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Using Plants to Make Green Energy

Yash Bhavsar[1] and Dr. Yajamana Ramu[#]

[1]Moorestown High School
[#]Advisor

ABSTRACT

New innovative ways are needed to address the climate change crisis. Burning fossil fuels to generate electricity is the largest contributor to global warming. Generating green energy using Biophotovoltaic Technology is one way to tackle this pressing problem. Biophotovoltaic Technology is the practice of harnessing electricity from the photosynthetic activities of plants such as moss and algae. The objective of this study is to maximize green energy production by testing this novel concept under different experimental conditions. We obtained 3 unique sources of moss and tested them under 5 different conditions: Control, Low Salt, High Salt, Low pH, High pH. Each day, voltage was measured at different time intervals until moss turned a brownish color and dried up. When voltages of Control samples were measured, all three sources peaked at similar values but on different days. Under Low Salt and High Salt conditions, peak voltage only reached about half of Control. Low pH condition was the only condition where the voltage exceeded Control. Measured voltage from High pH condition increased steadily over time, however, not reaching the same level as Control. Our results indicate that Control, Low pH, and High pH conditions generated higher electricity than Low Salt and High Salt conditions. In addition, voltage production was dependent on the source/quality of moss. In conclusion, we were able to generate measurable electricity using biophotovoltaics. Electricity production can be enhanced by increasing the amount of plant source and changing experimental conditions.

Introduction

Climate change is one of the most serious problems affecting the world today. Atmospheric carbon dioxide has increased at a rapid pace overtime. From 1895-1980, a span of 85 years, the global temperature has risen 1.8°F. In the past 40 years (1980-2020), the temperature has risen another 3°F, a change that is almost double over a significantly shorter period of time (NCEI.Monitoring.Info@noaa.gov, 2023). Some effects of climate change include rising sea level due to melting of glaciers, increased frequency of strong tornadoes and hurricanes, longer heatwaves, and droughts. These ominous events are having catastrophic effects on farming and the global food chain. Warming temperatures have extended and intensified the wildfire season and many forests have been burned and decimated in recent decades. This poses an existential crisis to humanity.

Majority of the global warming crisis is due to burning of fossil fuels for energy. As the world's population is growing, the demand for electricity is also increasing. It is predicted that by 2040, we will need at least 32% more energy compared to 2013 (Tschörtner et al., 2019). The process of generating electricity from fossil fuels releases large amounts of greenhouse gases like carbon dioxide, methane, and nitrous oxide. These gases trap heat from the sun in the Earth's atmosphere, causing the earth's surface to become warmer.

A major challenge is to find a renewable source of energy that replaces our dependence on fossil fuels. The Sun is the ultimate source of energy for all living things on Earth. Harnessing this energy is one of the great scientific and technological challenges. The sun's rate of delivery of energy is about 4 times higher than the current rate of worldwide energy consumption by humans (Gust et al., 2009). Technologies such as Microbial Fuel Cells (MFC), Artificial Photosynthesis, Microbial Electrochemical Technology and Biophotovoltaic Technology have emerged over the last few decades. These technologies have identified various methods of harnessing solar energy (Mahwash Mahar

Gul & Khuram Shahzad Ahmad, 2019; Gust et al., 2009; Tschörtner et al., 2019). MFCs produce electricity by using the electrons derived from biochemical reactions catalyzed by bacteria (Logan et al., 2006). MFC technology converts chemical energy into electrical energy by the action of microorganisms such as bacteria and fungi (Korneel Rabaey & Verstraete, 2005). It consists of an anode and a cathode, separated by a membrane or an ion exchange material. Microorganisms generate electrons through oxidation of organic compounds. These electrons are transferred to the cathode where they are combined with oxygen and protons. This transfer of electrons and redox reactions lead to generation of an electrical current (Maël Ruscalleda Beylier et al., 2011). Artificial Photosynthesis aims to generate biofuel cells and photocatalytic water splitting to generate hydrogen and oxygen. The first step in the production of these fuel cells involves the use of antenna/reaction center to absorb sunlight and to use water oxidation catalyst to convert water to hydrogen ions, oxygen and electrons. The second catalyst system uses electrons to make fuels such as carbohydrates, lipids and hydrogen gas, as clean and sustainable energy sources (Gust et al., 2009).

Biophotovoltaic Technology is a novel discipline that uses the sun's energy to generate electricity via plants (Tschörtner et al., 2019; Saar et al., 2018). This process uses photosynthesis to generate electricity in a climate-friendly way (Bradley et al., 2012; McCormick et al., 2011). Photosynthesis involves the splitting of water molecules to produce protons, electrons, and oxygen. An anode and cathode system can be utilized to form a circuit and measure the flow of subatomic particles (current) in the soil. A biophotovoltaic system transfers electrons, generated through photolysis of water, to an anode. These electrons can flow through an external circuit to recombine with protons and oxygen at the cathode. The electrical potential difference between the anode and cathode is used to generate a current.

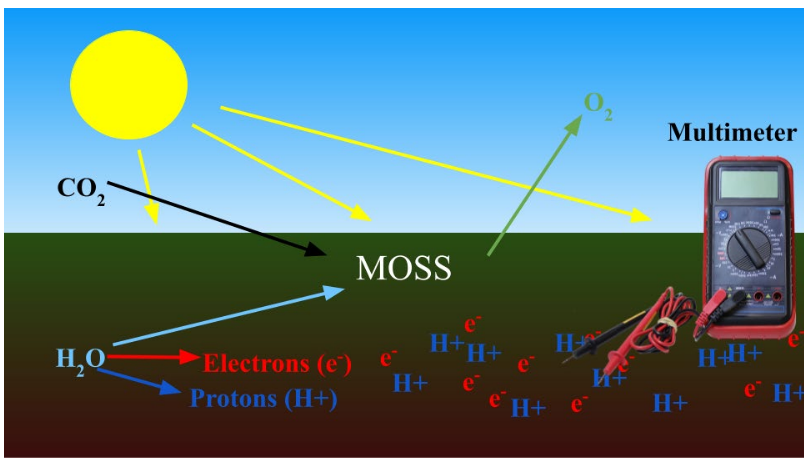

Figure 1. Diagram of Biophotovoltaic Technology

The objective of our research was to utilize Biophotovoltaic Technology to generate electricity. We chose moss as our source because of its abundance in urban environment. Moss can be found on roofs, walls and trees. Due to its low maintenance, increased moisture retention, versatility, and simplicity of growth, moss was the ideal choice over algae. We selected different types of moss and grew them in different salt and varying pH conditions to maximize its current generating potential.

Methods

A total of three different sources of moss were used in this research. Source 1 and 2 was *Hypnum curvifolium*, purchased from Lowe's and Home Depot, respectively. Source 3 was *Brachythecium wichurae* purchased from

LeafAndPlants Nursery located in Richmond, Texas. Miracle-Gro Soil for Root Growth was used throughout all experiments. Solutions such as 0.5M NaOH (Sodium Hydroxide), 6M HCl (Hydrochloric Acid), and Reagent-Grade Crystal NaCl (Sodium Chloride) were purchased from Carolina Biological Supply Company.

Five different solutions were made, each corresponding with a condition: Control, Low Salt, High Salt, Low pH, and High pH. Tap water was used as the Control. A Low Salt condition involved creating a 0.05M solution using NaCl (Sodium Chloride) and tap water, while the High Salt solution was prepared as a 0.5M solution with tap water and NaCl. Low pH solution was made by adjusting tap water to a pH of 5 using Hydrochloric Acid, and the High pH condition was adjusted to a pH of 9 using Sodium Hydroxide.

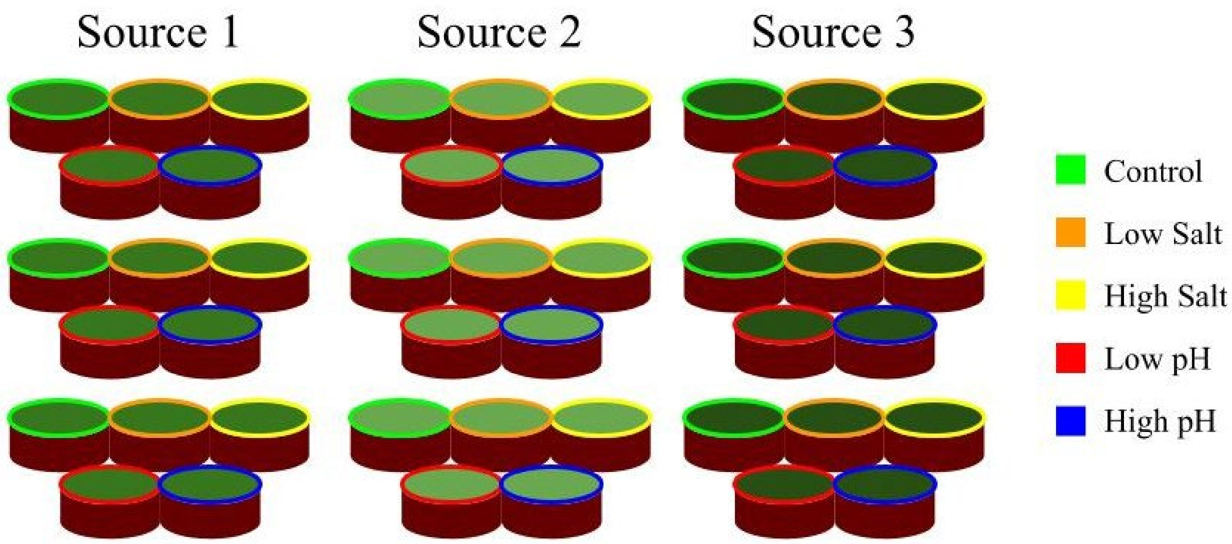

Figure 2. Configuration of Moss Experimental Conditions

Each bowl consisted of 3g of the corresponding source of moss and 75g of soil. For each source, there were 3 bowls per condition resulting in a total of 15 bowls (Figure 2). Over the course of 12 days, the bowls were consistently watered every other day with 45mL of the corresponding solution. The voltage was measured 3 times a day using a multimeter for each bowl. This resulted in 9 daily measurements under designated condition per source. For example, under Low Salt condition, there were 9 total values for each source. Then, the average was calculated of all 9 values and plotted as a bar along with standard error of mean (SEM) as an error bar (Figure 3B).

$$SEM = \frac{\sigma}{\sqrt{n}}$$

Equation 1

σ : standard deviation
n : number of samples

Results

Figure 3 shows the bar graph for all 5 conditions, separated by source. The results are graphed by number of days and the error bars are a Standard Error of Mean (SEM) calculation. The number of days that a particular moss source was able to produce measurable voltages varied from source to source. Under control condition, each source reached peak voltage on different days. Source 1, 2, & 3 reached its peak on Day 12, 2, & 9 respectively (Figure 3A). Source 3 produced the highest voltage (222 mV) under Control condition. This was used as a Control comparison denoted by asterisk and displayed in all other conditions for observation purposes. Table 1 displays peak voltages for each source per condition during the entire life cycle of moss. Under Low Salt condition, the peak voltage level dropped to 25-50% of Control for all 3 sources of moss: 163mV, 147mV, 100 mV respectively (Table 1). High Salt condition performed worse than Low Salt condition for Source 2 and 3: 124mV, 63mV respectively, Source 3 only reaching 30% of Control (Table 1). Voltage measured in Low pH environment remained very similar to Control, with Source 3 surpassing the Control condition by ~10%, 250mV (Figure 3D). Under High pH condition, measured voltage increased steadily overtime, peaking at ~75-90% of Control condition (Figure 3E). Out of 3 sources of moss, Source 3 was the most optimal in generating electricity under Control, Low pH, and High pH conditions. Source 1 did not change much between conditions and produced similar voltage under all conditions. On the other hand, high salt and high pH conditions deteriorated Source 2, almost reducing the voltage by ~50% of Control. In summary, there was noticeable variability among the sources of moss and the amount of green energy generated.

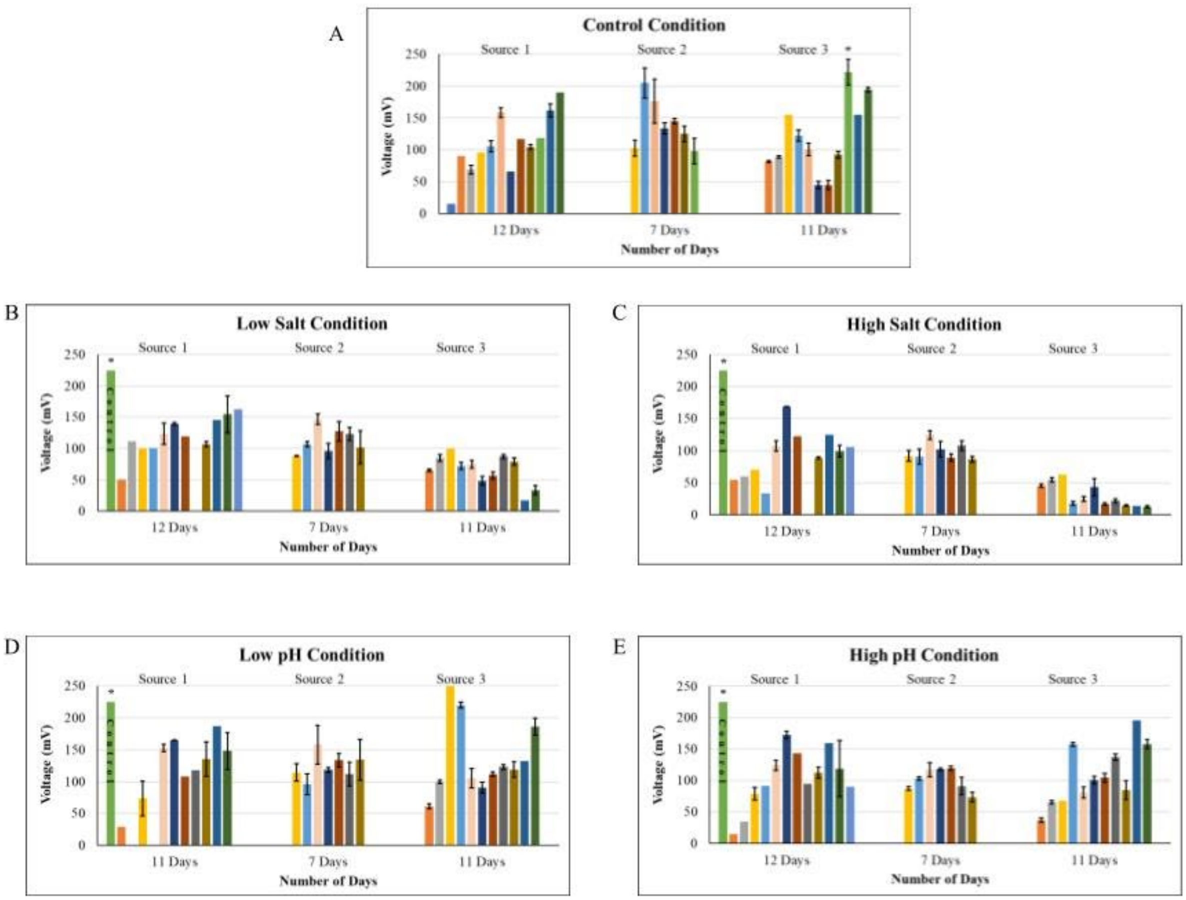

Figure 3. Daily average voltage measurements for three sources of moss with SEM. Figure 3A displays the average voltage produced by Moss Under the Control Condition. The (*) represents highest voltage measured in control condition and is used as a comparison to other conditions. Figure 3B shows the average electricity generated for each source of moss under Low Salt Condition. Figure 3C displays average voltage under High Salt Condition. Figure 3D shows the average voltage produced by Moss under Low pH Condition. Figure 3E displays average electricity generated for each source of moss under High pH Condition.

Table 1. Peak Voltage over the entire life cycle of moss (mV)

Conditions	Source 1	Source 2	Source 3
Control	190	205	222
Low Salt	163	147	100
High Salt	168	124	63
Low pH	187	158	250
High pH	172	120	196

Conclusion

Our objective of this study was to derive sustainable energy from plants using an innovative technology called Biophotovoltaic Technology. We were successfully able to generate electricity using this method. There were two critical factors that affected this process: the quality of moss and the growth solution. In our experiment, we discovered that not all moss sources were equal in energy production. *Hypnum curvifolium* from Lowe's (Source 1) was limited in its reliability due to very consistent results across all conditions. On the other hand, *Hypnum curvifolium* from Home Depot (Source 2), demonstrated subtle differences to saline and acidic conditions. Although, a pattern was noticeable, it was not as prominent as Source 3, *Brachythecium wichurae*. Source 3 was fresh moss cultivated under optimal conditions with increased moisture retention compared to other 2 dry mosses from Lowes and Home Depot. Discrepancies in the survival of moss could also be due to inferior quality of Source 2, hence, it perished in 7 days.

Moss growth varied with different experimental conditions, resulting in changes in measured voltage. Low and High Salt conditions reduced the overall produced voltage. Furthermore, the High Salt condition had the most drastic reduction in voltage. Based on these observations, we can conclude that salty conditions hinder moss growth. Voltage generation reached optimal levels under Low pH condition. This observation supports that moss growth is optimal under acidic conditions. The voltage generated under the basic condition was higher than that observed under saline conditions. This emphasizes the detrimental impact of salinity on moss growth. The Low pH conditions boosted moss growth and improved energy generation when compared to the High pH condition. Based on our findings, we can conclude that Control and Low pH Conditions can be utilized to optimize Biophotovoltaic Technology and maximize electricity generation. Furthermore, there is potential to achieve even higher voltages by using larger sample of moss and algae models.

While the amount of energy produced by biophotovoltaic cells is still only around a tenth of a power density provided by conventional solar fuel cell, this technology has several attractive features. Some of these include a clean source of energy, cost- efficiency, and fewer required resources. Biophotovoltaic systems can be used to power small electronic devices and lighting. The ultimate goal of this innovation is to provide power support to homes in rural areas where sunlight is abundant. This innovation has a lot of promise for the future if we can also figure out the storage of generated power. Development of this novel technology is a big step forward in our fight against climate change. Dedication of additional resources and funding can hasten the growth of this application and lead to meaningful green energy generation.

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