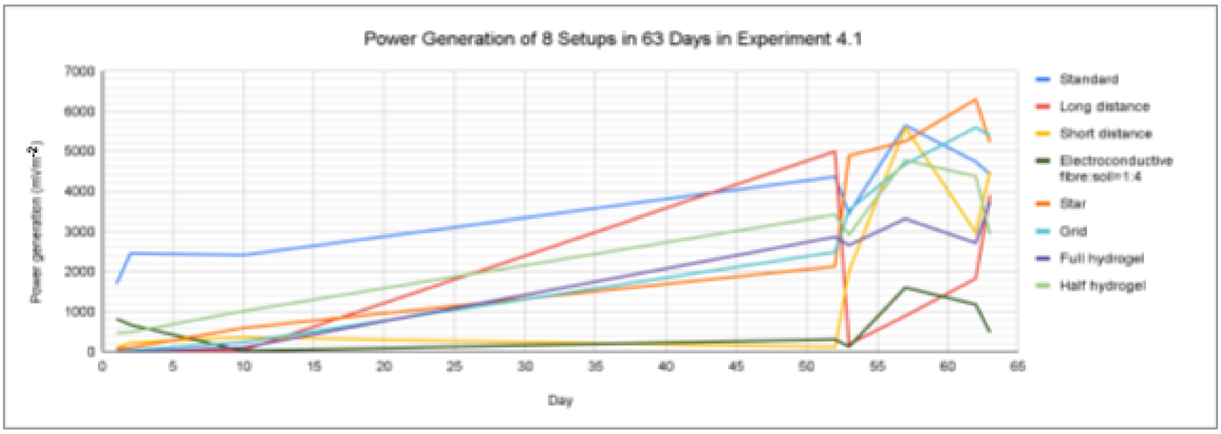

Fig. 2.21 Power generation of 9 setups in 63 days in experiment 4.1

2.4.1.2.1 Distance between layers of conductive materials

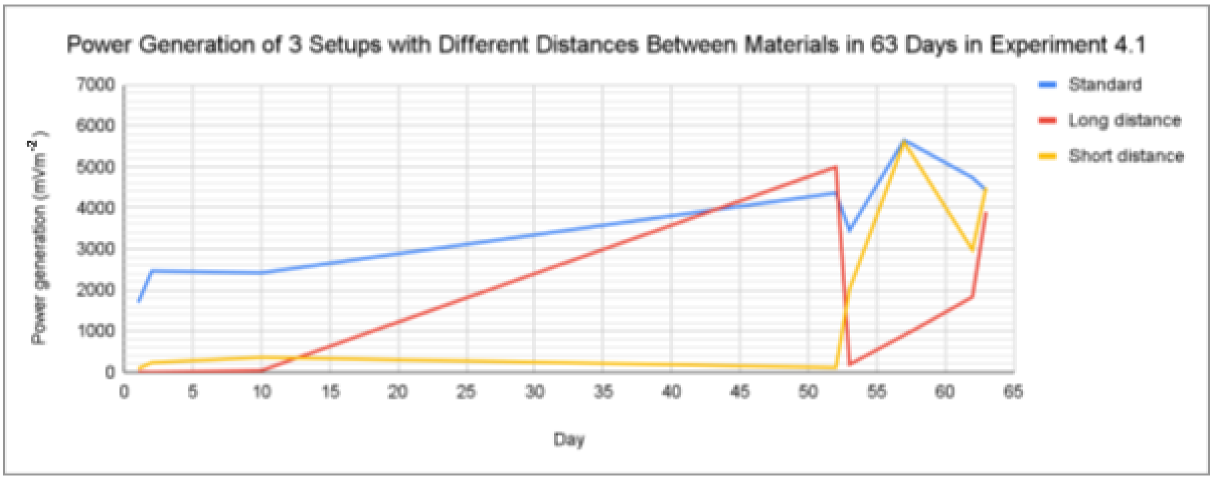

Fig. 2.22 Power generation of 3 setups with different distance between materials in 63 days in experiment 4.1

From the graph, the voltage generated by the standard devices had the highest power generation, followed by the device which had a short distance of 1.5 cm between layers of conductive materials, and hence the device which had a long distance of 4.5 cm between layers of conductive materials. It was deduced that hydrogen ions and high-energy electrons were hardly transferred when the distance between the layers of conductive materials was too long. However, if the distance was too short, less microorganisms in the soil reacted with organic substances, the number of electrons produced were hence decreased.

2.4.1.2.2 Ratio of electroconductive carbon fibre to soil

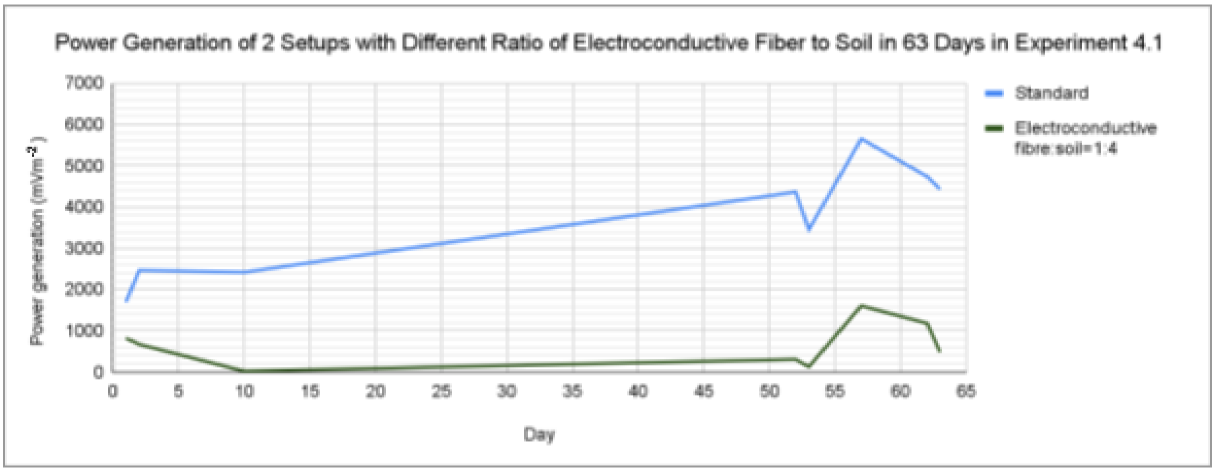

Fig. 2.23 Power generation of 3 setups with different ratio of electroconductive fibre to soil in 63 days in experiment 4.1

From the graph, the voltage generated by the device which had a lower ratio of electroconductive carbon fibre was much lower than that of standard, which had a higher ratio. It was deduced that more conductive materials added increased the chance of collecting electrons, thus higher voltage was measured.

2.4.1.2.3 Shape of copper wire electrode

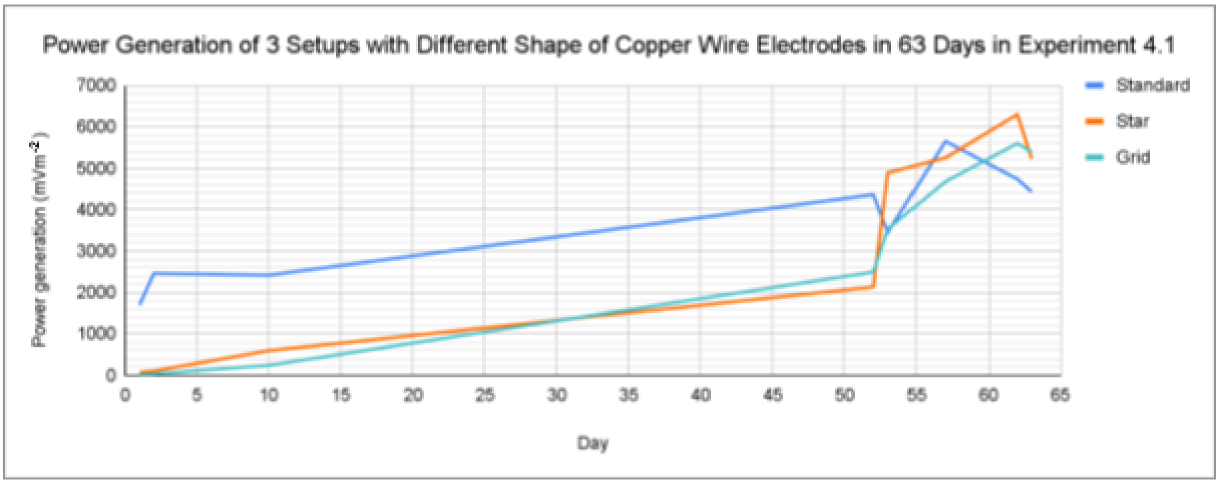

Fig. 2.24 Power generation of 3 setups with different shape of copper wire electrodes in 63 days in experiment 4.1

From the graph, the voltage generated by the standard device had the highest stability, while that of both 'star-shaped' and 'grid-shaped' devices were increasing gradually, and both the 'star-shaped' and 'grid-shaped' devices finally became higher than that of the standard device. It was deduced that it was because the covering areas of the 'grid-shaped' device was larger than that of the standard device.

2.4.1.2.4 Amount of hydrogel added

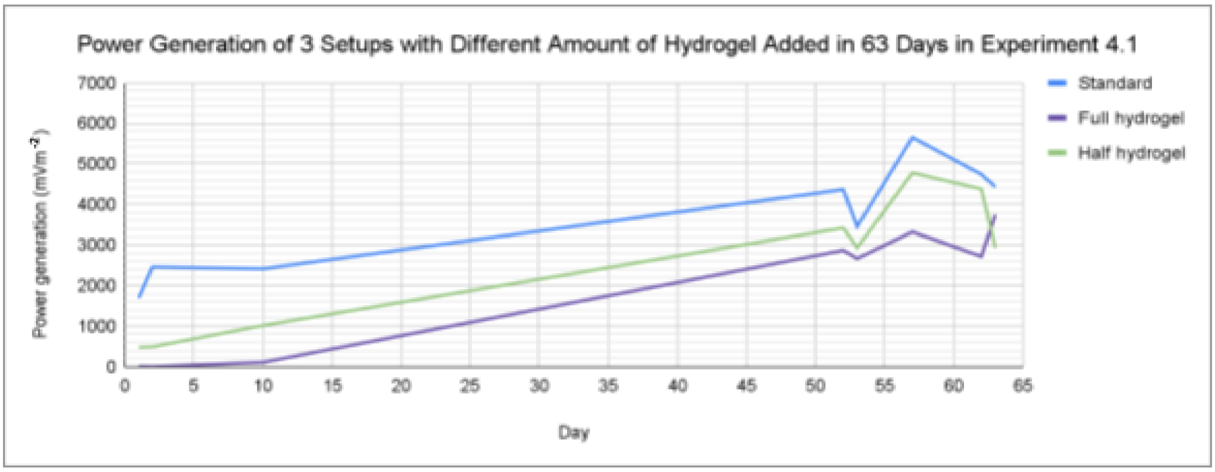

Fig. 2.25 Power generation of 3 setups with different amount of hydrogel added in 63 days in experiment 4.1

From the graph, the voltage generated by the standard device had the highest stability, while that of both devices added half and full hydrogel were increasing gradually. It was deduced that it was because the conductivity of the hybrid of hydrogel and soil was increased by adding hydrogel. The voltage generated by the standard device was also the highest among the three, followed by the device of half hydrogel mixture, while the voltage generated by the device of full hydrogel mixture was the lowest. It was deduced that although hydrogel could increase the conductivity of the soil, when the amount of hydrogel was increased, the amount of soil would be decreased. Less microorganisms would be hence found.

2.4.2 Finding better performance of electrodes to ameliorate standard devices

In part 1 of experiment 4.2, despite the plant itself and the environment, how the composition of electrodes in the device affects the rate of power generation and the stability is determined by wrapping the reserved copper wire and changing the copper wire electrode to copper sheet electrode. Meanwhile, in part 2 of experiment 4.2, the amount and stability of power generated within the whole day is determined by applying micro:bit to log data every 10 minutes in 24 hours and thus to find electrodes with better performance to ameliorate standard devices.

As power generated by plants in experiment 4.1 is still not stable even though the conductive materials are rearranged, four possible explanations were raised: First, the reserved copper wire has become the opposite electrode and reacts directly with its own electrode, electrons flow from the electrode to its reserved copper wire in the soil instead of the external circuit, the short circuit causes the voltage to be unstable. Second, the surface area of the copper wire with a shape of spital is too small which may result in the low reaction rate. Third, the power generation of plants depends on the status of the plant itself. Fourth, the stability of power generation of plants depends on other environmental factors, including duration of sunshine, duration and amount of watering, air velocity, etc.

Hence, the assembling part of the electrodes were changed instead of merely the arrangement: First, plastic wrap is used to prevent the contact of the reserved copper wire and soil, and thus only the two layers of electrode are reacting. Second, a copper wire electrode is replaced by a copper sheet electrode in order to uplift its surface area and the connection point of the sheet and the wire for recording data is welded to prevent bad contact. Third, three plants are set for each setting, the average value of them is hence calculated, so that the error caused by the status of the plants including its rhizodeposition rate could be minimised, the authenticity and credibility of the result would hence be increased. Fourth, unlike experiment 1 to 4.1, which were aimed to determine the feasibility of Power Plant in Plant, in experiment 4.2, a environment controlling device was set to control variables such as light intensity and amount of watering, attempting to implement the experiment in a controllable environment, to ensure the results are affected by the only changed variable in each plant. Meanwhile, the multimeter is replaced by micro:bit to measure the voltage generated by plants so that results can be recorded more frequently automatically to have more accurate results and credible conclusions. Data is logged every 10 minutes by manual measurement and micro:bit, so that the amplitude of power generated by plants could be observed more clearly, the stability could hence be discussed more deeply. Moreover, by applying micro:bit, data could be logged for 24 hours continuously. As a result, the power generation of plants with and without sunshine in a whole day could be compared.

Materials of experiment 4.2:

Material	Amount
Power Plant in Plant device	9
Heat shrinking tube (12 cm)	6
Copper Sheet	6
Multimeter	1
Micro:bit	3
Wire	36
Irrigation system	2
Fan	1
LED light especially for plant growing	2

2.4.2.1 Procedure of experiment 4.2:

1. Set three Power Plant in Plant devices regarding the procedure mentioned in Experiment 1 as the standard devices.
2. Prepare six copper wires, roll the first 135 cm into a spiral shape and reserve the remaining 15 cm. Wrap 12 cm of the reserved copper wire with plastic.
3. Set three Power Plant in Plant devices regarding the procedure mentioned in Experiment 1 with the wrapped copper electrodes as the 'plastic wrapped' devices.

Fig. 2.26 'Plastic wrapped' electrode

4. Prepare six copper sheets with the radius of 6 cm and puncture holes on the sheets. Prepare six copper wires with the length of 15 cm and weld the connection point of the wire and the sheet.

5. Set three Power Plant in Plant devices regarding the procedure mentioned in Experiment 1 with the copper sheet electrodes instead of the spiral-shaped copper wire as the 'copper sheet' devices.

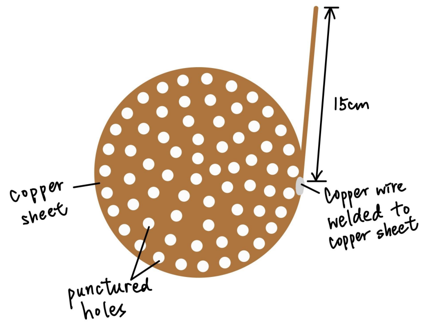

Fig. 2.27 Copper sheet electrode

6. Place the above nine Power Plant in Plant devices into the environment controlling device.

Fig. 2.28 Environment controlling device

7. Set the watering time of the watering system.
8. Download the micro:bit program to the micro:bit V2 (support data logging).

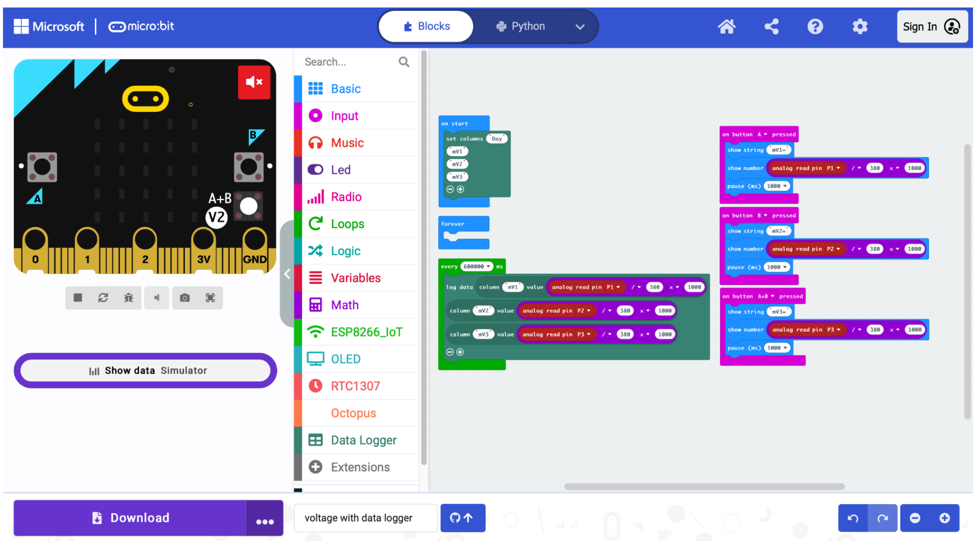

Fig. 2.29 Micro:bit blocks (python script in appendix 4)

9. Install the micro:bit V2 into the environment controlling device and connect the copper wire hanging outside the pot to the micro:bit.

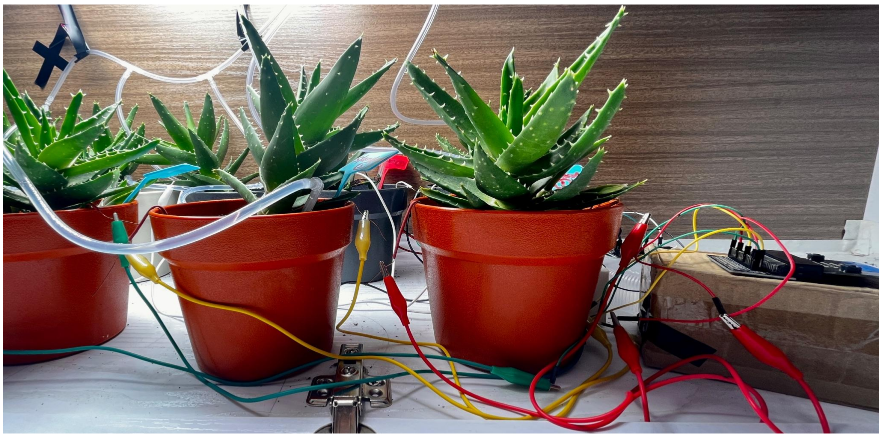

Fig. 2.30 Setup of micro:bit

10. Turn on the micro:bit. The micro:bit will log data every 10 minutes.
11. Download the data logged by the data logger of micro:bit after a period of time.

Ensuring fairness of tests:

1. The length of the copper wire used is unified to be 1.5 m.
2. The size of the flower pots whose radius and height are 7 cm and 12.5 cm respectively are unified.
3. The duration of sunshine is setted to be 12 hours from 0630 to 1830.

Fig. 2.31 Controlling the light intensity: LED light especially for plant growing

4. The amount of watering is set to be 40 mL and waters at 1725 every day. In regard to experiment 2, it was shown that watering could bring an obvious impact to the power generation of plants. Hence, instead of watering once per week, the frequency of watering was increased while the amount of it was decreased. As a result, the humidity of the soil could be maintained, and hence the active level of microorganisms in the soil.
5. Different environment factors, including amount and frequency of watering, air velocity and light intensity are controlled to minimise the error caused by the changing

of environment. Thus, the stability of the rate of photosynthesis and hence rhizodeposition could be enhanced.

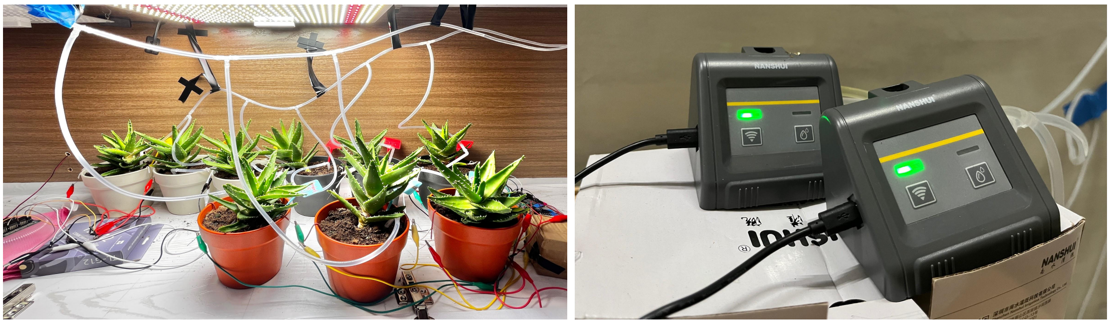

Fig. 2.32 Controlling amount and frequency of watering: irrigation system

6. The fan and vent are covered to prevent light outside of the environment controlling device from entering the device.

Fig. 2.33 Controlling the air velocity and ensuring ventilation: fan

Fig. 2.34 Controlling the air velocity and ensuring ventilation: vent

7. The micro:bits used in the experiment are turned on at the same time that they are collecting data of each plant at the same time and sharing the same power supply.

Details of each setup:

	Distance between layers of conductive materials (cm)	**Ratio of electroconductive carbon fibre to soil**	**Shape of copper wire electrode**	**Amount of hydrogel added**	**Plastic wrap**	**Copper sheet**
Standard	2	1:3.17	Spiral	No hydrogel	No	No
Plastic wrap	2	1:3.17	Spiral	No hydrogel	**Yes**	No
Copper sheet	2	1:3.17	No copper wire electrode	No hydrogel	No	**Yes**

2.4.2.2 Result of experiment 4.2 (part 1):

Average Power Generation of 3 Devices of Each Setup

Day	Time (min)	Standard (mVm^{-2})	Plastic Wrap (mVm^{-2})	Copper Sheet (mVm^{-2})
1	0	19264	26258	2256
	10	17943	30480	3145
	20	19345	26251	3466
	30	19289	25960	3300
	40	18837	25510	2772
	50	16482	24892	3172
	60	17868	25281	3266
2	0	1208	5520	3345
	10	1208	5108	3680
	20	1130	4739	3552
	30	1097	4319	3906
	40	1113	4003	3707
	50	1110	3837	3590
	60	1102	3631	3767
7	0	16065	52461	3654
	10	18343	52133	3586
	20	16972	61244	3624
	30	18355	50997	3869
	40	21293	53674	3775
	50	19068	52838	3707
	60	25214	54669	3654
8	0	23059	55899	3699
	10	25673	52966	3477
	20	27399	53672	3609
	30	25327	54890	3639
	40	28483	67226	3665
	50	21090	51369	3334
	60	25595	56836	3710
Average		16033	**35238**	3497

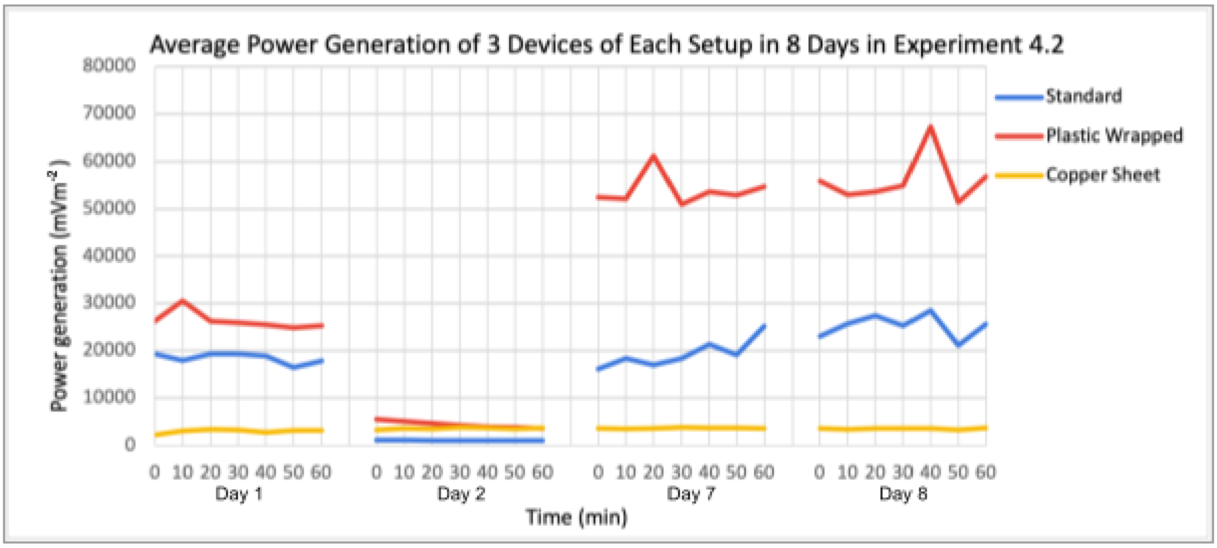

Fig. 2.35 Average Power Generation of 3 Devices of Each Setup in 8 Days in Experiment 4.2

From the graph, the average power generation of ‘plastic wrapped’ devices has obviously increased. It was deduced that it was because when the reserved copper wire was wrapped by plastic, the decomposition of rhizodeposits by microorganisms and the reaction of hydrogen ions and oxygen focused on the electrode which acts as anode and electrode which acts as cathode respectively, electrons flow from the electrode to the external circuit instead of its reserved copper wire, and thus short circuit in the soil is prevented. Therefore, the amount of power generated by ‘plastic wrapped’ devices increased. On the other hand, the voltage generated by the ‘copper sheet’ device had the highest stability. It was deduced that it was because the contact area of copper sheet increased and the surface of copper is more equally distributed in the layer. Therefore, the power generated by the ‘copper sheet’ device is the highest among the tested setups in experiment 4.2. However, the power generation of the ‘copper sheet’ device is the lowest. It was deduced that it was because the area of holes on the copper sheet is not large enough for roots to grow through. Also, the area which allows microorganisms, hydrogen ions and high-energy electrons to pass through is decreased. In the long term, replacing the copper wire electrodes by copper sheets might affect the growth of plants. Thus, the effectiveness of decomposition of organic substances by microorganisms inside the soil is not yet maximised.

Untreated data of result of experiment 4.2 (part 1) could be found in appendix 5.

2.4.2.3 Result of experiment 4.2 (part 2):

Power Generation of 3 Devices of Each Setup in 1 Day

Time (h)	Time (min)	Standard (mVm^{-2})	Plastic Wrap (mVm^{-2})	Copper Sheet (mVm^{-2})
0	0	38066.3333212630	104682.416633474	5551.34027601753
	10	37868.0711685481	104880.678786188	5154.81597058771
	20	38066.3333212630	104880.678786188	5154.81597058771
	30	38066.3333212630	104484.154480759	4956.55381787279
	40	37471.5468631183	104484.154480759	5154.81597058771
	50	38066.3333212630	103492.843717184	5154.81597058771
Average		37934.1585527864	104484.154480758	5187.85966270686
1	0	37868.0711685481	100122.387121030	5154.81597058771
	10	38264.5954739779	101510.222190035	5353.07812330262
	20	38462.8576266929	100320.649273745	4956.55381787279
	30	37273.2847104034	100518.911426460	4758.29166515788
	40	37273.2847104034	101906.746495465	4956.55381787279
	50	38462.8576266929	102501.532953609	4956.55381787279
Average		37934.1585527864	101146.741576724	5022.64120211109
2	0	37273.2847104034	100915.435731890	4956.55381787279
	10	37868.0711685481	100915.435731890	5154.81597058771
	20	37273.2847104034	101510.222190035	4956.55381787279
	30	37075.0225576885	101708.484342750	5353.07812330262
	40	37075.0225576885	101906.746495465	5154.81597058771
	50	37075.0225576885	101510.222190035	5154.81597058771
Average		37273.2847104034	101411.091113677	5121.77227846855
3	0	38264.5954739779	101311.960037320	5154.81597058771
	10	36876.7604049735	101510.222190035	5154.81597058771
	20	37471.5468631183	101708.484342750	4956.55381787279
	30	36876.7604049735	101510.222190035	5154.81597058771
	40	36678.4982522587	101708.484342750	5154.81597058771
	50	37273.2847104034	101708.484342750	4560.02951244297
Average		37240.2410182842	101576.309574273	5022.64120211110
4	0	37669.8090158332	101708.484342750	5353.07812330262
	10	36480.2360995438	101708.484342750	5154.81597058771

	20	36480.2360995438	101708.484342750	4956.55381787279
	30	37075.0225576885	101906.746495465	4956.55381787279
	40	37471.5468631183	102105.008648180	5154.81597058771
	50	37471.5468631183	101708.484342750	5154.81597058771
Average		37108.0662498077	101807.615419107	5121.77227846855
5	0	37471.5468631183	102105.008648180	4956.55381787279
	10	37273.2847104034	101906.746495465	4956.55381787279
	20	37471.5468631183	102303.270800895	4956.55381787279
	30	36678.4982522587	101906.746495465	4956.55381787279
	40	36480.2360995438	101906.746495465	5551.34027601753
	50	37273.2847104034	102105.008648180	4956.55381787279
Average		37108.0662498077	102038.921263941	5055.68489423025
6	0	36480.2360995438	102303.270800895	4956.55381787279
	10	36480.2360995438	102501.532953609	4956.55381787279
	20	36480.2360995438	102105.008648180	4758.29166515788
	30	37273.2847104034	102303.270800895	4956.55381787279
	40	37273.2847104034	102501.532953609	5154.81597058771
	50	37273.2847104034	102501.532953609	4956.55381787279
Average		36876.7604049736	102369.358185133	4956.55381787279
7	0	36678.4982522587	102699.795106324	4758.29166515788
	10	36678.4982522587	102699.795106324	5154.81597058771
	20	36281.9739468288	102501.532953609	4758.29166515788
	30	37075.0225576885	102105.008648180	4758.29166515788
	40	36281.9739468288	102501.532953609	5154.81597058771
	50	35885.4496413990	102501.532953609	5551.34027601753
Average		36480.2360995437	102501.532953609	5022.64120211110
8	0	36480.2360995438	102501.532953609	5353.07812330262
	10	36876.7604049735	101906.746495465	5154.81597058771
	20	36480.2360995438	102105.008648180	5154.81597058771
	30	36876.7604049735	101906.746495465	4956.55381787279
	40	37273.2847104034	102105.008648180	4758.29166515788
	50	36876.7604049735	102105.008648180	4560.02951244297
Average		36810.6730207353	102105.008648180	4989.59750999194

9	0	38066.3333212630	101510.222190035	4758.29166515788
	10	37471.5468631183	101708.484342750	4560.02951244297
	20	36876.7604049735	100915.435731890	4956.55381787279
	30	37075.0225576885	102303.270800895	4956.55381787279
	40	36678.4982522587	102105.008648180	4758.29166515788
	50	37075.0225576885	102105.008648180	4758.29166515788
Average		37207.1973261651	101774.571726988	4791.33535727703
10	0	36876.7604049735	101510.222190035	4956.55381787279
	10	36876.7604049735	101510.222190035	4560.02951244297
	20	36678.4982522587	100717.173579175	4758.29166515788
	30	36678.4982522587	100915.435731890	4758.29166515788
	40	37075.0225576885	101906.746495465	4758.29166515788
	50	36678.4982522587	101510.222190035	4758.29166515788
Average		36810.6730207353	101345.003729439	4758.29166515788
11	0	36678.4982522587	101113.697884605	4758.29166515788
	10	37273.2847104034	100518.911426460	4758.29166515788
	20	36281.9739468288	100518.911426460	4758.29166515788
	30	36678.4982522587	101311.960037320	4758.29166515788
	40	36480.2360995438	101708.484342750	4758.29166515788
	50	36678.4982522587	100320.649273745	4758.29166515788
Average		36678.4982522587	100915.435731890	4758.29166515788
12	0	36083.7117941139	101113.697884605	4560.02951244297
	10	37075.0225576885	101311.960037320	4758.29166515788
	20	37075.0225576885	101906.746495465	4560.02951244297
	30	36876.7604049735	101708.484342750	4956.55381787279
	40	36678.4982522587	101510.222190035	4956.55381787279
	50	37075.0225576885	101311.960037320	4758.29166515788
Average		36810.6730207353	101477.178497915	4758.29166515788
13	0	36083.7117941139	101510.222190035	5154.81597058771
	10	36480.2360995438	101311.960037320	4758.29166515788
	20	37471.5468631183	101113.697884605	4956.55381787279
	30	37075.0225576885	101510.222190035	4956.55381787279
	40	36678.4982522587	101510.222190035	4956.55381787279

	50	37471.5468631183	100915.435731890	5154.81597058771
Average		36876.7604049736	101311.960037320	4989.59750999194
14	0	36480.2360995438	101510.222190035	4956.55381787279
	10	36678.4982522587	101113.697884605	4956.55381787279
	20	36876.7604049735	100717.173579175	5154.81597058771
	30	36678.4982522587	100717.173579175	5154.81597058771
	40	36480.2360995438	100518.911426460	4956.55381787279
	50	36281.9739468288	100717.173579175	4560.02951244297
Average		36579.3671759012	100882.392039771	4956.55381787279
15	0	36281.9739468288	100717.173579175	5353.07812330262
	10	36480.2360995438	100320.649273745	4956.55381787279
	20	36281.9739468288	100717.173579175	4956.55381787279
	30	37669.8090158332	100320.649273745	4956.55381787279
	40	36678.4982522587	100320.649273745	5154.81597058771
	50	36480.2360995438	100717.173579175	4956.55381787279
Average		36645.4545601395	100518.911426460	5055.68489423025
16	0	35687.1874886841	100717.173579175	4956.55381787279
	10	36083.7117941139	100717.173579175	4956.55381787279
	20	35885.4496413990	101113.697884605	5154.81597058771
	30	35687.1874886841	101113.697884605	4956.55381787279
	40	35687.1874886841	101113.697884605	4956.55381787279
	50	35687.1874886841	101510.222190035	4956.55381787279
Average		35786.3185650416	101047.610500366	4989.59750999194
17	0	36281.9739468288	100915.435731890	4758.29166515788
	10	36281.9739468288	101510.222190035	5154.81597058771
	20	35885.4496413990	101906.746495465	4758.29166515788
	30	36876.7604049735	100915.435731890	4560.02951244297
	40	37273.2847104034	101311.960037320	4758.29166515788
	50	36480.2360995438	101906.746495465	4560.02951244297
Average		36513.2797916629	101411.091113677	4758.29166515788
18	0	37075.0225576885	101708.484342750	4956.55381787279
	10	36083.7117941139	102105.008648180	4758.29166515788
	20	36678.4982522587	102303.270800895	5154.81597058771

	30	37075.0225576885	102105.008648180	4758.29166515788
	40	36876.7604049735	102501.532953609	4758.29166515788
	50	37471.5468631183	102699.795106324	4956.55381787279
Average		36876.7604049736	102237.183416656	4890.46643363449
19	0	36876.7604049735	102501.532953609	4956.55381787279
	10	36083.7117941139	102303.270800895	4956.55381787279
	20	35885.4496413990	102303.270800895	4956.55381787279
	30	36083.7117941139	102501.532953609	4758.29166515788
	40	36480.2360995438	102898.057259039	4758.29166515788
	50	35488.9253359692	103096.319411754	4560.02951244297
Average		36149.7991783522	102600.664029967	4824.37904939618
20	0	36281.9739468288	103492.843717184	4956.55381787279
	10	36480.2360995438	103096.319411754	4956.55381787279
	20	36281.9739468288	103492.843717184	4560.02951244297
	30	36281.9739468288	103492.843717184	4758.29166515788
	40	36281.9739468288	103691.105869898	5154.81597058771
	50	35885.4496413990	103889.368022614	4956.55381787279
Average		36248.9302547097	103525.887409303	4890.46643363449
21	0	36480.2360995438	104285.892328044	5154.81597058771
	10	35885.4496413990	103889.368022614	4758.29166515788
	20	35885.4496413990	103889.368022614	4956.55381787279
	30	36083.7117941139	103889.368022614	4956.55381787279
	40	36480.2360995438	104087.630175329	4956.55381787279
	50	36281.9739468288	104087.630175329	4758.29166515788
Average		36182.8428704714	104021.542791090	4923.51012575364
22	0	35687.1874886841	104285.892328044	4758.29166515788
	10	36480.2360995438	104087.630175329	5154.81597058771
	20	36480.2360995438	104285.892328044	4956.55381787279
	30	35687.1874886841	104285.892328044	5154.81597058771
	40	35885.4496413990	104484.154480759	4758.29166515788
	50	36083.7117941139	104087.630175329	4956.55381787279
Average		36050.6681019948	104252.848635924	4956.55381787279
23	0	35885.4496413990	104682.416633474	4956.55381787279

	10	36083.7117941139	104682.416633474	4758.29166515788
	20	36480.2360995438	104880.678786188	5353.07812330262
	30	36281.9739468288	104682.416633474	4956.55381787279
	40	34695.8767251096	104682.416633474	5154.81597058771
	50	35092.4010305394	104285.892328044	5154.81597058771
Average		35753.2748729224	104649.372941354	5055.68489423025

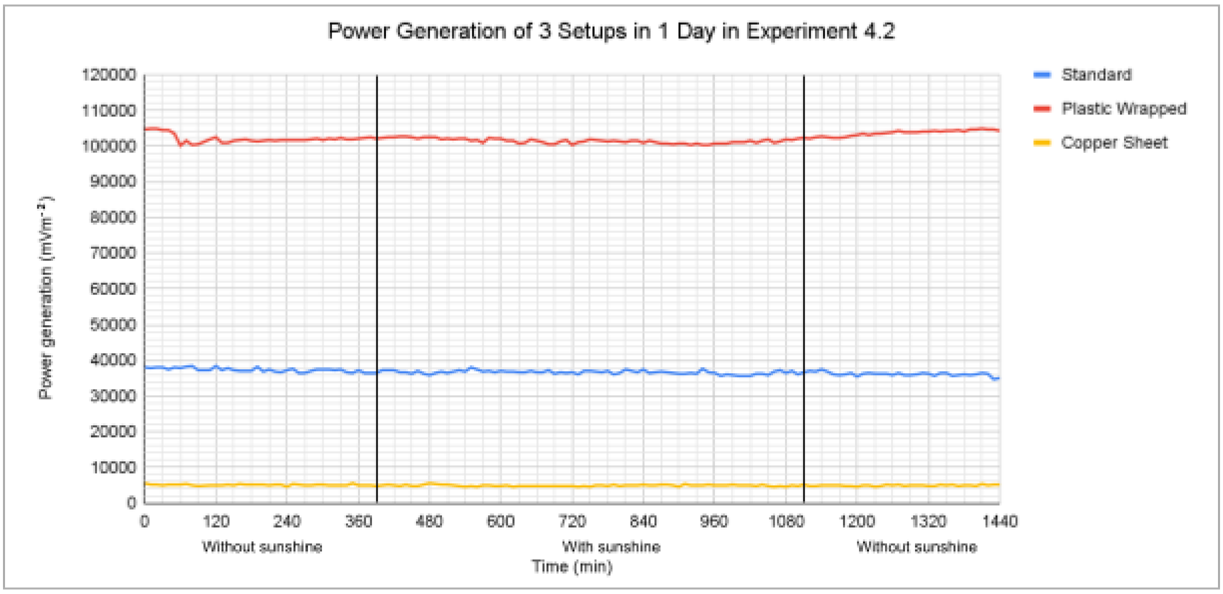

Fig. 2.36 Power generation of 3 setups in 1 day in experiment 4.2

From the graph, the voltage generated by standard, 'plastic wrapped' and 'copper sheet' devices is stable within the whole day, both with and without sunshine. It was deduced that it was because the amount of rhizodeposits continuously excreted at day time are large enough for microorganisms to decompose for at least 24 hours. Therefore, even when there is no sunshine, there is still enough undecomposed rhizodeposits excreted at day time to be decomposed for the whole night. In this experiment, the conclusion of experiment 1 and 2 that it did not seem to be much correlation between light intensity and power generation of plants is further supported.

2.4.3 Finding the shape of electrodes that generate more electricity in Power Plant in Plant devices

In experiment 4.1, the average power generation of 'star-shaped' and 'grid-shaped' devices is the second and third highest respectively. Therefore, the amount of power generated by devices containing the two shapes of electrode is further investigated in part 1 of experiment 4.3. Considering that the amount of power generated by 'plastic wrapped' devices was obviously higher, all reserved copper wires in the devices in experiment 4.3 are wrapped by plastic. Meanwhile, in part 2 of experiment 4.3, the amount and stability of power generated within the whole day is determined by applying micro:bit to log data every 10 minutes in 24 hours and thus to find if the shape of electrodes affect the stability of power generated within the whole day.

2.4.3.1 Procedure of experiment 4.3:

1. Prepare eighteen copper wires, roll the first 135 cm into a spiral shape and reserve the remaining 15 cm. Wrap 12 cm of the reserved copper wire with plastic.
2. Set three Power Plant in Plant devices regarding the procedure mentioned in Experiment 1 with the wrapped copper wires in the shape of spiral as the standard devices.
3. Set three Power Plant in Plant devices regarding the procedure mentioned in Experiment 1 with the wrapped copper wires in the shape of star as the ‘star-shaped’ devices.
4. Set three Power Plant in Plant devices regarding the procedure mentioned in Experiment 1 with the wrapped copper wires in the shape of grid as the ‘grid-shaped’ devices.
5. Place the above nine Power Plant in Plant devices into the environment controlling device.
6. Set the watering time of the watering system.
7. Download the micro:bit program to the micro:bit V2 (support data logging).
8. Install the micro:bit V2 into the environment controlling device and connect the copper wire hanging outside the pot to the micro:bit.
9. Turn on the micro:bit. The micro:bit will log data every 10 minutes.
10. Collect the data by manual measurement every 10 minutes.
11. Download the data logged by the data logger of micro:bit after a period of time.

Materials of experiment 4.3:

Material	**Amount**
Power Plant in Plant device	9
Multimeter	1
Micro:bit	3
Wire	36
Irrigation system	2
Fan	1
LED light especially for plant growing	2

Details of each setup:

	Distance between layers of conductive materials (cm)	**Ratio of electroconductive carbon fibre to soil**	**Shape of copper wire electrode**	**Amount of hydrogel added**	**Plastic wrap**
Standard	2	1:3.17	Spiral	No hydrogel	Yes
Star	2	1:3.17	**Star**	No hydrogel	Yes
Grid	2	1:3.17	**Grid**	No hydrogel	Yes

2.4.3.2 Result of experiment 4.3 (part 1):

Average Power Generation of 3 Devices of Each Setup

Day	**Time (min)**	**Standard (mVm^{-2})**	**Star (mVm^{-2})**	**Grid (mVm^{-2})**
1	0	52090	44792	47256
	10	50724	44119	46123
	20	49686	44973	46673
	30	52198	45241	47637
	40	72268	44714	46565
	50	51728	45136	46502
	60	49619	44124	46675
2	0	57605	51196	54435
	10	55671	50894	53928
	20	55322	50344	52934
	30	56799	52552	54978
	40	55975	52095	55229
	50	55530	51459	53971
	60	55638	51927	53961
3	0	54460	56522	53878
	10	57080	52986	52662
	20	52585	52577	52223
	30	52115	49717	49498
	40	52389	50189	49139
	50	53777	49360	49061
	60	51977	49925	48843
4	0	55819	57559	56213
	10	47125	53855	52165
	20	53747	54317	53152
	30	57740	54895	52893
	40	57775	55940	54167
	50	59154	55299	53662
	60	56183	54689	52401
Average		**54742**	50764	51315

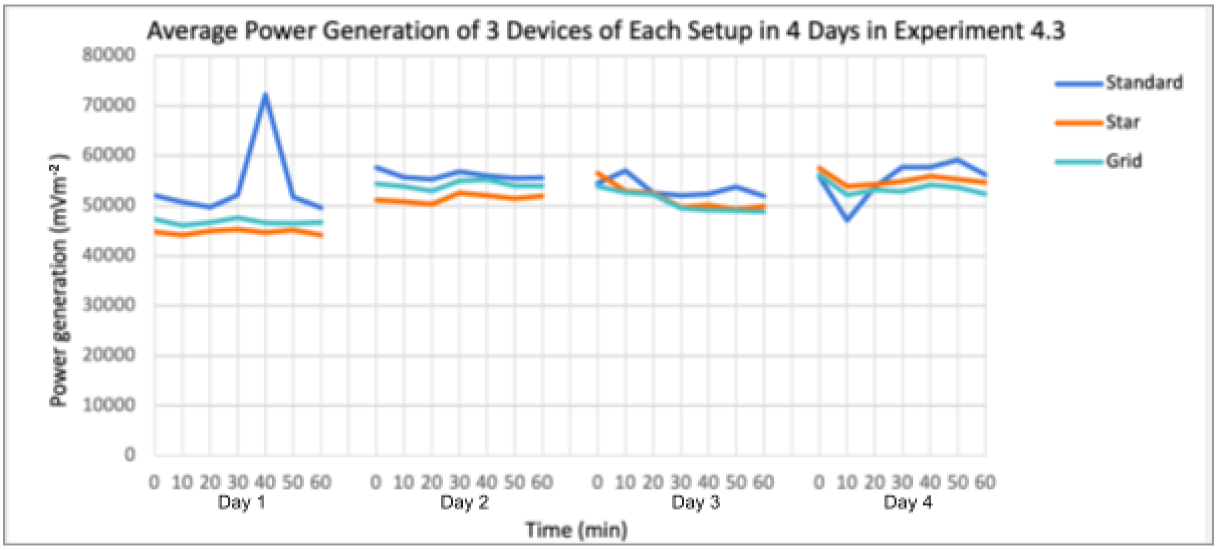

Fig. 2.37 Average power generation of 3 devices of each setup in 4 days in experiment 4.3

From the data, the average power generation of the devices with standard setup is the highest, followed by the devices with grid-shaped copper wire electrodes and hence the devices with star-shaped copper wire electrodes. However, the power generation of the 'grid-shaped' and the 'star-shaped' devices were more stable than the spiral standard device.

Untreated data of result of experiment 4.3 (part 1) could be found in appendix 6.

2.4.3.3 Result of experiment 4.3 (part 2):

Power Generation of 3 Devices of Each Setup in 1 Day

Time (h)	**Time (min)**	**Standard (mVm^{-2})**	**Star (mVm^{-2})**	**Grid (mVm^{-2})**
0	0	110630.281214921	96355.406219447	106070.251702478
	10	110828.543367636	96157.144066732	105475.465244333
	20	111026.805520351	96157.144066732	106268.513855192
	30	110828.543367636	95958.881914018	105673.727397048
	40	111225.067673065	96355.406219447	106268.513855192
	50	111423.329825780	96355.406219447	105871.989549763
Average		110993.761828231	96223.231450970	105938.076934001
1	0	111026.805520351	96157.144066732	106268.513855192
	10	111026.805520351	96355.406219447	106466.776007907
	20	111423.329825780	96553.668372162	106268.513855192
	30	111026.805520351	96157.144066732	106268.513855192
	40	111225.067673065	96355.406219447	106268.513855192
	50	111225.067673065	96355.406219447	106268.513855192

Average		111158.980288827	96322.362527328	106301.557547312
2	0	111225.067673065	96553.668372162	106268.513855192
	10	111225.067673065	96355.406219447	106268.513855192
	20	111225.067673065	96355.406219447	106665.038160622
	30	111423.329825780	96355.406219447	106268.513855192
	40	111225.067673065	96553.668372162	106466.776007907
	50	111225.067673065	96751.930524877	106665.038160622
Average		111258.111365184	96487.580987924	106433.732315788
3	0	111225.067673065	96355.406219447	106466.776007907
	10	111225.067673065	97346.716983021	106665.038160622
	20	111423.329825780	96553.668372162	107259.824618768
	30	111225.067673065	96751.930524877	106665.038160622
	40	111423.329825780	96355.406219447	106665.038160622
	50	111621.591978495	96553.668372162	107061.562466052
Average		111357.242441542	96652.799448519	106797.212929099
4	0	111621.591978495	96751.930524877	107061.562466052
	10	111423.329825780	96553.668372162	106863.300313337
	20	111621.591978495	96553.668372162	107061.562466052
	30	111225.067673065	96751.930524877	106863.300313337
	40	111423.329825780	96751.930524877	107458.086771482
	50	111423.329825780	96553.668372162	107656.348924197
Average		111456.373517899	96652.799448519	107160.693542410
5	0	111225.067673065	96950.192677592	107259.824618768
	10	111621.591978495	96553.668372162	108251.135382342
	20	111225.067673065	96751.930524877	107458.086771482
	30	111819.854131210	97148.454830307	107458.086771482
	40	111423.329825780	96950.192677592	107656.348924197
	50	111621.591978495	97148.454830307	108251.135382342
Average		111489.417210018	96917.148985473	107722.436308435
6	0	111621.591978495	96950.192677592	108052.873229627
	10	111621.591978495	97148.454830307	107458.086771482
	20	111423.329825780	97148.454830307	107854.611076912
	30	111819.854131210	96950.192677592	107854.611076912

	40	111621.591978495	97544.979135736	107656.348924197
	50	111819.854131210	97544.979135736	107854.611076912
Average		111654.635670614	97214.542214545	107788.523692674
7	0	111819.854131210	97148.454830307	107854.611076912
	10	111621.591978495	96751.930524877	107656.348924197
	20	111819.854131210	97148.454830307	108251.135382342
	30	111819.854131210	96950.192677592	108251.135382342
	40	112018.116283925	96950.192677592	107854.611076912
	50	111423.329825780	96751.930524877	108052.873229627
Average		111753.766746972	96950.192677592	107986.785845389
8	0	111621.591978495	96751.930524877	107854.611076912
	10	111621.591978495	96355.406219447	107854.611076912
	20	111423.329825780	96355.406219447	107458.086771482
	30	111423.329825780	96157.144066732	107458.086771482
	40	111026.805520351	96355.406219447	107458.086771482
	50	110630.281214921	96157.144066732	107656.348924197
Average		111291.155057304	96355.406219447	107623.305232078
9	0	110630.281214921	96157.144066732	107656.348924197
	10	111026.805520351	96157.144066732	107259.824618768
	20	110630.281214921	95958.881914018	107458.086771482
	30	110630.281214921	95760.619761303	107656.348924197
	40	110828.543367636	95760.619761303	107854.611076912
	50	110828.543367636	95760.619761303	107061.562466052
Average		110762.455983397	95925.838221898	107491.130463601
10	0	110233.756909491	95760.619761303	107458.086771482
	10	110630.281214921	95364.095455873	107259.824618768
	20	110432.019062206	95562.357608588	107458.086771482
	30	110630.281214921	95562.357608588	107061.562466052
	40	110630.281214921	95364.095455873	107259.824618768
	50	110432.019062206	95364.095455873	107259.824618768
Average		110498.106446444	95496.270224349	107292.868310886
11	0	110233.756909491	95364.095455873	107656.348924197
	10	110432.019062206	95760.619761303	107259.824618768

	20	110432.019062206	95562.357608588	107259.824618768
	30	110035.494756776	95760.619761303	107259.824618768
	40	110630.281214921	95562.357608588	107259.824618768
	50	110233.756909491	95562.357608588	107259.824618768
Average		110332.887985848	95595.401300707	107325.912003006
12	0	110233.756909491	95562.357608588	107061.562466052
	10	110432.019062206	95958.881914018	107458.086771482
	20	110233.756909491	95364.095455873	107259.824618768
	30	111026.805520351	95562.357608588	107061.562466052
	40	110035.494756776	95958.881914018	107259.824618768
	50	110035.494756776	95562.357608588	107656.348924197
Average		110332.887985848	95661.488684945	107292.868310886
13	0	110233.756909491	95760.619761303	107061.562466052
	10	110233.756909491	95760.619761303	107259.824618768
	20	110035.494756776	95364.095455873	106665.038160622
	30	110035.494756776	95760.619761303	107854.611076912
	40	109440.708298631	95364.095455873	107458.086771482
	50	110035.494756776	95760.619761303	107259.824618768
Average		110002.451064657	95628.444992826	107259.824618767
14	0	109440.708298631	95562.357608588	107259.824618768
	10	109837.232604061	95562.357608588	107259.824618768
	20	109638.970451346	95562.357608588	107259.824618768
	30	109837.232604061	95562.357608588	107458.086771482
	40	109837.232604061	95562.357608588	107259.824618768
	50	109638.970451346	95760.619761303	106863.300313337
Average		109705.057835585	95595.401300707	107226.780926648
15	0	109837.232604061	95364.095455873	107259.824618768
	10	109440.708298631	95562.357608588	107458.086771482
	20	109440.708298631	95760.619761303	107656.348924197
	30	110035.494756776	95562.357608588	107656.348924197
	40	109837.232604061	95760.619761303	107854.611076912
	50	110630.281214921	95958.881914018	107854.611076912
Average		109870.276296180	95661.488684945	107623.305232078

16	0	110432.019062206	95958.881914018	107854.611076912
	10	112414.640589355	96157.144066732	107854.611076912
	20	109440.708298631	96157.144066732	108449.397535057
	30	109837.232604061	96751.930524877	108052.873229627
	40	109440.708298631	96751.930524877	108052.873229627
	50	109242.446145916	97148.454830307	108052.873229627
Average		110134.625833133	96487.580987924	108052.873229627
17	0	109044.183993201	96950.192677592	108052.873229627
	10	109837.232604061	96751.930524877	108449.397535057
	20	109440.708298631	96751.930524877	108449.397535057
	30	109440.708298631	96157.144066732	108647.659687771
	40	105475.465244333	96355.406219447	104087.630175329
	50	105277.203091618	96355.406219447	102303.270800895
Average		108085.916921746	96553.668372162	106665.038160623
18	0	105871.989549763	96157.144066732	102501.532953609
	10	105673.727397048	96355.406219447	101311.960037320
	20	105871.989549763	96553.668372162	101311.960037320
	30	106268.513855192	96553.668372162	101510.222190035
	40	105871.989549763	96355.406219447	101708.484342750
	50	106268.513855192	96355.406219447	101510.222190035
Average		105971.120626120	96388.449911566	101642.396958511
19	0	106268.513855192	96553.668372162	101113.697884605
	10	108449.397535057	96751.930524877	101510.222190035
	20	108052.873229627	96950.192677592	101510.222190035
	30	105277.203091618	96950.192677592	101510.222190035
	40	106665.038160622	97148.454830307	101708.484342750
	50	107458.086771482	97743.241288451	101708.484342750
Average		107028.518773933	97016.280061830	101510.222190035
20	0	107259.824618768	97544.979135736	102105.008648180
	10	108251.135382342	97346.716983021	102303.270800895
	20	105673.727397048	97544.979135736	102105.008648180
	30	109044.183993201	97544.979135736	102105.008648180
	40	109044.183993201	98139.765593881	102501.532953609

	50	107854.611076912	97941.503441166	102699.795106324
Average		107854.611076912	97677.153904213	102303.270800895
21	0	109242.446145916	98338.027746596	102898.057259039
	10	109242.446145916	98139.765593881	102898.057259039
	20	108251.135382342	98338.027746596	102699.795106324
	30	109242.446145916	98536.289899311	102699.795106324
	40	109440.708298631	98734.552052026	103096.319411754
	50	109044.183993201	98536.289899311	103294.581564469
Average		109077.227685321	98437.158822954	102931.100951158
22	0	108845.921840486	98932.814204741	102898.057259039
	10	108845.921840486	99329.338510171	103294.581564469
	20	108845.921840486	99131.076357456	103492.843717184
	30	109440.708298631	99527.600662886	103492.843717184
	40	109440.708298631	100122.387121030	103294.581564469
	50	109638.970451346	100518.911426460	103691.105869898
Average		109176.358761678	99593.688047124	103360.668948707
23	0	108647.659687771	100320.649273745	103691.105869898
	10	108647.659687771	100518.911426460	103889.368022614
	20	109242.446145916	100122.387121030	103691.105869898
	30	108647.659687771	100518.911426460	103889.368022614
	40	109638.970451346	100717.173579175	104087.630175329
	50	109044.183993201	100717.173579175	104484.154480759
Average		108978.096608963	100485.867734341	103955.455406852

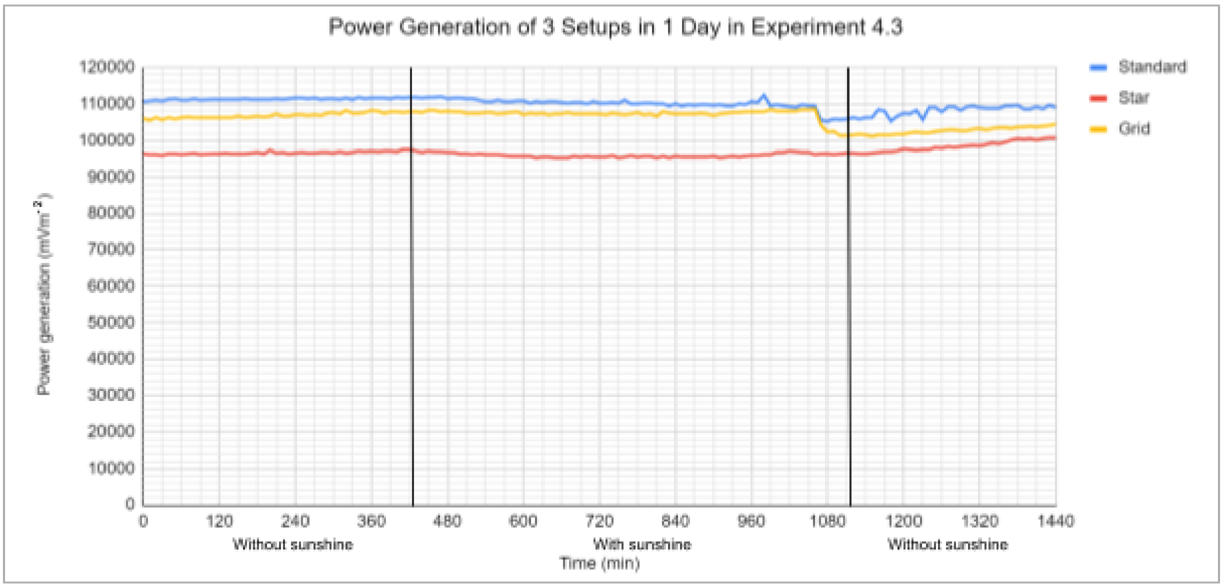

Fig. 2.38 Power generation of 3 setups in 1 day in experiment 4.3

From the graph, the voltage generated by standard, 'star-shaped' and 'grid-shaped' devices is stable within the whole day, both with and without sunshine.

3 Discussion

3.1 Conclusion

First, there were electrons released during the photosynthesis of plants, which can be measured by multimeter and micro:bit, while the highest average power generation was 6069 mVm^{-2}. Second, the amount of watering had the greatest effect on the amount of electricity generated by plants. The power generation of plants after watering was higher than that of before watering, the longer the period that the plants were not watered, the lower the power generations were. Third, the amount of power generated was not affected by light intensity and temperature. Fourth, wrapping the reserved copper wire by plastic obviously enhances the performance of copper electrodes and electrodes with different shapes remain the power generation. Fifth, the power generated by plants was stable within the whole day, both with and without sunshine, indicating the high potential and high efficiency of Power Plant in Plant.

3.2 Errors and improvements

First, after the above-mentioned experiments, it was found that the power generation of different plants was not stable at all in the experiments. It was deduced that an obvious effect was caused by every tiny factor due to the low stability of the plants. The number of plants would hence be increased to uplift the stability. It was hoped that this could make the results of the experiments more precise.

Second, more kinds of plants would be tried in the future, so that more data could be collected and compared. For example, using the most common grass in Hong Kong for the experiment, to make it more related with the actual situation in Hong Kong and determine the feasibility of applying Power Plant in Plant in Hong Kong; trying to produce the bases of the device with other materials, to find out the most suitable combination and hence uplift the efficiency of Power Plant in Plant.

Third, plants in a relatively larger area were not as efficient as plants in a relatively smaller area. It was presumed that it was because more factors affecting the accuracy of the plants were found in the environment of a relatively larger area.

Fourth, the principle of Power Plant in Plant is not well-studied. The whole mechanism and the principle would be delved.

3.3 Prospects

First, it is hoped that the technology could be applied in different greenbelt areas, such as laying the circuit under the plants in parks, and adding USB interfaces on branches, so that the common people could charge their phones, chargers, etc. while they are resting.

Second, it is also wished that the technology could be popularised, so that the lay public could be indulged in planting and hence plant various plants at home as eco chargers.

Third, if the measure could be applied to large-scale farming, it is conceived that a large amount of electricity could be generated for personal use or selling for farmers, and hence relieve the energy crisis.

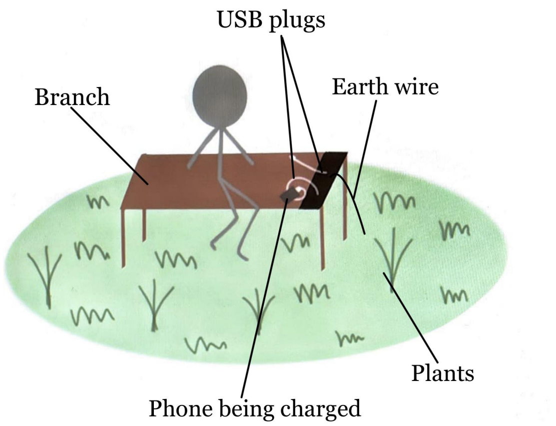

Fig. 3.1 Park (large-scale application)

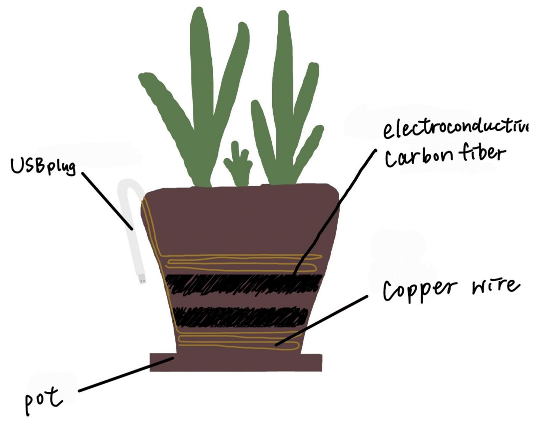

Fig. 3.2 Eco charger (household application)

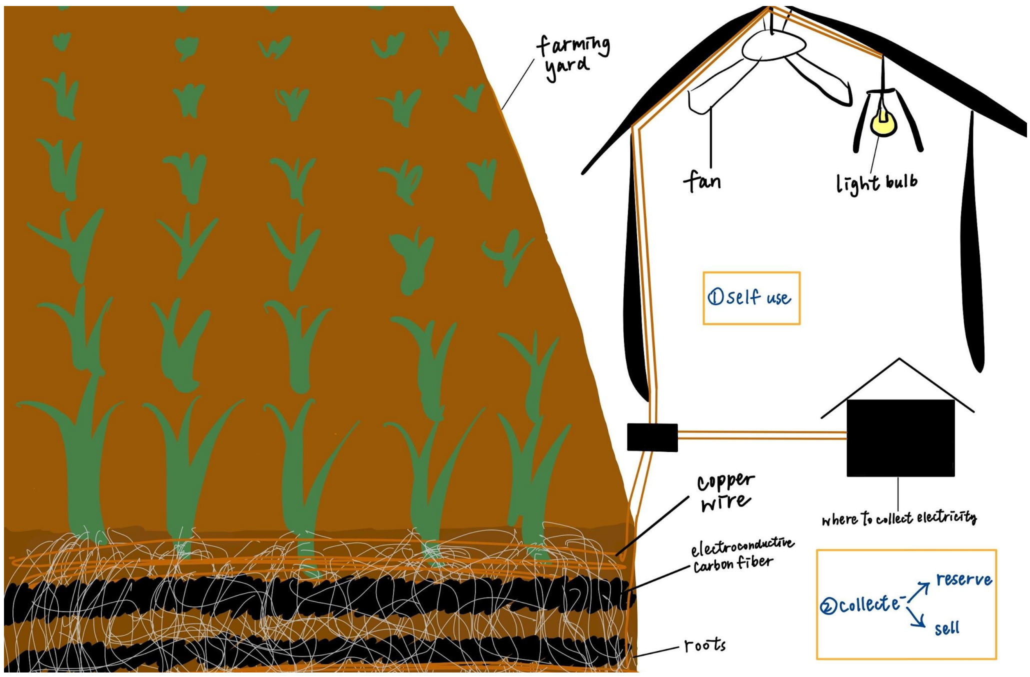

Fig. 3.3 Large-scale farming

4 Conclusion

The rhizodeposits excreted from plants could be used to produce high-energy electrons by microorganisms, and hence generate electricity. However, the power generation of plants is not yet efficient. How the power generation rate could be uplifted still requires the study of scientists.

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6 Appendix

6.1 Appendix 1

Untreated data of result of experiment 1:

Date	Day	*Aloe vera* (mV)	*Dracaena trifasciata* (mV)	*Catharanthus roseus* (mV)	Light intensity (lux)	Temperature (℃)
2021.11.02	2	37.0	11.3	2.0	2051	16.9
2021.11.04	4	55.0	12.8	1.5	2460	14.8
2021.11.08	8	85.0	7.5	3.9	2540	16.7
2021.11.10	10	59.2	7.8	0.2	2540	17.3
2021.11.15	15	67.0	15.0	0.3	2320	18.9
2021.11.18	18	70.3	10.1	1.4	1940	14.9
2021.11.29	29	80.5	43.4	2.0	2090	15.6
2021.12.09	39	169.0	32.6	18.7	2740	17.1
2021.12.15	55	101.6	35.1	82.6	2740	18.9

6.2 Appendix 2

Untreated data of result of experiment 3:

Date	Day	Before watering(mV)	After watering(mV)	Light intensity(lux)	Temperature(℃)
2022.04.08	3	13	14.6	19430	24.5
2022.04.10	5	24	26.6	6270	25
2022.04.12	7	11	13.9	19540	24.7
2022.04.16	11	11	21.1	6400	19.3
2022.04.18	13	25	28.2	1137	23.8
2022.04.21	16	52	65.5	379	26.5
2022.04.24	19	46	42.5	12780	24
2022.04.25	20	21	55.9	1655	25.1
2022.04.28	23	19	26.5	8920	28.2

6.3 Appendix 3

Untreated data of result of experiment 4.1:

Date	Day	Standard (mV)	Long distance: 4.5cm (mV)	Short distance: 1.5cm (mV)	Full hydrogel (mV)	Half hydrogel (mV)	Star (mV)	Grid (mV)	Soil:electroconductive fibre=4:1 (mV)
6/12/2022	1	22.5	0.1	1.2	10.9	1.0	0.2	0.1	6.3
7/12/2022	2	32.7	0.0	3.1	8.9	1.4	0.5	0.0	6.5
15/12/2022	10	32.1	0.5	4.8	0.3	7.9	3.2	1.4	13.5
26/1/2023	52	57.9	66.3	1.5	4.1	28.3	33.1	38.1	45.4
27/1/2023	53	45.8	2.5	26.8	1.7	64.9	46.9	35.4	38.9
1/2/2023	57	75.0	11.9	74.3	21.3	69.7	62.1	44.1	63.4
6/2/2023	62	62.9	24.3	39.5	15.7	83.6	74.3	36.1	58.1
7/2/2023	63	58.8	51.8	59.7	6.4	69.4	71.6	49.7	38.9
Average		48.5	19.7	26.4	8.7	40.8	36.5	25.6	33.9
Min. value		22.5	0.0	1.2	0.3	1.0	0.2	0.0	6.3
Max. value		75.0	66.3	74.3	21.3	83.6	74.3	49.7	63.4

6.4 Appendix 4

Python script:

```
def on_button_pressed_a():
    basic.show_string("mV1=")
    basic.show_number(pins.analog_read_pin(AnalogPin.P1) / 380 * 1000)
    basic.pause(1000)
input.on_button_pressed(Button.A, on_button_pressed_a)

def on_button_pressed_ab():
    basic.show_string("mV3=")
    basic.show_number(pins.analog_read_pin(AnalogPin.P3) / 380 * 1000)
    basic.pause(1000)
input.on_button_pressed(Button.AB, on_button_pressed_ab)

def on_button_pressed_b():
    basic.show_string("mV2=")
    basic.show_number(pins.analog_read_pin(AnalogPin.P2) / 380 * 1000)
    basic.pause(1000)
input.on_button_pressed(Button.B, on_button_pressed_b)

datalogger.set_column_titles("Day", "mV1", "mV2", "mV3")

def on_every_interval():
    datalogger.log(datalogger.create_cv("mV1", pins.analog_read_pin(AnalogPin.P1) / 380 * 1000),
        datalogger.create_cv("mV2", pins.analog_read_pin(AnalogPin.P2) / 380 * 1000),
        datalogger.create_cv("mV3", pins.analog_read_pin(AnalogPin.P3) / 380 * 1000))
loops.every_interval(600000, on_every_interval)

def on_forever():
    pass
basic.forever(on_forever)
```

6.5 Appendix 5

Untreated data of result of experiment 4.2 (part 1):

Day	Time (min)	Standard 1 (mV)	Standard 2 (mV)	Standard 3 (mV)	Plastic Wrap 1 (mV)	Plastic Wrap 2 (mV)	Plastic Wrap 3 (mV)	Copper Sheet 1 (mV)	Copper Sheet 2 (mV)	Copper Sheet 3 (mV)
1	0	6.2	11.9	749.0	11.9	7.7	1026.0	56.3	3.6	Broken
	10	7.0	9.5	698.0	11.8	5.9	1196.0	81.0	2.5	Broken
	20	7.7	9.6	753.0	12.8	5.5	1027.0	86.7	5.3	Broken
	30	6.7	9.4	752.0	12.7	10.0	1011.0	85.3	2.3	Broken
	40	7.4	9.7	733.0	12.0	5.8	998.0	70.3	3.3	Broken
	50	7.9	9.4	639.0	12.0	3.2	976.0	83.1	1.1	Broken
	60	7.7	8.8	695.0	11.8	3.9	991.0	85.0	1.7	Broken
2	0	10.1	6.4	31.6	15.7	6.0	198.1	85.3	3.5	Broken
	10	9.7	6.5	31.9	13.8	4.2	185.4	95.4	2.3	Broken
	20	9.9	6.6	28.5	14.4	5.8	168.5	91.1	3.2	Broken
	30	10.4	6.8	26.5	14.7	4.5	152.8	99.9	3.8	Broken
	40	9.9	6.5	27.9	14.9	2.6	141.9	96.3	2.1	Broken
	50	9.7	6.1	28.4	14.0	5.0	133.8	92.9	2.4	Broken
	60	9.8	6.1	28.0	13.6	4.0	127.0	96.4	3.6	Broken
7	0	21.0	14.7	604.0	13.8	5.2	2070.0	93.5	3.5	Broken
	10	20.8	13.6	696.0	10.2	5.7	2060.0	92.5	2.7	Broken
	20	23.1	18.7	634.0	12.6	6.1	2420.0	95.5	0.7	Broken
	30	21.6	20.3	689.0	14.1	6.6	2010.0	97.3	5.4	Broken
	40	18.6	23.3	806.0	13.2	4.1	2120.0	99.5	0.7	Broken
	50	21.7	17.6	720.0	10.1	3.9	2090.0	97.9	0.5	Broken
	60	22.1	25.9	956.0	13.3	3.6	2160.0	96.6	0.4	Broken
8	0	24.8	31.4	862.0	12.7	3.2	2210.0	97.7	0.5	Broken
	10	24.5	30.8	967.0	12.7	6.4	2090.0	91.7	0.6	Broken
	20	27.7	32.3	1031.0	13.1	4.1	2120.0	95.2	0.6	Broken
	30	24.9	32.6	951.0	12.4	3.3	2170.0	95.9	0.7	Broken
	40	24.8	23.4	1086.0	12.9	4.0	2660.0	96.9	0.4	Broken
	50	23.1	28.7	788.0	11.1	4.4	2030.0	88.0	0.5	Broken
	60	24.9	25.3	969.0	12.2	1.0	2250.0	97.9	0.6	Broken

6.6 Appendix 6

Untreated data of result of experiment 4.3 (part 1):

Day	Time (min)	Standard 1 (mV)	Standard 2 (mV)	Standard 3 (mV)	Star 1 (mV)	Star 2 (mV)	Star 3 (mV)	Grid 1 (mV)	Grid 2 (mV)	Grid 3 (mV)
1	0	21.9	2.3	2050.0	28.9	60.7	1694.0	5.2	7.5	1869.0
	10	22.6	3.2	1994.0	30.9	56.9	1669.0	5.6	7.0	1824.0
	20	15.6	1.9	1961.0	32.4	59.4	1699.0	6.4	7.1	1845.0
	30	17.3	1.2	2060.0	29.4	61.1	1711.0	7.8	7.1	1882.0
	40	15.2	2.5	2860.0	32.4	59.1	1689.0	6.4	6.8	1841.0
	50	17.7	2.1	2040.0	31.8	60.5	1705.0	5.8	6.9	1839.0
	60	18.4	2.4	1955.0	30.9	59.1	1667.0	6.1	6.5	1846.0
2	0	20.9	2.9	2270.0	9.3	36.3	1993.0	3.2	4.4	2160.0
	10	22.9	3.9	2190.0	7.3	34.3	1985.0	2.9	4.5	2140.0
	20	21.6	1.3	2180.0	5.5	35.2	1964.0	3.5	4.3	2100.0
	30	20.5	1.2	2240.0	5.7	36.9	2050.0	4.7	4.5	2180.0
	40	16.8	2.1	2210.0	7.8	36.6	2030.0	4.8	4.4	2190.0
	50	18.1	3.1	2190.0	3.9	35.2	2010.0	4.7	4.4	2140.0
	60	23.2	2.3	2190.0	4.4	33.3	2030.0	4.4	4.3	2140.0
3	0	21.7	6.9	2140.0	23.6	17.1	2210.0	1.1	4.3	2140.0
	10	26.1	6.8	2240.0	28.2	21.7	2060.0	1.3	5.7	2090.0
	20	28.5	5.4	2060.0	33.2	20.4	2040.0	3.1	6.4	2070.0
	30	26.7	8.5	2040.0	28.4	32.3	1919.0	3.3	10.7	1957.0
	40	27.1	9.0	2050.0	30.7	42.8	1925.0	13.9	10.8	1932.0
	50	30.4	11.0	2100.0	26.2	25.3	1914.0	12.1	10.5	1931.0
	60	17.8	11.9	2040.0	19.1	32.9	1936.0	13.9	10.0	1921.0
4	0	21.6	11.1	2190.0	30.2	21.8	2240.0	11.8	6.6	2220.0
	10	20.4	9.1	1847.0	34.1	10.4	2100.0	11.1	6.1	2060.0
	20	25.1	5.1	2110.0	29.4	13.5	2120.0	10.3	6.2	2100.0
	30	20.5	8.7	2270.0	28.8	17.1	2140.0	10.1	6.1	2090.0
	40	22.8	7.8	2270.0	26.8	20.7	2180.0	10.8	6.1	2140.0
	50	20.0	5.5	2330.0	25.4	6.6	2170.0	10.8	6.0	2120.0
	60	20.1	7.1	2210.0	35.3	12.4	2130.0	10.3	6.3	2070.0