Philippine Science High School - Eastern Visayas Campus

Center for Research in Science and Technology

Pawing, Palo, Leyte, 6501

7th IMake WeMake: Create. Invent, Innovate

Project PAGSACA: PMFC and Organic Solar Cells Accumulating Charge through Agriculture

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ABSTRACT

Project PAGSACA stands for PMFC And orGanic Solar cells for Accumulating Charge through Agriculture. The title PAGSACA comes from the Filipino and Waray word ”pagsaka”; in Filipino, it means *to farm*, and in Waray-waray, a language spoken in the provinces of Samar, Leyte, and Biliran, it means *to rise* or *go upwards*. This title encapsulates the project's main goal of innovating the idea of vertical farming with the combined use of different technologies such as Plant Microbial Fuel Cells (PMFCs), Electroculture, Organic Solar/Photovoltaic Cells, and Internet of Things (IoT) Systems pioneering a new field of sustainable, smart, and modular vertical farming. To narrow the study’s scope, the project was configured around the plant *Oryza sativa* or rice due to its significant importance not just to the Filipino people but also to the wider international community. Project PAGSACA serves as a basis for innovation in the agricultural sector by providing a viable solution to vertical farming’s major challenges while providing additional unique benefits of its own.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS **1**
ABSTRACT **2**
TABLE OF CONTENTS **3**
I. RATIONALE AND OBJECTIVES **4**
- Rationale 4
- Objectives 5
- Significance of the Study 6
- Scope and Limitations 6

II. BACKGROUND **7**
- Vertical Farming 7
- Organic Solar Cells 8
- Plant Microbial Fuel Cells 9
- Electroculture 10
- Internet of Things (IoT) System 11
- Full Stack Web Development 11

II. METHODOLOGY **12**
- Research Design 12
- Procedures 12
- Integrated Materials 13
- Project Dimensions 14
- Tech Stack 16
- Experimentation 17
  - Electroculture 18
  - Plant Microbial Fuel Cells 19

III. TECHNOLOGY VALIDATION **19**
- Local Farmers 20
- Local Agency 21
- International Horticulturist 22
- Additional Tests 23

IV. RESULTS AND DISCUSSION **24**
- Data Collection 24
- Data Analysis 25
- Results of Additional Testing 28

V. ACTUAL PROJECT COST **28**
VI. RECOMMENDATION **30**
VII. CONCLUSION **31**
REFERENCES **33**

I. RATIONALE AND OBJECTIVES

Rationale

The Philippines is built on agriculture; it's the backbone of our nation. Out of the 30 million hectares of the Philippines, 13.42 or 45% is used for agricultural crop cultivation. As of 2022, about a quarter of all employed Filipinos work in the agricultural sector (Brown et al., 2023; Statista Research Department, 2023a). Yet, it only accounts for 8.9% of the country's GDP (Brown et al., 2023; Statista Research Department, 2023b).

From the Hacienda System in the Spanish Colonial rule to the current cycle of debt and poverty, the story of agriculture in the Philippines is not without its challenges and complexities (Maslang, 2014; Peña, 2023). Lands dedicated to agriculture have been decreasing due to urbanization, agricultural policy reforms, and the abandonment of farming as a profession (Adamopoulos & Restuccia, 2020; Elauria, 2015; Lagare, 2021). As of 2015, the Philippines has now cultivated over 70% of its farmable land leaving only around 30% for expansion (Elauria, 2015; The World Bank 2022). Even then, not all of this space can be used for farming as some will inevitably be used for urbanization. The decreasing number of Filipinos interested in pursuing agriculture has been attributed to the high level of difficulty despite the low income associated with farming (Brown et al., 2023; Elauria, 2015). The declining agricultural sector is a multifaceted problem not only involving farmers but also politicians, landowners, local communities, national infrastructure, the climate, and an array of other factors (Briones & Habito, 2005; Far Eastern Agriculture, 2021; Guzman, 2018; Lagare, 2021; Purugganan, 2021; Talavera, 2022; The World Bank, 2020). However, precisely because of this interconnected nature, innovations in this sector can significantly cascade throughout the entire nation. That is why according to the World Bank (2020), agriculture is the heart of our nation and innovations in it are the key to reducing poverty and accelerating growth on a national scale.

There are many ways we can look to improve our agricultural sector. However, being true to its purpose, improvements can essentially be boiled down to growing more food, from less land, in a faster period of time. This is a common theme found in world changing discoveries in the agricultural field such as the invention of nitrogen fertilizers, the discovery of modern crop breeding, application of pesticides, and the adoption of modern equipment; they all essentially just help us create more food from less resources.

Objectives

A. Main Objective

   This project aimed to design, develop, and evaluate a sustainable, smart, and modular outdoor vertical paddy field farm.

B. Sub Objective:

   1. Design a realistic prototype based on strong scientific principles and underrepresented concepts with great potential
   2. Develop both hardware and software prototype iteratively to solve any unforeseen problems that may arise
   3. Evaluate the prototype using internal assessments and external presentations to potential stakeholders

Significance of the Study

The resulting prototype of Project PAGSACA can serve as a framework for further innovations and research that could greatly benefit not only agriculture in the Philippines but also agricultural practices internationally. Having the potential to generate more food from less land in a shorter period of time can have great impacts on global supply chains and prices of commodities that are applicable to the current paddy field setup if ever the design were to be industrialized for mass production. More than anything, this project may serve as a way for more researchers and people in general to think more about our country's agriculture and how they can do their part to improve it.

Scope and Limitations

The development of Project PAGSACA included a combination of the following concepts and technologies for the final prototype: (1) Vertical Farming, (2) Plant Microbial Fuel Cells or PMFC, (3) Electroculture, (4) Organic Solar Cells, (5) Automation and Internet of Things System, and a (6) Web Application to serve as an interactive user interface.

The final prototype was designed to put emphasis on the modular nature of the project with regards to vertical farming. Modules were created that housed and included the target features and technologies. For the purposes of this project, steel and acrylic were the main materials used in the creation of the modules, as both are easily obtainable and sturdy while being relatively inexpensive and simple to work with.

As for the plant setups, the project was configured around *Oryza sativa* or rice due to its cultural, national, and even international significance, with it being one of the most common staple foods in the world, particularly in Asia. The plant is also relatively simple and quick to grow and easy to obtain.

It is important to note that the purpose of this project was only to create a prototype that could serve as a proof of concept rather than a marketable product. This is emphasized by the relatively high total cost of the project due to issues in manufacturing and material procurement. Any wide scale use would require extensive industrialization and optimization for manufacturing and economy of scale. It is also for this reason that the project limited the size of the prototype due to budgetary and design constraints.

II. BACKGROUND

Vertical Farming

Vertical farming is what most people would think of when faced with the problem of farming more food from less land. Although they may seem like a new trendy term in the agricultural field, they are actually not a new idea. Vertical farms can be traced all the way back to 600 BC and the Hanging Gardens of Babylon. However, they have only recently gained traction due to recent technological advancements that peer into its potential in scalability (Al-Kodmany, 2018). There are already dozens of operating vertical farms in the world. Other than saving space it also improves food security, reduces the amount of herbicides and pesticides used in farming, helps recycle organic waste, and even fights climate change (Al-Kodmany, 2018). However, vertical farms are expensive and cost alot to maintain. One of their main issues is the additional energy needed for the system. This energy is what powers the artificial LED lights to compensate for the lack of natural light and pumps that send water and fertilizer to the plants (Kalantari et al., 2018). Therefore, by solving or mitigating such drawbacks we can increase the viability of vertical farming as a potential wide scale solution.

Organic Solar Cells

Since energy is one of the largest issues of vertical farming, a technology often complementary to it are solar panels. Solar panels are composed of several solar cells wired together to convert the sun's light energy into electricity. Majority of these solar cells are made up of inorganic materials such as monocrystalline or polycrystalline silicon. However, there has been growing interest in the manufacturing of organic solar cells or OSCs made from small organic molecules such as pigments with the application of semiconducting polymers (Hoppe & Sariciftci, 2004). Due to this make up, OSCs are lightweight, flexible, aesthetically pleasing, low cost, non-toxic in nature, and environmentally friendly (El-Atab et al., 2020, Xu et al., 2020). A major drawback of OSCs is that they generally have less efficiency than conventional inorganic counterparts meaning they generate less electricity for the same area. However, the potential of OSCs's inherent flexible nature is yet to be explored in terms of increasing its efficiency and making up for this gap. A study done by El-Atab et al. (2020), attempted to capture sunlight in 3 dimensions instead of the usual 2 dimensions from a flat panel. Their implementation was composed of a sphere made of inorganic solar panels with results increasing efficiency by 39.5% to 101% when compared to normal flat rectangular panels. Due to OSC's flexible and occasionally semi-transparent nature, it would be more suitable for shapes such as spheres and arcs that collect sunlight in 3 dimensions as illustrated in the study by El-Atab et al. (2020). Furthermore, their semi transparent nature would mean additional light could potentially be scattered and reflected within the 3 dimensional shape further potentially increasing efficiency. Finally, a rounded shape would allow for hotspots to be distributed throughout the day throughout different parts of the solar panel. This is important as high temperatures and temperature fluctuations have been found to decrease the overall efficiency in solar panels (Arshad et al., 2014; Razak et al., 2016; Zaini et al., 2015). Thus by having a more rounded shape, the sunlight would only be perpendicular to one row of solar cells at a time throughout the day instead of all at once towards the sun's zenith distributing the overall temperature experienced by the panel theoretically increasing efficiency.

Plant Microbial Fuel Cells

Plant Microbial Fuel Cells or PMFCs enable the production of electricity directly from the growth of plants while not inhibiting the food cultivation/production process and may even potentially improve it with the incorporation of electroculture and plant disease/abnormality detection. PMFC is the method of using MFC or Microbial Fuel Cells in combination with a plant to create a bio-system improving the electricity generation by up to 18 times (Brunelli et al., 2016; Kabutey et al., 2019). This works by collecting the electrons with electrodes from specific electrogenic bacteria that are common in almost any soil on Earth as they eat organic matter in the soil (Brunelli et al., 2016). These electrogenic bacteria however only release electrons when in an anaerobic environment or specifically in the absence of oxygen. This reason is why paddy fields or other marshes are the ideal environment for implementing PMFC as the water can serve as a sealant from any oxygen to enter. Rice Paddy Field MFC (RP-MFC) is projected to produce 40 to 80 mW/m^2 with the potential to approximately triple the electrical output by adding supplements such as zero valent iron (ZVI) (Schamphelaire et al., 2008; Kouzuma et al., 2014; Matsumoto et al., 2020). Although power generation through PMFC is relatively weak, it is still enough to power sensors that can be used to collect data about the plant and its immediate surroundings or small LEDs (Brunelli et al., 2016; Kouzuma et al., 2014). Additionally, the rate of electricity generation and trends or deviations from the normal can indicate abnormalities in the plant such as diseases that weaken the plant thereby potentially informing the farmer before any physical symptoms (Brunelli et al., 2016). Furthermore, the small electricity generation from the PMFC setup means touching the water and, therefore, farming with the setup is safe and cannot pose any danger to anyone who uses it. Finally, as the electrons travel between electrodes in the water, the plant is exposed to a weak electric current that connects the next concept of electroculture.

Electroculture

Plants exposed to weak electric currents have been shown to increase plant growth, number of leaves, fresh and dry weight, mineral content, and valuable bioactive compounds (Dannehl, 2018). This process of exposing plants to electricity is often referred to as electroculture. Electroculture is based on the principle that electricity would stimulate the plant’s physiological processes, such as its metabolism, increasing growth rate. Electroculture has a history of being branded as pseudoscience due to unscientific inventions such as the atmospheric coils that originally popularized it.

Despite this, there still have been several studies in the past few years that have legitimized several of its claims making it a credible idea to pursue (Manguiam et al., 2019; Basallote et al., 2022). There have been little to no studies currently on electroculture in the context of a paddy field with soil saturated in water. As water would naturally have a better conductance than soil, it should theoretically benefit the system. Finally, electroculture and PMFC can ideally create a feedback loop between themselves where the plant would create electricity that could be used to improve itself, allowing it to generate even more electricity.

Internet of Things (IoT) System

The Internet of Things, or commonly referred to as IoT, refers to a network of interconnected physical devices such as sensors and appliances. There has been a growing move to incorporate IoT in the agricultural field due to its convenience in automating traditionally laborious tasks such as irrigation (Basallote et al., 2022). An IoT system can also be helpful for remote monitoring of an agricultural field through a connection to an interface often using the internet.

Full Stack Web Development

Full stack web development refers to the development of web applications with both a frontend and backend. The frontend refers to anything client side or anything a user visiting the site can see. Meanwhile, the backend refers to everything that happens outside the view of the user visiting the website and often incorporates server processes and a database. The database can serve as a bridge between the web application and the IoT system as microcontrollers with WiFi such as the Arduino R4 WiFi and ESP32 can upload sensor data to an online database that a web application is also connected to.

II. METHODOLOGY

Research Design

This project was developed following the iterative developmental research design, going back and forth between the different steps in the developmental process.

Procedures

The completion of this project was done through multiple procedures and processes. This was done to spread out the difficulty and be able to divide the labor among the members.

The project began by doing scientific research into a working theory based on strong scientific foundations and concepts with great potential. Based on the research, the members brainstormed and designed a device that incorporates the concepts that were previously scouted. Following this, a 3D model was created using Fusion 360 to semi-finalize it.

After thorough discussion and revisions, a final decision regarding the design was made and the materials to be used for the design. The availability of materials based on factors such as price, distance, and delivery time was then done. The procurement of materials was then done accordingly.

Once the materials arrived, the building of the prototype was then started. Subsequently, the microcontrollers and electronics were then programmed and built into a circuit to cater to the IoT system. The IoT system's interface is then designed and programmed.

Once the prototype was finished, the scientific theory was then tested through miniature setups. These setups were then tested and checked if there were any failures or significant outputs. The results from the scientific investigation and prototype testing were then analyzed. Based on the gathered data, redesigns were then implemented to address the previously noticed concerns and problems. For evaluation purposes, the project has undergone multiple presentations, consultations, and interviews with potential stakeholders namely local farmers, local agencies, and an international horticulturist for their input. Finally, necessary changes were made based on their inputs.

Integrated Materials

The materials used to create the module were all bought locally. The steel angle bars and flat bars were purchased from the local hardware store while the acrylic glass was bought from the local glass hardware store. Following this, the steel frame was constructed and welded in a local machine shop where it was also polished and painted. On the other hand, the acrylic casing was manually scored and built by us using a glass adhesive, layered with another silicone adhesive to fortify its water tightness. Most importantly, the graphite electrodes were purchased online and were also cut and installed manually. Finally, full spectrum LED strip lights were used to line the underside of each plant module allowing them to provide a supplementary source of light for the plants in the module below them.

The control hat module is the brains of the device. It consists of the microcontroller and other electronics that were already provided in the 7th IMake WeMake Developmental Kit or bought. Specifically, the main microcontroller was the ESP32 as it is both relatively cheap despite having WiFi capabilities. Several buck and boost converters were also used to allow a wide range of voltage from the power bank servicing as the power supply. These converters were important due to the 12V fans and water pumps for each module. Additionally, a good portion of the components were not available locally such as the solar cell and several electrical components; hence, they were purchased online through stores such as Lazada and Shoppee.

Project Dimensions

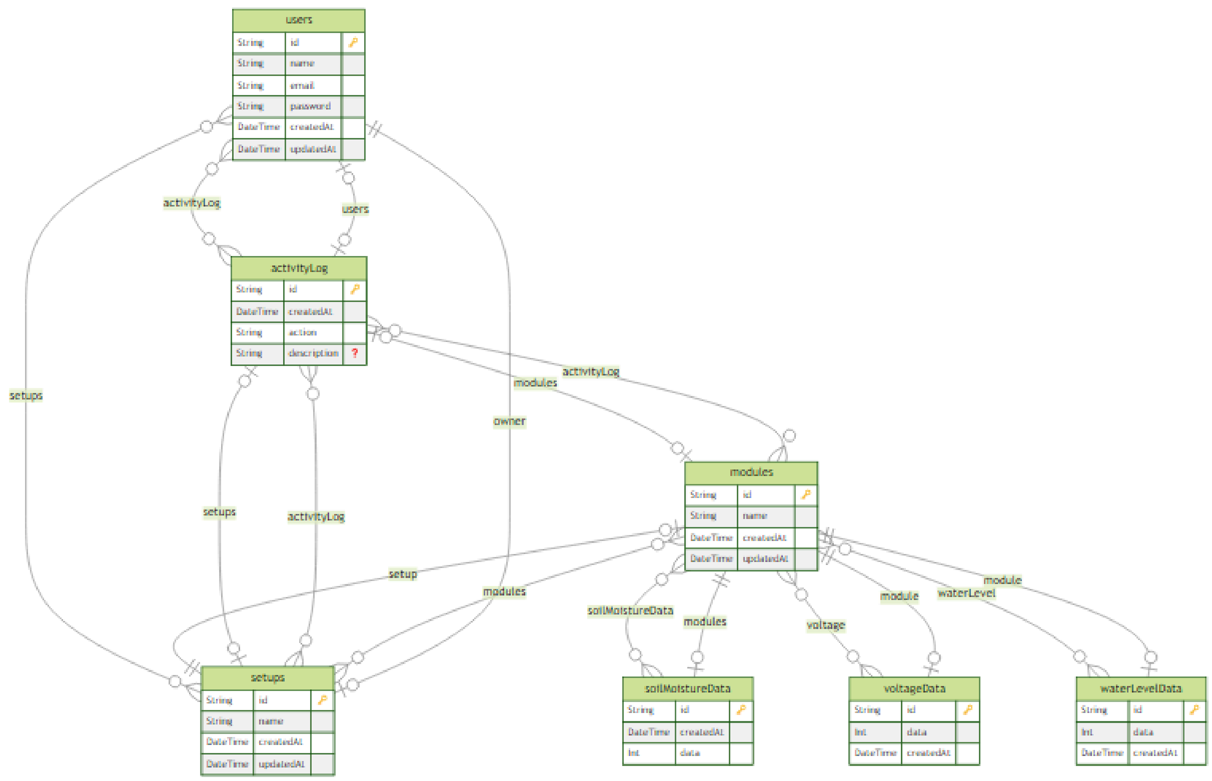
The dimensions of each plant module is 10 inches by 10 inches by 10 inches, essentially a 10 inch cube. The dimensions of the control hat is half the height of a plant module so 10 x 10 x 5 inches. There is about a 1 inch gap between the top of the acrylic inner case and the top angle bar of each module for carrying as well as airflow. The steel angle bars were 5mm thick while the acrylic was a 1/8 inch thickness for walls and 3/16 inch thickness for floors.




Tech Stack

The web application was created with React and Nextjs incorporating the Node.js runtime with additional libraries such as TailwindCSS for styling, shadcn/ui for the css component library, and Prisma as the Object Relational Mapping (ORM) Library. It follows industry standard practices and conventions hence can be easily adapted and updated by future developers aiming to improve on our project.

Both the web app and the IoT system are connected to a SupaBase PostgreSQL database. SupaBase is a backend as a service (BaaS) product that can provide additional functionality such as authentication, hosting, real-time databases, and scaling. PostgreSQL is a popular relational database management system (RDBMS) that has more features than its lighter weight counterpart MySQL. The different levels of normalization were strictly observed when creating tables and relationships. Below is an Entity Relational Diagram or ERD of the current database for Project PAGSACA to visually display the relationships between tables.

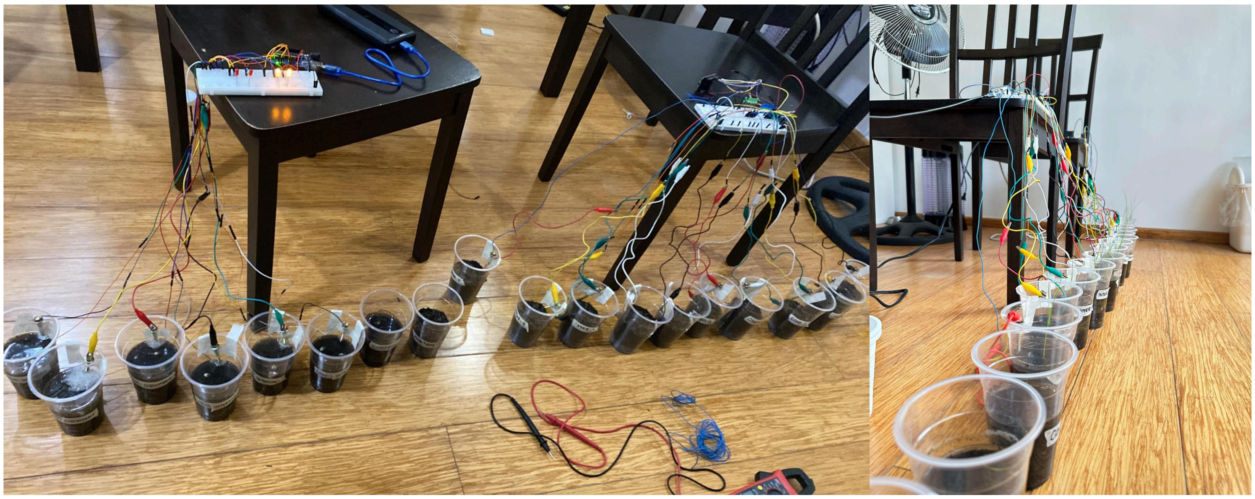


Experimentation

Tests and experimentations were conducted for the various features of the project, with the Plant Microbial Fuel Cells (PMFC) and Electroculture setups being given the utmost importance to find the optimal configuration for increased plant growth and electricity generation. All results were compared to a control group of 2 plant pots made with plastic cups and a basic rice setup.

Electroculture

A simple setup was created to determine the effect of Electroculture on the growth of rice and another simple PMFC setup was created to determine the electrical output.



Each electroculture cup was made the same way as the controls but with installed metal screws acting as electrodes. The electrode closer to the base of the cup served as the anode while the electrode only touching the surface of the soil on top served as the cathode. All the cups' electrodes were then connected to a microcontroller, either an ESP32 or Arduino R4, to control the voltage the treatment received by modifying the “AnalogWrite” of a pin to only a certain pulse width modulation (PWM). In total, 14 treatments were created in this way with varying voltages and intervals ranging from 0.1V to 5V. All treatments were divided into two major groups: one constantly receiving a voltage, and another receiving a voltage at intervals of 5 minutes every hour. Each cup was planted with exactly 5 seeds of the same variety from the same source. This test was conducted to determine the optimal voltage level and the effects of having a constant electric output as opposed to having an output on intervals. Another reason for this was to experiment on the effects of short burst high voltages against constant low voltage.

Plant Microbial Fuel Cells

The Plant Microbial Fuel Cell or PMFC setups were made using the same configuration but with graphite electrodes. The first electrode, the cathode, protrudes from the soil while the other electrode, the anode, rests submerged below it. Each electrode is then connected to the other using a wire with no additional external voltage input. The electricity generated by the pots were then monitored, noting down the output current and voltage levels using a multimeter. Additionally, with the current generated by the PMFC setup leading to passive Electroculture, plant growth was also monitored for any significant effects and changes as opposed to the other Electroculture and control setups.

III. TECHNOLOGY VALIDATION

The evaluation of the prototype included internal testing through experiments and consultations/interviews with several potential stakeholders of the project. All interviews and consultations were aimed to gauge the feasibility of the project, its specific niche in the market, and any potential improvements, concerns, or ideas based on the experience and knowledge of experts in the field. Each session took about an hour and was always accompanied with a very lively discussion. In summary, all of the consultations and interviews yielded generally positive feedback and excitement for the project.

Local Farmers

An interview and consultation for the perspective of the local community on the project was conducted with Ma’am Conrada V. Oñas from Tanauan, Leyte, a farmer with over 60 years of experience farming rice and with extensive knowledge on the processes and labors of traditional farming. She explained how the real main problems the farmers in the area were facing were the system and the lack of water.

She elaborated how the farmers in our province were highly dependent on the Department of Agriculture and how revisions on the current system of subsidies needs to be heavily revised.

Finally, she explained how important water supply is to rice farming. In her experience, lacking water supply leads to only one harvest per year with small and unhealthy crops compared to the two to three harvests possible when water is abundant. This ties back also to the systemic issue as she describes ill intentioned peers who would steal other farms’ by blocking channels.

Although Project PAGSACA cannot address a systemic issue, its design can be adapted to potentially help address the water shortage issue. An optional submersible pond pump will be able to attach to the influent pipe of the control hat instead of the regular 12V pump to allow for water collection from deep wells later on. Additionally, a rainwater collection system or module can be developed to add to the existing setup. However, all solutions to these problems stay limited in a way or form decreasing feasibility of wide scale adoption in local farming communities of the current initial prototype of the project.

Local Agency

To complete the local community's perspective on Project PAGSACA a consultation and interview was done with the Region 8 Department of Agriculture Rice Program Division.

The audience consisted of several experts from soil analysts, agriculturalists, and agribusiness specialists. There was overall a positive response to the presentation with much excitement over the concepts the prototype demonstrated. There were naturally a lot of comments, ideas, and suggestions for the project as the discussion was very lively with a relatively large number of people experts in their own sub-field present. They were very eager to hear from us again if ever we wished to pursue this project further together with them in the future.

One major group of suggestions essentially boiled down to doing more research on the topics used in the project. They were first interested in how the different microbes in the soil from different kinds of soil could affect the PMFC system. Secondly, they recommended researching if electroculture can potentially break seed dormancy better than the current method of prolonged sun exposure and submerging the seeds in water. Next, they recommended a more indepth research into the potential of electroculture for pest control of small insects and specifically snails. Majority of the core concepts implemented in this project were chosen due to their promising potential despite their low popularity; hence, there is still generally lacking literature on specifics outside their main ideas. They also suggested more research and testing of our prototype if more could be made to test different configurations and environments prototypes can be deployed in such as indoor grow/storage rooms as well. They're final thoughts and recommendations included marketing the prototype to larger farms and seedlings as service farms.

International Horticulturist

Finally, to gain insight to how Project PAGSACA would potentially do in the international scene an interview was conducted with Sir. Matthew Nicholas, a horticulturist and internationally licensed farmer from New Zealand.

Sir. Matthew had a very pleasant and positive response to the presented prototype. He had mentioned how he believes Project PAGSACA could be promising in existing large scale modern farms. The main concern he had concerned airflow on the stagnant water. To alleviate this, the prototype was redesigned to increase the space between the top angle bar and acrylic faces and a small 12V fan was installed into the electronic packs to induce airflow. He also introduced the concept of slowly introducing stress to the seedlings as it reaches the 3 leaf stage to prepare it to survive after transplanting. This was incorporated by changing the algorithm that controls the water pump to slowly introduce more water over time and the fan to turn on more frequently following the seed's growth.

Additional Tests

Finally, several additional tests were performed on the project itself ensuring its functionality. This included but is not limited to ensuring the module's waterproofing and automated irrigation system, testing the incorporated IoT system, and manually reading current through the multimeter to check the circuit and proper installation of the electroculture-PMFC feedback loop. A multitude of small scale tests were performed on the individual components of the prototype as well as on the fully assembled prototype itself to guarantee complete functionality.

IV. RESULTS AND DISCUSSION

Data Collection

As mentioned previously, this section will elaborate over the results of the experiment described in section II. Methodology, Electroculture and PMFC. Below is a table summarizing the collected data where the prefix “INTER” refers to treatments following the interval shock of 5 minutes every hour. Likewise, the “CONST” id prefix refers to the treatments with a constant current being used, while the “CONTROL” prefix for control groups. The data collected for each seedling was their height from the base of the step to their highest point all in centimeters.

ID	Voltage (V)	Plant 1 (cm)	Plant 2 (cm)	Plant 3 (cm)	Plant 4 (cm)	Plant 5 (cm)	# in 3 Leaf	# in 2 Leaf	# in 1 Leaf
INTER 1	0.1	13.7	16.1	8	11	6.2	1	4	0
INTER 2	0.9	22	11.5	10.5	0	0	0	0	3
INTER 3	1.7	13.5	0	0	0	0	0	0	1
INTER 4	2.5	9.5	10	0	0	0	0	0	2
INTER 5	3.3	10.02	0	0	0	0	0	1	0
INTER 6	4	16.3	18.6	10.4	0	0	0	3	0
INTER 7	5	7.7	12.5	14	0	0	1	1	1
CONST 1	0.1	14	2.5	12.9	0	0	0	0	3
CONST 2	0.9	19.3	3.5	0	0	0	0	1	1
CONST 3	1.7	0	0	0	0	0	0	0	0

CONST 4	2.5	21.3	18.5	0.5	0	0	0	2	0
CONST 5	3.3	5.5	4.2	0	0	0	0	0	2
CONST 6	4	0	0	0	0	0	0	0	0
CONST 7	5	0	0	0	0	0	0	0	0
PMFC	>0.1	0	0	0	0	0	0	0	0
CONTROL 1	0	0	0	0	0	0	0	0	0
CONTROL 2	0	5	0	0	0	0	0	0	1

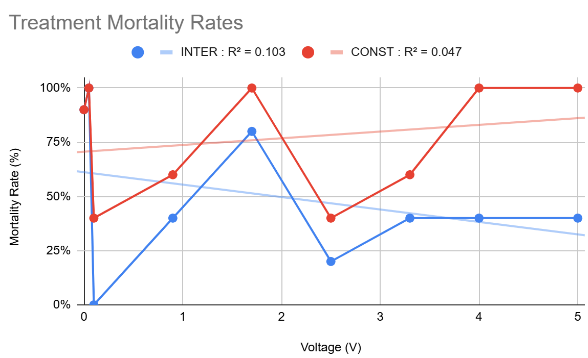
Data Analysis

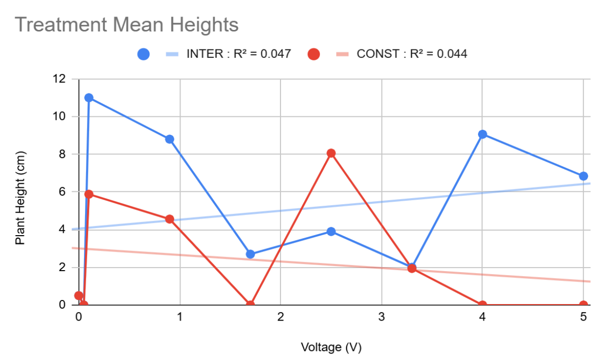
The table below summarizes the data from the table above by looking at key dependent variables such as the mortality rate, mean height, and median height. Mortality rate was computed as the total number of plants that did not sprout divided by the total number of seeds in the cup, 5. Hence, a lower mortality rate would be a more ideal outcome .

ID	Voltage (V)	Mortality Rate (%)	Mean Height (cm)	Median Height (cm)
INTER 1	0.1	0%	11	11
INTER 2	0.9	40%	8.8	10.5
INTER 3	1.7	80%	2.7	0
INTER 4	2.5	20%	3.9	0
INTER 5	3.3	40%	2.004	0
INTER 6	4	40%	9.06	10.4
INTER 7	5	40%	6.84	7.7
CONST 1	0.1	40%	5.88	2.5
CONST 2	0.9	60%	4.56	0
CONST 3	1.7	100%	0	0
CONST 4	2.5	40%	8.06	0.5
CONST 5	3.3	60%	1.94	0
CONST 6	4	100%	0	0
CONST 7	5	100%	0	0
PMFC	>0.1	100%	0	0
CONTROL 1	0	100%	0	0
CONTROL 2	0	80%	1	0

	Mortality Rate	Mean Height	Median Height
AVERAGE CONTROL	90%	0.5	0
TOTAL AVERAGE	61%	3.867294118	2.505882353

From these tables, we are able to do descriptive statistical analysis for findings. This is done by plotting the data points and using linear regression to get the best fit line representing a general trend. These charts below show this data visually allowing us to quickly recognize underlying patterns.





Next we use the Single Factor Analysis of Variance (ANOVA) to test for statistical significance through the computed p-values. This was done using the data tools available in Microsoft Excel. The data found for the INTER Mortality Rate, INTER Mean Height, and CONST Mortality Rate all had a p-value less than 0.05 surpassing the 95% confidence interval and thus qualifying them as statistically significant unlike CONST Mean Height.

INTER

Voltage	Mortality Rate
0.1	0%
0.9	40%
1.7	80%
2.5	20%
3.3	40%
4	40%
5	40%

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	7	17.5	2.5	3.016667
Column 2	7	44.304	6.329143	12.23648

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	51.31817	1	51.31817	6.728864	0.023484	4.747225
Within Groups	91.51887	12	7.626573			
Total	142.837	13				

Voltage	Mean Height
0.1	11
0.9	8.8
1.7	2.7
2.5	3.9
3.3	2.004
4	9.06
5	6.84

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	7	17.5	2.5	3.016667
Column 2	7	44.304	6.329143	12.23648

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	51.31817	1	51.31817	6.728864	0.023484	4.747225
Within Groups	91.51887	12	7.626573			
Total	142.837	13				

CONST

Voltage	Mortality Rate
0.1	40%
0.9	60%
1.7	100%
2.5	40%
3.3	60%
4	100%
5	100%

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	7	17.5	2.5	3.016667
Column 2	7	5	0.714286	0.078095

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	11.16071	1	11.16071	7.212648	0.019829	4.747225
Within Groups	18.56857	12	1.547381			
Total	29.72929	13				

Voltage	Mean Height
0.1	5.88
0.9	4.56
1.7	0
2.5	8.06
3.3	1.94
4	0
5	0

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	7	17.5	2.5	3.016667
Column 2	7	20.44	2.92	10.73507

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.6174	1	0.6174	0.089792	0.769568	4.747225
Within Groups	82.5104	12	6.875867			
Total	83.1278	13				

A lot can be interpreted from the results of this data analysis. However, the main key takeaway is that the treatments with 0.1V and 0.9V generally resulted with the lowest mortality rate and highest mean heights. Furthermore, due to the results of the experiment being statistically significant in the dataset, the final prototype of Project PAGSACA uses this range of 0.1 to 0.9 V.

Although the experiment for the electroculture yielded favorable results, it is important to note that these results are not indicative of a rigorous scientific conclusion. They are simply the results from one experiment during one instance. It is also important to note that all treatments and controls underperformed regularly expected mortality rates and heights. This can possibly be attributed to a compromise in one or more of the control variables such as bad seeds, incompatible soil, and improper water. However, all treatments and controls used the same sources for their control variables and were all prepared the exact same way. Thus, results of this experiment can alternatively demonstrate the benefits of electroculture in environments with unfavorable conditions for the plants. Further research and replications are needed and are suggested to conclusively solidify that these results and conclusions are consistent.

Results of Additional Testing

All results from all additional tests for the prototype functionality yielded positive results. The acrylic case within each module was capable of storing water and soil without any seeping out. The automated irrigation system works as intended although pump strength is occasionally inconsistent. The incorporated IoT system connects to all modules and can communicate with the web application through an online database. The delivered voltage to each module was read to be appropriate through a digital multimeter and works in tandem with the electroculture-PMFC feedback loop.

V. ACTUAL PROJECT COST

Project PAGSACA definitely did not come for free. However, the developmental cost is equivalent to the generated value cost by maximizing already existing equipment and materials readily available such as the 7th IMake WeMake Developmental Kit and school equipment. The total cost to develop and build the project was around Php 14,000 and the cost of the prototype if it had to be commercialized at its current state would also cost around the same Php 14,000. This price breakdown is displayed in the table below.

COMMERCIAL COSTS						
Part Name	Item	Units	Cost	Labor (if applicable)	Description	Total
Hat	Power Supply	1	500	0	Power Bank included in kit	
	ESP32	1	350	0	included in kit	
	Solar Cell	1	650	0		
	Acrylic Casing	1	880	0		
	Assorted Electronics & Wires	1	500	0		2880
Module	Acrylic Casing	1	1000	0		
	Graphite Electrode	3 orders of 2 pcs	720.5	0		
	Frame	1	1000	1700		
	Growth Lights	1	250	0		
	Compartment	1	300	0	Acrylic	4970.5
Externals Needed per Module	Hose	1	100	0		
	Water Pump	2	300	0		
	Wires	1	100	0		
	Reservoir	2	0	0	Water Juggs	500
Total of 1 Module ONLY						4420.5
Total of a full device with 1 Module						8350.5
Total of a full device with 2 Modules						13821
Total of full device with N modules						ceil(N/4)*2880 + 5470.5N

This figure however should be taken with a grain of salt. Due to time constraints several materials had to be bought based on how quickly they could arrive rather than most cost-effective. Additionally, it can be interpreted that this is the maximum price of such a prototype as optimizations and a manufacturer's economy of scale can significantly lower the costs. An example of this is how the current control hat can only support up to 2-4 modules; however, a larger scaled version could have a control hat potentially capable of supporting tens of modules simultaneously sparring costs. Finally, the prototype focused on presentability and sturdiness, thus strictly speaking we estimate it possible to create a similarly sized prototype for only around Php 3000 by using already existing household items instead.

It should also be iterated that this high asking price is also why the prototype was created with modular parts and principles. This is to invite either incremental additions over time or cheaper alternatives to other modules that can serve the specific needs of the farmer. Using Project PAGSACA in practice does not necessarily include having to use all designed modules together as its modular design is meant for customizability both in function and in price.

VI. RECOMMENDATION

Despite the complete functionality of Project PAGSACA, a prototype is still only a prototype. There is a lot of room for improvement as previously hinted to with suggestions from the Tech Validation section. Firstly, the material used for the frame of the device is steel due to the lack of aluminum materials and professional aluminum welders in the area; it is recommended that aluminum be used in developing this device to reduce the system weight of the modules. Secondly, additional improvements can be made to the IoT and web application to make it production ready such as implementing user authentication and ways to properly register modules with additional controls. Furthermore, the organic solar cell that sits on top of the control panel can be further researched on to be molded into a sphere with concave mirrors underneath to truly capture sunlight in 3 dimensions and increase efficiency as in the original design but was not pursued due to budgetary and technical limitations. Moreover, the materials used for prototype build can definitely be improved in terms of quality, costs, and craftsmanship through better equipment. Next, an “electroculture-PMFC kit” could potentially be developed to apply the core concepts of Project PAGSACA on already existing paddy fields without having to transfer any land to modules. This kit could be composed of the graphite electrodes and a miniature control hat that can implement the electroculture-PMFC concepts to an existing paddy field after following installation instructions. Finally in general, more research on each of the core concepts Project PAGSACA uses to take advantage of them and their synergies with each other more.

VII. CONCLUSION

In conclusion, a prototype of Project PAGSACA was successfully created. It is a functioning sustainable, automated, outdoor vertical farming device that incorporates the concepts of electroculture, plant microbial fuel cells, organic solar cells, and IoT systems to currently grow rice on a paddy field setup. The benefits of the prototype found to include (1) minimized horizontal space for urban farming through vertical farming, (2) automated farming labor practices and processes such as irrigation and plant monitoring, (3) increased resistance to pests and diseases due to the nature of vertical farming and electroculture together with possible early detection through automated monitoring, (4) potentially increased growth rate and germination from electroculture and some vertical farming practices, (5) a new method for basic real-time plant monitoring based on the bio-electricity generated by PMFC as a “plant’s heartbeat”, (6) plant microbial-based bioelectricity production from PMFC, (7) a new solar cell configuration to increase efficiency by diffusing heat throughout the day, and (8) sustainable, smart, and modular farming that is designed to remain adaptable to as many use cases as possible while also being financially flexible. Future research is recommended on all aspects of the prototype to improve it for commercial use, specifically this includes ways to increase supportable plant variety and the optimization of the electroculture-PMFC configuration.

This project serves as but a small example of the potential improvements we can still bring to a centuries old practice still deeply ingrained in our culture. As a nation, we must look back to what every single citizen needs, look back at our roots, and take a step forward towards a brighter future through innovations in our agriculture.

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