Production of Acidic and Alkaline Water Through Water Ionization by Electrolysis Method for PH & Moisture Soil Using Solar Cell Modules

A MASTER’S THESIS

SUBMITTED TO
THE SCHOOL OF ELECTRICAL ENGINEERING

By
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PENGESAHAN

APPROVAL PAGE

A MASTER'S THESIS

Produksi Air Asam dan Basa Melalui Ionisasi Air dengan Metode Elektrolisis untuk PH dan Kelembaban Tanah Menggunakan Modul Sel Surya

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Approved and authorized to fulfill one of the requirements of Program of Master of Electrical-Telecommunication Engineering School of Electrical Engineering Telkom University Bandung

Bandung, August 9, 2025

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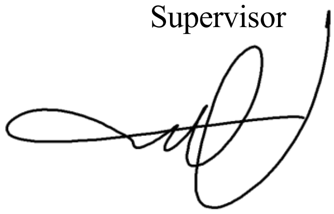	
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I declare that all information in this document has been obtained and presented following academic rules and ethical conduct. I also declare that, as required by these rules and conduct. I have fully cited and referenced all materials and results not original to this work.

August 9, 2025
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ABSTRAK

Sektor pertanian Indonesia kini menghadapi tantangan besar untuk meningkatkan produktivitas sambil menjaga keberlanjutan lingkungan, terutama akibat tingginya ketergantungan pada pupuk kimia dan menurunnya kualitas tanah. Sejalan dengan target nol emisi karbon 2060, dibutuhkan pendekatan ramah lingkungan seperti penggunaan air elektrolit (basa dan asam) sebagai alternatif pupuk kimia. Penelitian ini mengevaluasi penggunaan Portable Water Ionizer (PWI) bertenaga panel surya 20 Wp, dengan lima jenis larutan elektrolit (NaCl, KCl, NH_4Cl, KIO_3, dan air mentah), untuk menilai konsumsi energi, efisiensi elektrolisis, serta dampaknya terhadap tanah dan pertumbuhan tanaman.

Hasil menunjukkan bahwa sistem dengan larutan elektrolit memiliki index pemanfaatan daya dari sumber hingga 33% lebih tinggi dibandingkan tanpa larutan, dan sejalan dengan produksi gas hidrogen selama proses elektrolisis. Air elektrolit basa terbukti mampu meningkatkan pH tanah dari asam menjadi netral (6,3–7,0) tanpa mengubah kelembaban tanah secara signifikan. Perlakuan dengan KCl dan KIO_3 pada kondisi basa (P3) menunjukkan pertumbuhan optimal pada bayam hijau, bayam merah, dan kangkung, sedangkan NaCl dan NH_4Cl menghambat pertumbuhan akibat toksisitas ion. Temuan ini mendukung potensi penerapan sistem elektrolisis berbasis energi surya dengan larutan elektrolit tertentu sebagai pendekatan berkelanjutan dalam pertanian modern.

Kata kunci: Elektrolisis, Pertanian, Air basa, Modul Sel Surya, Tanah Optimal

ABSTRACT

Indonesia's agricultural sector is currently facing major challenges in increasing productivity while maintaining environmental sustainability, particularly due to high dependence on chemical fertilizers and declining soil quality. In line with the 2060 net-zero carbon emissions target, environmentally friendly approaches such as the use of electrolyte water (alkaline and acidic) as an alternative to chemical fertilizers are needed. This study evaluates the use of a 20 Wp solar-powered Portable Water Ionizer (PWI) with five types of electrolyte solutions (NaCl, KCl, NH_4Cl, KIO_3, and raw water) to assess energy consumption, electrolysis efficiency, and their impact on soil and plant growth.

Results showed that the system with electrolyte solutions had up to 33% higher Power Utilization Index (PUI) compared to one without solutions, and was consistent with hydrogen gas production during the electrolysis process. Alkaline electrolyte water was found to effectively increase soil pH from acidic to neutral (6.3–7.0) without significantly altering soil moisture. Treatment with KCl and KIO_3 under alkaline conditions (P3) showed optimal growth in green spinach, red spinach, and water spinach, while NaCl and NH_4Cl inhibited growth due to ion toxicity. These findings support the potential application of solar-powered electrolysis systems with specific electrolyte solutions as a sustainable approach in modern agriculture.

Keywords: Electrolysis, Agriculture, Alkaline Water, Solar Cell Module, Optimal Soil

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Bismillaahirrahmaanirrahiim. Alhamdulillahirabbil'alamin.

In the name of Allah, the Most Gracious, the Most Merciful. All praise is due to Allah, the Lord of the Worlds, the Most Compassionate, the Most Merciful. The Master of the Day of Judgment. O Allah, thank you for Your Grace and Bless, so I was able to complete the study. Without Your Kindness, I will not be able to finish this thesis and achieve the Master's degree.

The completion of this thesis signifies the culmination of my journey toward earning a Master's degree. This achievement would not have been possible without the unwavering support, encouragement, prayers, and contributions from my family, mentors, colleagues, and friends. Therefore, the author would like to express the deepest gratitude and thanks to:

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Perhaps that all is what the author can say. I do apologize if there is a misspelling for name and titles. For the parties who missed the above gratitude, I apologize profusely for the negligence. May Allah the All-Knowing, whom nothing escapes His control, record your kindness and reward it with the best possible reward.

PREFACE

Praise be to Allah SWT for His Grace and Gifts, so that the author can complete this thesis entitled" **Production of Acidic and Alkaline Water Through Water Ionization by Electrolysis Method for PH & Moisture Soil Using Solar Cell Modules"** to be submitted to fulfill one of the requirements of obtaining a Master's degree in Electrical Engineering. May prayers and peace be always upon the Prophet Muhammad SAW, family, friends, and his followers. Aamiin.

Designing a system to produce alkaline and acidic water that will be utilized in the agricultural sector is necessary to improve food health. This thesis proposes the Production of Acidic and Alkaline Water Through Water Ionization by Electrolysis Method for Agricultural Fertilizers Using Solar Cell Modules to meet the Indonesian government's target of increasing food and achieving net zero emissions by 2060. In addition, it is also to cover the shortcomings of previous research. The results of this thesis are still novice, so it is open to researchers to further explore and develop further.

Unintentional errors in this thesis may not be realized by the author. Therefore, suggestions from the readers are highly expected to improve this thesis. Finally, the author hopes that this thesis can be useful, especially for those who are interested and want to know more about rateless channel coding techniques.

Bandung, August 9, 2025

Muh. Adrian Hidayat

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LIST OF ABBREVIATION

SCM	: Solar Cell Module
PWI	: Portable Water Ionizer
PH	: Potential Hydrogen
TDS	: Total Dissolved Solid
PPM	: Part Per Million
NaCl	: Natrium Chloride
KCl	: Potassium Chloride
KIO_3	: Potassium Iodate
NH_4Cl	: Ammonium Chloride
ANOVA	: Analysis of Variance
H_2	: Hydrogen
PUI	: Power Utilization Index

CHAPTER I
INTRODUCTION

1.1 Background

Rapid population growth and increasing food demand have pushed the agricultural sector to look for innovative solutions to increase crop productivity. However, today the agricultural sector faces major challenges in increasing productivity and sustainability amidst climate change and global population growth. According to Prof. Iswandi from IPB University (May 28, 2022) “72% of Indonesian farmland is degraded due to low organic matter caused by excessive chemical fertilizer use”. By that statement, improving food health (reducing the use of chemicals) is one of the main challenges in agriculture in Indonesia, and also related to Permentan No. 64/2013 on organic farming systems. Efficient and environmentally friendly use of fertilizers is key to overcoming this challenge.

Water is an essential component for the survival of all living things, including plants. Water has a vital role in plants because it serves to dissolve nutrients in the soil or planting media, making it easier for plant roots to absorb them [1]. Optimal soil conditions are diferent each plant, for example plants with crumbly textured soil (pH 6-7) such as chili and mustard greens while for plants with loose textured soil (ph 5.5) such as long beans [2] and soil moisture ranging from 60% to 70% [3]. Without sufficient water, plants cannot grow and develop optimally. If plants experience drought, cell division activity will be disrupted, which in turn will affect the growth and development of the plant [1]. Conversely, excessive water will also be bad for plant growth. Therefore, the right quality and quantity of water determine the success of agricultural production.

Regarding water quality, one innovative approach that is attracting attention is the use of ionized water, both acidic and alkaline, produced through the electrolysis process. Electrolysis is an electrochemical process that uses electrical energy to change the chemical reactions that occur. This electrolysis process requires a DC electric current to provide a negative charge on the anode and a positive charge on the cathode where the anions on the anode will oxidize and produce acidic water and the cations on the cathode will reduce and produce alkaline water [4]. Jiang et al. have conducted research related to the use of alkaline water through ionized water using the magnetic method (MIW (Magnetized Ionized Water)) in Xinjiang, China. The results showed that the water was able to increase plant height and cotton leaf area compared to without using MIW. However, the use of the water ionization method through the magnetization method is expensive[5]. Then, Lu et al. have also conducted research related to the utilization of alkaline water in irrigation systems connected to agriculture in China. The results show that irrigation with ionized water (alkaline water) can increase the nitrogen supply capacity of the soil, but attention needs to be paid to drainage for soils with poor structure. However, this study still does not look at the potential of acidic water in agriculture [6]. Based on these studies, the use of ionized water, both acidic and alkaline, produced through the electrolysis process, is an attractive option for application in agriculture. Ionized water has shown significant potential in improving fertilizer efficiency and effectiveness. However, through these studies, it still requires large energy inputs, which may limit its application in rural areas or developing countries. In addition, no research examines the use of electrolyzed alkaline water as a substitute for fertilizer simultaneously, especially in Indonesia.

In this study, four types of electrolyte solutions were selected: potassium chloride (KCl), potassium iodate (KIO_3), ammonium chloride (NH_4Cl), and sodium chloride (NaCl). Each of these compounds was chosen based on their ionic content and potential contribution to plant growth. KCl and KIO_3 serve as sources of potassium ions (K^+), which are essential macronutrients involved in enzyme activation, stomatal regulation, carbohydrate transport, and cellular expansion. Potassium also improves plant tolerance to abiotic stress. KIO_3, in particular, contains iodine (I^-), which in trace amounts has been reported to stimulate root growth and enhance antioxidant production in leafy vegetables [7],[8]. NH_4Cl was selected as a source of ammonium nitrogen (NH_4^+), a critical component for synthesizing amino acids, proteins, and chlorophyll. However, excessive ammonium may lead to phytotoxic effects if not balanced with nitrate sources [9]. Meanwhile, NaCl was included to mimic saline stress conditions, as sodium (Na^+) and chloride (Cl^-) ions are common in low-quality irrigation water. Although NaCl is not typically used as a fertilizer, it plays a role in assessing plant physiological tolerance to moderate salinity and understanding ion-specific responses [10]. Thus, the selection of these electrolytes enables not only the assessment of their fertilization potential but also the investigation of plant physiological responses to key ions when applied through electrolysis-based irrigation systems powered by solar energy. Considering this, the integration of solar-powered electrolysis systems becomes highly relevant for sustainable agriculture in tropical countries like Indonesia.

Indonesia is a country that is traversed by the equator and it has abundant solar resources. Under normal weather conditions, the Indonesian region is exposed to sunlight for around 10-12 hours every day with total energy radiation intensity (Ir) from 2010-2019 has a range from 3.4 to 4.1 kWh/day [11]. Data from the Directorate General of New Renewable Energy and Energy Conservation (EBTKE) in 2019, shows that the installed capacity of solar electricity in Indonesia has only reached 100 MW or 0.05 percent and then increased rapidly to 250 percent or around 250 MW in 2022. However, this is still far from Indonesia's available solar power potential of 207.898 GW. For example, the calculation results of solar electricity potential in an area in DKI Jakarta amounted to 152,742.24 kWh/day [12]. The Indonesian government through Presidential Regulation No. 12 of 2022 has encouraged the use of new renewable energy to achieve Net Zero Emission by 2060. Seeing the potential of solar energy in Indonesia, efforts to utilize solar energy need to be increased to achieve the target of solar potential in Indonesia. One form of effort is to create a system or tool that uses a Solar Cell Module (SCM). Ekki Kurniawan et al. have conducted research to make a water ionizer using SCM (Solar Cell

Module) to produce alkaline water and acidic water. The results show that electrolysis can convert mineral water into alkaline water with a pH of up to 9.80 and acidic water with a pH down to 5.04 with a solar cell module as an energy source for energy efficiency [13]. Then the latest research by Ekki Kurniawan et al. also shows that the use of Solar Cell Modules (SCM) is very promising to be used as a source of electricity in the electrolysis process to produce alkaline water and acid water [14]. Table 1.1 shows the Comparative Analysis of Household-Scale Power Sources in Indonesia.

Table 1. 1 Comparative Analysis of Household-Scale Power Sources in Indonesia

Parameter	Source Power Type				
	Solar Cell Modules (SCM)	PLN Grid Electricity	Small Wind Turbine	Household Biogas Generator	Diesel Generator
Energy Independence & Accessibility (Weight: 20%)	Highly independent, only needs sunlight. Potential in Indonesia >400 GWp [15]. Ideal to off-grid areas.	Not independent, fully dependent on national grid infrastructure.	Moderately independent, but highly location-specific; economic wind potential ~60 GW in limited regions [16].	Moderately independent, requires continuous feedstock supply (livestock manure/agro-waste) [16].	Not independent, relies on continuous diesel fuel logistics [17].
	5 (1.00)	1 (0.20)	3 (0.60)	4 (0.80)	2 (0.40)
Type of Current (Weight: 20%)	DC (Direct Current)	AC (Alternating Current)	AC (Alternating Current)	AC (Alternating Current)	AC (Alternating Current)
	5 (1.00)	1 (0.20)	1 (0.20)	1 (0.20)	1 (0.20)
Operational Cost (LCOE) (Weight: 20%)	Very low. LCOE ~IDR 600–900/kWh ($0.04–0.06) [18]. Minimal maintenance.	Medium. Tariff ~IDR 1,450–1,800/kWh ($0.10–0.12).	Very low. LCOE ~IDR 450–1,200/kWh ($0.03–0.08) [19].	Medium. LCOE ~IDR 1,000–2,200/kWh ($0.07–0.15). Requires feedstock management [17]..	Very high. LCOE >IDR 3,600/kWh (> $0.25) due to fuel and servicing [17].
	5 (1.00)	3 (0.60)	5 (1.00)	3 (0.60)	1 (0.20)
Environmental Impact (Weight: 15%)	Very low. Life-cycle emissions 11–50 gCO_2-eq/kWh [18].	Very high. Average Indonesia grid ~750 gCO_2-eq/kWh due to coal dominance [18],[17].	Lowest. 4–25 gCO_2-eq/kWh [18].	Low. 15–40 gCO_2-eq/kWh. Reduces methane from waste.	Very high. ~700-1,000 gCO_2-eq/kWh + local air pollution [17].
	5 (0.75)	2 (0.30)	5 (0.75)	4 (0.60)	1 (0.75)

Initial Investment (CAPEX) (Weight: 10%)	Medium. ~IDR 14–20 million/kW ($900–1,300) [18].	Low if grid exists, but high if new connection needed.	High. ~IDR 17–25 million/kW ($1,100–1,600) [16].	Very high. ~IDR 31–78 million/kW ($2,000–5,000) [17].	Lowest. ~IDR 6–12 million/kW ($400–800) [17]..
	3 (0.30)	4 (0.40)	2 (0.20)	2 (0.20)	5 (0.50)
Power Stability & Availability (Weight: 10%)	Low. Intermittent; capacity factor in Indonesia ~15–25% [18].	Very high. CF >90%, generally always available except during outages.	Low. Highly intermittent, CF ~25–45% [16].	High. Dispatchable, CF >85% [17].	Very high. CF >90% [17].
	2 (0.20)	5 (0.50)	2 (0.20)	4 (0.40)	5 (0.50)
Maintenance Complexity (Weight: 5%)	Very low. Solid-state; only periodic cleaning.	Very low; handled by utility (PLN).	Medium; mechanical parts inspection needed [2].	High; feedstock handling, residue disposal, and generator service.	High; requires oil changes, filter replacement, and engine servicing.
	5 (0.25)	5 (0.25)	3 (0.15)	2 (0.10)	2 (0.10)
Total Score	**4.50**	2.45	3.10	2.90	2.65

Score explanation: 1 = Very poor; 2 = Poor; 3 = Fair; 4 = Good; 5 = Very good. The value is Score × Weight.

Seeing the potential of abundant solar resources as well as the limitations of previous research and also Indonesian government regulations such as Permentan No. 64 of 2013 concerning organic farming systems and Presidential Regulation No. 12 of 2022, this thesis will discuss the production of alkaline and acidic water through an electrolysis process used different types of electrolyte solutions to maintain soil in optimal conditions hopefully can replace chemical fertilizers in short-cycle crops using solar cell modules. It is hoped that this research can overcome resource efficiency problems and improve food health in the agricultural sector in Indonesia.

1.2 Problem Identification

Based on the background explanation, we can conclude that this thesis has three problems. The first problem is according to Prof. Iswandi from IPB University (May 28, 2022) "72% of Indonesian farmland is degraded due to low organic matter caused by excessive chemical fertilizer use". This contradicts *Permentan No. 64/2013*, which aims to reduce chemical inputs for healthier agriculture. The second problem is although Indonesia receives 3.4–4.1 kWh/day of solar radiation, solar power installation remains low. Its only 250 MW by 2022 (EBTKE), far below its potential. The third problem is opportunity in ionized water technology by all the previous research such a Ekki kurniawan et. al and Jiang et. al. To solve the problem, here are some formulations of the problems of this thesis:

1. How does the system performance due to Power Utilization Index (PUI) compare when performing the electrolysis process between using a strong electrolyte solution (KCl) and without using electrolyte (raw water)?
2. How does alkaline and acidic water for each electrolysis solution affect measured soil and plant parameters?

1.3 Objective

This study aims to provide new knowledge on the production of acidic and alkaline water through electrolysis using PWI with solar energy resources. The electrolyzed water will be analyzed for its potential as a substitute for chemical fertilizers in plant growth. The specific objectives of this study are as follows:

1. Determine how the system performance due to Power Utilization Index (PUI) compares when performing the electrolysis process between using a strong electrolyte solution (KCl) and without using electrolyte (raw water).
2. Find out how alkaline and acidic water for each electrolysis solution affect measured soil and plant parameters.

1.4 Hypotesis

The initial hypotheses derived from the research questions and objectives are as follows:

1. Comparison of system performance due to Power Utilization Index (PUI) between using a strong electrolyte solution (KCl) and without using electrolyte (raw water) shows that the PUI of the system when electrolyzing using a strong electrolyte (KCl) will be greater than that without electrolyte (raw water).
2. The alkaline water and acidic water resulting from the electrolysis of each type of solution used will affect the pH and humidity of the soil. Then, the alkaline water and acidic water from the electrolysis of each type of solution used will also affect the measured plant parameters, namely plant height, leaf length, and leaf number.

1.5 Scope of Work

To keep the experiment from being too long, this thesis limits the works as follows this research will be limited to the implementation of the water ionization method using the electrolysis method in the agricultural field, especially for main optimal ph and moist soil for plant. Then, this research will also be limited to electricity sources through renewable energy, namely solar cell modules (SCM). This research will also be limited to use raw water and several types of electrolyte solutions as a solution to accelerate the electrolysis process. These electrolyte solutions are NaCl, KCl, KIO_3, and NH_4Cl solutions. In addition, the object of this research will also be limited to plants with short life cycles such as water spinach, red spinach and green spinach.

1.6 Expected Result

This thesis is expected to produce alkaline and acidic water through the electrolysis method by utilizing solar energy through Solar Cell Modules (SCM), which will then be implemented in the agricultural field. In addition, it is also hoped that this study's results can prove that using alkaline water can be an alternative to chemical fertilizers. With that, this research will provide research results that can support resource efficiency and improve food health in Indonesia.

1.7 Research Methodology

To achieve success in conducting this research, the methodology used are:

1. Literature review on electrolysis and the role of alkaline/acidic water by reading journals, articles, websites, and others. (8 Weeks) (September - October 2024)
2. Creating and designing system workflows using flowcharts and diagram block approaches. (8 Weeks) (November - December 2024)
3. Implementing the system that has been created and data collecting for analysis. (12 Weeks) (January 2024 - March 2025)
4. Analyzing and evaluating the measurement results for conclusion. (4 Weeks) (April - May 2025)

CHAPTER II
BASIC CONCEPTS

2.1 Ideal Gas law

Gas is one of the three fundamental states of matter and plays an essential role in the study of chemistry. The physical properties of an ideal gas are closely linked to its molecular structure, while its chemical behavior also depends on its atomic or molecular composition. The behavior of a gas as a single molecule provides a clear example of how macroscopic properties are determined by microscopic structures. Gases are generally classified into two categories: ideal gases and real gases. Among them, the ideal gas is the simplest model that approximates the behavior of real gases under specific conditions. Ideal gases obey the ideal gas law, whereas real gases may deviate from this law under certain circumstances. The general equation for an ideal gas is expressed as [20] :

$$PV_m = nRT \tag{2.1}$$

Where:
P = Pressure at the atmosfer (atm)
V_m = Molar Gas Volume (L/mol)
n = Number of moles
R = Ideal gas constant (8.314 J/mol·K or 0.08206 L·atm/mol·K)
T = Temperature (Kelvin)

2.2 Faraday Law

Faraday's law (1) states that the mass of a substance released or produced during electrolysis is directly proportional to the total electric charge (Q) or the electric current (I) flowing through the system over a certain period of time (t) [21]. Mathematically, this relationship can be expressed as in equations (2.2), (2.3), and (2.4):

$$G = Q = I \cdot t \tag{2.2}$$

As is known, a reduction reaction takes place at the cathode during electrolysis, which can be represented as:

$$\mathrm{L}^{n+}(aq) + ne^- \rightarrow \mathrm{L}(s) \tag{2.3}$$

To produce one mole of element L, n moles of electrons are required. Hence, the total electric charge needed to produce the substance is:

$$Q = n(e^-) \cdot F \tag{2.4}$$

Where:
F = Faraday Constant = 96.485 C/mol
G = mass of substance produced (grams)
Q = total electric charge (Coulombs)
I = electric current (Amperes)
t = time (seconds)
n = number of electrons involved (oxidation state)
n(e−) = moles of electrons

To determine the volume of a substance, the following equation is used:

$$V = \frac{G}{Ar.X} \qquad (2.5)$$

Where:
V = volume of the substance
G = mass of the substance
Ar · X = relative atomic mass of the substance

2.3 Electrolysis

An electrolysis cell is a type of electrochemical cell that utilizes electrical energy to trigger chemical reactions. In a 24% electrolysis cell, the cathode is negatively charged, while the anode is positively charged, according to the principle of electric current flow. The components of an electrolysis cell include a substance that can undergo ionization, electrodes, and a power source (such as a battery). Electric current flows from the negative pole of the battery to the negatively charged cathode. This process causes the solution to ionize, producing cations and anions. The cations will undergo a reduction reaction at the cathode, while the anode will undergo an oxidation reaction [4].

During the electrolysis process, the electrode is supplied with a direct current (DC), causing the compounds in the electrolyte to break down into ions, leading to an oxidation-reduction reaction that produces gas. In this process, oxygen atoms form negatively charged ions (OH-), while hydrogen atoms form positively charged ions (H+). At the positive pole, H+ ions are attracted to the negatively charged cathode, where they attach. Hydrogen atoms then form hydrogen gas in bubbles that rise from the cathode. Similarly, OHions combine at the anode, producing oxygen gas in the form of bubbles [13].

The electrolysis of water involves breaking down water (H2O) into oxygen (O2) and hydrogen gas (H2) by passing an electric current through the water. At the cathode, two water molecules react by capturing two electrons, producing H2 and hydroxide ions (OH^-). Simultaneously, at the anode, two other water molecules decompose into oxygen gas (O2), releasing four H+ ions, while electrons flow to the cathode. The H+ and OHions neutralize to form more water molecules. The overall balanced reaction for water electrolysis can be represented as [22]:

$$2H_2O(l) \longrightarrow 2H_2(g) + O_2(g) \tag{2.6}$$

At the cathode, which receives a negative voltage, two reduction reactions occur. The first reaction involves two moles of electrons ($2e^-$) combining with two moles of hydrogen ions (H^+) to produce one mole of hydrogen gas (H_2), with a standard electrode potential (E°) of 0.00 volts. The second reaction involves two moles of electrons ($2e^-$) reacting with two moles of water ($H_2O(l)$) to form one mole of hydrogen gas (H_2) and one mole of hydroxide ions (OH^-), with a potential of E° = -0.83 volts.

Reactions at the cathode:

$$2H^+(aq) + 2e^- \longrightarrow H_2(g) E^o = 0.00V \tag{2.7}$$

$$2H_2O(l) + 2e^- \longrightarrow H_2(g) + 2OH^-(aq) E^o = -0.83V \tag{2.8}$$

At the anode, which receives a positive voltage, two oxidation reactions occur. In the first, OHions produce oxygen gas (O_2) and water molecules with a potential of E° = +0.40 volts. In the second reaction, water molecules decompose into oxygen gas, releasing 4 H+ ions and electrons, with a potential of E° = +1.23 volts.

Reactions at the anode:

$$4OH^-(aq) \longrightarrow O_2(g) + 2H_2O(l) + 4e^- E^o = +0.40V \tag{2.9}$$

$$2H_2O(l) \longrightarrow O_2(g) + 4H^+ + (aq) + 4e^- E^o = +1.23V \tag{2.10}$$

The negative OHions will combine with basic mineral ions such as Ca2+, Mg2+, Na+, and K+ to form alkaline water. Conversely, acidic ions like Cl-, SO42-, NO3-, CO32-, and others will gather at the positive electrode, joining with Hions to form acidic water. Meanwhile, the remaining H+ and OHions undergo neutralization, resulting in the reformation of some water molecules. The process of forming acidic water and alkaline (kangen) water is illustrated in Figure 2.1 [23]

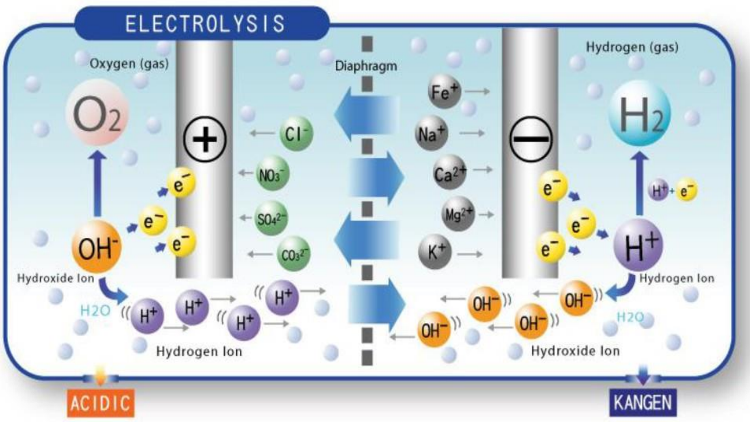


Figure 2. 1 The process of water electrolysis produces oxygen gas and acidic water on the anode side, and hydrogen gas and alkaline water on the cathode side [23]

In this study, there were several types of solutions used, namely NaCl solution, KCl solution, KIO3 solution, NH4Cl solution, and raw water. Therefore, there were differences in the reactions between each solution at the cathode and the anode. The following are the reactions that occurred in each solution.

1. Sodium Chloride (NaCl) Solution
   Initial Dissociation: $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$
   Cathode (-): Reduction
   Reaction:

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

Explanation: Water is preferentially reduced because its standard reduction potential ($E \approx -0.83$ V at pH 7) is significantly less negative than that of sodium ions ($E° = -2.71$ V).

Anode (+): Oxidation
Reactions:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$$
$$Cr(s) \rightarrow Cr^{3+}(aq) + 3e^-$$

Explanation: The applied potential and aggressive chloride ions disrupt the protective passive layer (Cr_2O_3) on the SUS 304 electrode. This exposes the underlying metals, leading to the oxidation of both the primary component, iron, and the more thermodynamically reactive chromium.

Subsequent Reactions

- Formation of Sodium Hydroxide: Highly soluble NaOH is formed in the solution from spectator Na^+ ions and cathodically produced OH^- ions, increasing alkalinity.
- Precipitation of Metal Hydroxides: Metal cations released from the anode migrate to the cathode and precipitate in the high-pH environment.

$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$$
$$Cr^{3+}(aq) + 3OH^-(aq) \rightarrow Cr(OH)_3(s)$$

2. Potassium Chloride (KCl) Solution
   Initial Dissociation: $KCl(s) \rightarrow K^+(aq) + Cl^-(aq)$
   Cathode (-): Reduction
   Reaction:

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

Explanation: The reduction of water ($E \approx -0.83$ V at pH 7) is thermodynamically favored over the reduction of potassium ions ($E° = -2.93$ V).

Anode (+): Oxidation
Reactions:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$$
$$Cr(s) \rightarrow Cr^{3+}(aq) + 3e^-$$

Explanation: The active SUS 304 anode corrodes, as the oxidation of its metallic components is more favorable than the oxidation of chloride ions or water.

Subsequent Reactions

- Formation of Potassium Hydroxide: Spectator K^+ ions and produced OH^- ions form highly soluble KOH.
- Precipitation of Metal Hydroxides: Fe^{2+} and Cr^{3+} ions from the anode precipitate as $Fe(OH)_2(s)$ and $Cr(OH)_3(s)$ at the cathode surface.

3. Potassium Iodate (KIO_3) Solution
   Initial Dissociation: $KIO_3(s) \rightarrow K^+(aq) + IO_3^-(aq)$
   Cathode (-): Reduction
   Reaction:

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

Explanation: Water is the most easily reduced species compared to potassium ions (E° = -2.93 V) and iodate ions.

Anode (+): Oxidation
Reactions:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$$
$$Cr(s) \rightarrow Cr^{3+}(aq) + 3e^-$$

Explanation: The iodate ion (IO_3^-) is a strong oxidizing agent, creating a highly corrosive environment that aggressively attacks the passive layer of the anode, leading to significant oxidation of both iron and chromium.

Subsequent Reactions

- Formation of Potassium Hydroxide: Soluble KOH is formed in the solution.
- Precipitation of Metal Hydroxides: Cations from the dissolving anode form visible deposits of $Fe(OH)_2(s)$ and $Cr(OH)_3(s)$ at the cathode.

4. Ammonium Chloride (NH_4Cl) Solution
   Initial Dissociation: $NH_4Cl(s) \rightarrow NH_4^+(aq) + Cl^-(aq)$
   Cathode (-): Reduction
   Reaction: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

Explanation: The reduction of water is the dominant cathodic pathway over the reduction of the ammonium ion.

Anode (+): Oxidation
Reactions:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$$
$$Cr(s) \rightarrow Cr^{3+}(aq) + 3e^-$$

Explanation: The active anode corrodes as its metallic components are more easily oxidized than the species present in the solution.

Subsequent Reactions

- Formation of Ammonia: OH^- ions produced at the cathode react with NH_4^+ ions to form aqueous ammonia (NH_3).

$$NH_4^+(aq) + OH^-(aq) \rightleftharpoons NH_3(aq) + H_2O(l)$$

- Precipitation of Metal Hydroxides: $Fe(OH)_2(s)$ and $Cr(OH)_3(s)$ precipitate at the cathode.

5. Raw Water

Composition: Contains water (H_2O) and various dissolved mineral ions (e.g., Ca^{2+} , Mg^{2+}).

Cathode (-): Reduction

Reaction:

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

Explanation: Water is the most abundant and easily reducible species in the system.

Anode (+): Oxidation

Reactions:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$$
$$Cr(s) \rightarrow Cr^{3+}(aq) + 3e^-$$

Explanation: In a low-anion environment, the oxidation of the active SUS 304 electrode is the primary anodic process.

Subsequent Reactions

- Precipitation of Mineral Hydroxides: Hydroxide ions react with dissolved mineral ions from the raw water, forming scale.

$$Ca^{2+}(aq) + 2OH^-(aq) \rightarrow Ca(OH)_2(s)$$
$$Mg^{2+}(aq) + 2OH^-(aq) \rightarrow Mg(OH)_2(s)$$

- Precipitation of Anode-Derived Hydroxides: The precipitate also consists of hydroxides from the corroding anode.

$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$$
$$Cr^{3+}(aq) + 3OH^-(aq) \rightarrow Cr(OH)_3(s)$$

To calculate the efficiency value of the electrolysis process, we can use the following equation [24]:

$$\eta_e = \frac{Q \cdot E}{Voper \cdot Ioper} \qquad 2.11$$

Where:

ηe: Electrolyzer efficiency (%)

Q: Hydrogen production rate, ml/sec

E: Calorific value of Hydrogen, J/ml

Voper: Operating voltage (V)

Ioper: Operating current (A)

2.4 Alkaline and Acid Water

Alkali is derived from Arabic, referring to alkali ion salts or alkaline substances that contain alkali or alkaline earth metals. The alkali and alkaline earth metals commonly found in the Earth's crust include sodium, potassium, magnesium, and calcium, with respective mass abundance percentages of 2.5 %, 2.0 %, 2.4 %, and 4.2 % [25]. These elements easily react with others and are found in nature in mineral compounds such as NaCl, KCl, KNO3, CaCO3, KCl, MgCl2, 6H2O, MgSO4, 7H2O, and others. Water containing these compounds is called mineral water, which can be converted into acidic and alkaline water using electrolysis technology. An acid is a molecular entity or chemical species that can donate protons or form covalent bonds with an electron pair. Acidic water produced from the oxidation of mineral water during electrolysis is also referred to as Super-Oxidized Water (SOW). SOW is generated through redox reactions during electrolysis. It contains a mixture of oxidizing compounds, primarily HOCl, with a pH of 5.0–6.5 and an ORP value greater than 950 mV. SOW can act as a new antiseptic or disinfectant capable of killing microorganisms within minutes of exposure [26]. The acidic water produced from oxidation, known as" super-oxidized water," can be used to inhibit the growth of viruses, fungi, and harmful bacteria in wounds. Super-oxidized water is created by breaking down sodium chloride through a semi-permeable membrane, followed by electrolysis to generate oxychlorine ions [27].

2.5 Solar Cell Module (SCM)

Solar Cell Module is an electronic device consisting of several solar cells with direct current (DC) output. Several things affect the output of solar cell modules such as SCM tilt angle, light intensity, and temperature [28], [29]. Further explanations related to SCM such as solar cells, SCM output, and others will be explained in the next subsection.

2.5.1 Solar Cell

Solar energy is a limitless and inexhaustible energy source, which can be used as an alternative energy by converting it into electricity through solar cells. A solar cell is a device that transforms sunlight into electrical energy via the photovoltaic effect, which is why it is also referred to as a photovoltaic cell (PV cell). To determine the performance of a solar cell, an efficiency equation is used [22].

2.5.2 Output SCM

Witono et.al has conducted a study of the solar cell module's (SCM) ability to absorb solar energy in Malang, Indonesia. This study, measured and compared 2 types of SCM, namely SCM with polycrystalline material (100 wp) and SCM with amorphous material (88 wp). Figure 2.2 [29] shows the measurement results of SCM output (Watt) with polycrystalline and amorphous materials. It can be seen that the ideal time for maximum SCM power output is from 11:00 to 13:00. In addition, the comparison of the output produced by polycrystalline SCMs is greater than the output produced by amorphous SCM. This is due to the different material efficiency values and output specifications of the SCM. However, the biggest influence is the different material types that make the output very different. The polycrystalline material has an efficiency of 15% to 20% while the amorphous material is only about 7%. Based on this comparison, the SCM with polycrystalline material was chosen as the type of SCM to be used in this study. Equation 2.7 can be used to calculate the efficiency value of SCM [29].

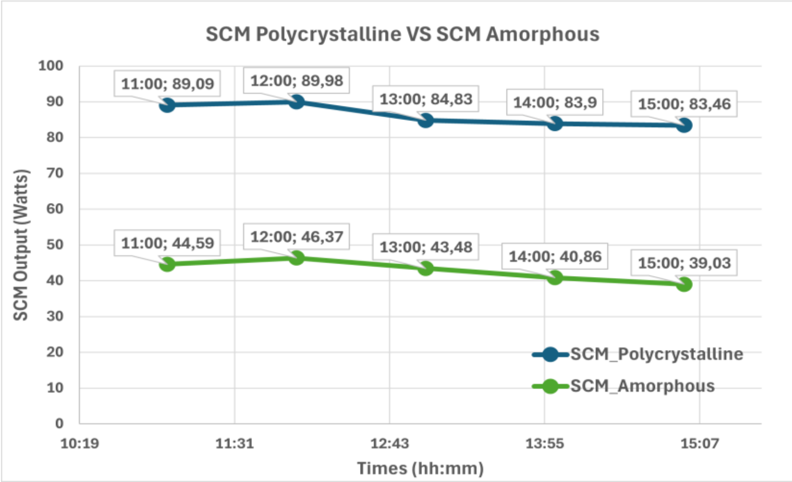


Figure 2. 2 Graph of SCM Polycrystalline VS SCM Armophous [29]

$$\eta_{SCM} = \left(\frac{P}{GXA}\right) x\ 100\% \qquad (2.12)$$

Where:

ηSCM: Efficiency of solar cell module (%) P: Cell Power (Watt)

G: Solar Intensity (W/m2)

A: SCM Area

The power efficiency of a solar panel is influenced by changes in the orientation angle, light intensity, and surface temperature. Based on the data, the percentage of influence from the orientation angle is 88.3%, light intensity is 96.3%, and surface temperature is 94.9% [29].

2.5.3 Performance Characteristics and Analysis of PV-Electrolysis Systems

The evaluation of a photovoltaic (PV)-powered electrolysis system's performance must extend beyond the nominal power rating of the PV module (20 Wp), as such ratings are defined under standard test conditions (STC) and fail to represent the actual operational output under real environmental conditions, which vary dynamically with solar irradiance and cell temperature [30]. Therefore, a valid analysis requires a methodology to first determine the actual power available from the PV module and then to evaluate how effectively the electrolyzer utilizes that available power.

A. PV Module Performance Characteristics

The instantaneous operating performance of a PV module can be represented by its current–voltage (I–V) and power–voltage (P–V) characteristics [31]. Figure 2.3 shows the current-voltage (I–V) and power-voltage (P–V) characteristics. The peak of the P–V curve corresponds to the Maximum Power Point (Pmpp), which defines the maximum deliverable power under specific environmental conditions and serves as the system's actual input power (Pin).

A key parameter in assessing the quality and ideality of a PV module's I–V curve is the Fill Factor (FF), defined as the ratio of the maximum output power to the product of open-circuit voltage (Voc) and short-circuit current (Isc) [32]:

$$FF = \frac{Vmpp\ x\ Impp}{Voc\ x\ Isc} \quad (2.13)$$

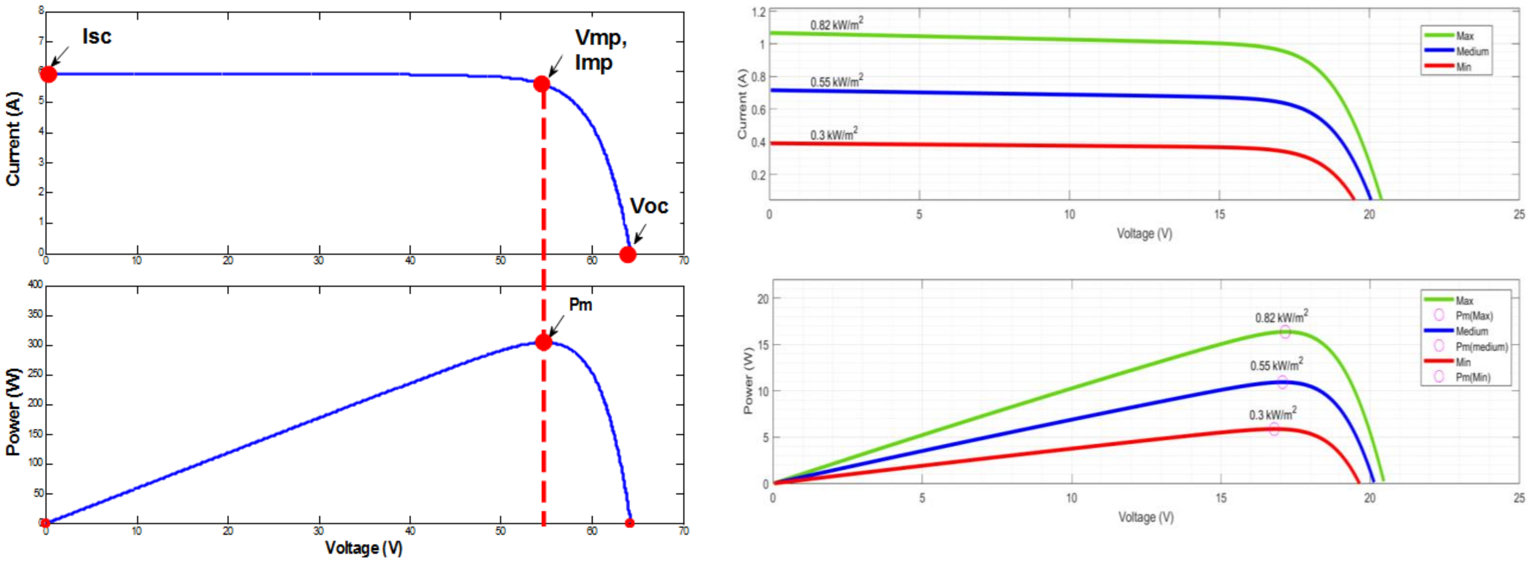


Figure 2. 3 Characteristics of PV Module current-voltage (I–V) and power-voltage (P–V)

B. Mathematical Modeling for Actual Performance Prediction

When direct measurement of Pmpp using an I–V curve tracer is not feasible, mathematical modeling is employed. For crystalline silicon PV modules, the most widely accepted method is the Single-Diode Model [33], which represents the PV cell as an equivalent electrical circuit. The model's key input, the photocurrent (Iph), links the simulation to measured environmental parameters and is computed as follows [33]:

$$Iph = Iscref + Ki\ (T - Tref)) \times \frac{G}{Gref} \quad (2.14)$$

The calculated Iph is then substituted into the complete Single-Diode Model equation, which accounts for diode behavior and parasitic resistances:

$$I = Iph - I0\ [e^{q\,(V+I\_Rs)/nKT} - 1] - \frac{(V+I_{Rs})}{Rsh} \quad (2.15)$$

Solving (2.15) over a range of voltages yields the full I–V and P–V characteristics, enabling accurate determination of the Actual Maximum Power Point (Pmpp) for the measured environmental conditions [33].

C. System Evaluation Metric: Power Utilization Index (PUI)

After obtaining Pmppactual, system performance can be assessed using the Power Utilization Index (PUI), introduced by Yahyaoui et al. [34]. PUI quantifies the load matching efficiency between the PV module and the electrolyzer, and is expressed as:

$$\text{PUI} = \frac{Pactual}{Pmpp} \times 100\% \qquad (2.16)$$

A high PUI value signifies efficient power transfer and optimal matching of the electrolyzer's operating point to the PV module's MPP, while a low value reflects substantial mismatch losses. This metric enables direct performance comparison under varying operational scenarios, such as the application of different electrolyte solutions [34].

Description:		Unit:
FF	(Fill Factor, a quality parameter of a solar cell)	(0 - 1)
Vmpp	(Voltage at Maximum Power Point)	Volt (V)
Impp	(Current at Maximum Power Point)	Ampere (A)
Voc	(Open-Circuit Voltage)	Volt (V)
Isc	(Short-Circuit Current)	Ampere (A)
I	(Output current from the solar cell to the load)	Ampere (A)
V	(Output voltage at the solar cell terminals)	Volt (V)
G	(Actual solar irradiance measured in the field)	W/m^2
Gref	(Reference irradiance at Standard Test Conditions (STC))	1000 W/m^2
Iscref	(Short-circuit current under STC (from datasheet))	Ampere (A)
Ki	(Temperature coefficient for current (from datasheet))	A/K or A/°C
T	(Actual absolute temperature of the solar cell)	Kelvin (K)
Tref	(Reference temperature under STC)	25 °C or 298.15 K
Iph	(Photogenerated current (current produced by light))	Ampere (A)
I0	(Diode reverse saturation current)	Ampere (A)
q	(Elementary charge of an electron (1.602×10^{-19} C))	Coulomb (C)
Rs	(Series resistance)	Ohm (Ω)
Rsh	(Shunt resistance)	Ohm (Ω)
n	(Diode ideality factor)	Dimensionless
k	(Boltzmann constant (1.381×10^{-23} J/K))	Joule/Kelvin
PUI	(Power Utilization Indeks)	Percent (%)
Pactual	(Average Actual power consumed by the electrolyzer)	Watt (W)
Pmpp	(Actual maximum power available from the solar panel)	Watt (W)

2.5.4 SCM implementation for electrolysis system

One experiment involving a water electrolysis system using a solar cell module (SCM) was conducted at the Desert Energy Research Center laboratory (Cairo, Egypt) for hydrogen production purposes [24]. Figure 2.3 shows the water electrolysis system consisting of an 8 Wp SCM and measuring instruments. The water electrolysis process using the SCM was operated for one day in the summer (September 26, 2016), from 08:00 AM to 03:00 PM. The electrolyzer, or electrolysis device, consists of a plexiglass box measuring 15x5x20 cm^3, as shown in the Figure. The box is divided into two equal chambers to separate the hydrogen gas from the oxygen gas produced. Graphite and stainless steel (316L) were used as electrodes, with a diameter of 6 mm and varying heights from 25 mm to 40 mm. Both electrodes were submerged in the electrolyte and mounted to the chamber surfaceusing rubber stoppers. However, this study still has limitations as it does not include an MPPT component (for maximum power) and a battery (for resistance to current fluctuations from the SCM).

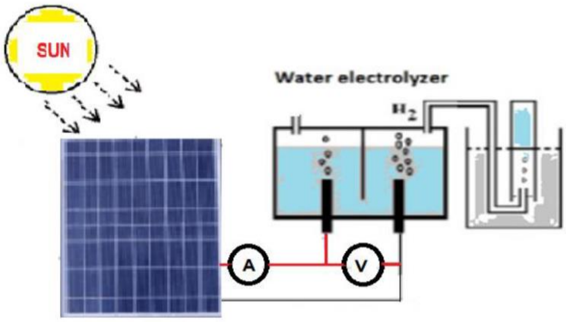


Figure 2. 4 Water Electrolyzer Using SCM [24]

2.6 Statistical Analysis

This section explains the statistical analysis methods used in this study to obtain statistical analysis results that prove the hypothesis. This section is divided into three tests, namely the normality test, homogeneity test, and parametric test, in this case, ANOVA.

2.6.1 Normality Test

The normality test is a fundamental prerequisite in statistical analysis, particularly for parametric tests such as ANOVA. This test evaluates whether the data distribution within each group approximates a normal distribution. Among the most widely used methods is the Shapiro-Wilk test, which is especially suitable for small sample sizes ($n < 50$). According to Isnawan [35], the Shapiro-Wilk test calculates a W statistic that assesses the degree of deviation from a normal distribution.

Shapiro-Wilk Formula:

$$W = (\sum a_i \cdot x_{(i)})^2 / \sum (x_i - \bar{x})^2 \qquad (2.13)$$

Where:

- $x_{(i)}$: the i-th ordered value (order statistic)
- a_i: constants derived from the covariance matrix of a standard normal distribution.
- $\bar{x}$: sample mean

2.6.2 Homogeneity of Variance Test

The homogeneity of variance test is used to verify whether the variances across different groups are equal. This assumption is vital for parametric comparisons involving multiple groups. One commonly applied method is Levene's Test, which tests the null hypothesis that group variances are homogeneous. As noted by Isnawan [35] and Pamungkas [36], Levene's test evaluates deviations of each observation from its group median.

Levene's Test Formula:

$$W = [(N - k) / (k - 1)] \times [\sum N_i (Z_{i\cdot} - Z_{\cdot\cdot})^2 / \sum\sum (Z_{ij} - Z_{i\cdot})^2] \qquad (2.14)$$

Where:

- $Z_{ij} = |Y_{ij} - \hat{Y}_i|$: absolute deviation from the group median
- k: number of groups
- N: total number of observations

2.6.3 One-Way Analysis of Variance (ANOVA)

ANOVA is a statistical method used to test for significant differences between the means of three or more independent groups. It is particularly suitable when analyzing one dependent variable against one independent variable with three or more categories. According to Isnawan [35] and Sihombing [37], the core principle of ANOVA is comparing between-group variance with within-group variance.

F-Statistic Formula:

$$F = \frac{MSBetween}{MSWithin} = (\frac{SSBetween}{dfBetween}) / \frac{SSWithin}{dfWithin} \quad (2.15)$$

Where:
- SS: Sum of Squares
- df: degrees of freedom
- MS: Mean Squares

2.7 Relevant Studies

Table 2.1 shows previous studies related to the use of acidic water and alkaline water and the development of electrolyzer devices, both those that use renewable energy sources and those that do not. The following are the results of a literature review that will be used to identify gaps in previous studies and fill those gaps.

Table 2. 1 Relevant Studies

No.	Author(s)	Title	Contribution Summary	Limitations & Research Gap
1	A. Hasibuan et al. (2020)	Electrolysis-based Water Purification	Developed a water purification system using solar-powered electrolysis. Demonstrated reduced TDS and pH control.	Limited to clean water applications; no integration with agriculture or varied electrolyte types. Gap: Did not explore use of acidic/alkaline water for soil conditioning.
2	A. Rahmawati (2021)	Electrolyzer Development Using Solar Cell	Designed a solar-powered electrolyzer with improved portability and voltage efficiency.	Focused on electrical aspects only. Gap: No discussion on water quality or agricultural use.
3	S. W. Utomo (2022)	Utilization of NaCl Electrolyte for Alkaline Water	Produced alkaline water using NaCl solution with pH up	Limited to household use; non-renewable energy.

			to 8.9.	Gap: No integration with solar, no soil application.
4	M. Widiyanto (2021)	Electrolyzed Water for Hydroponics	Used alkaline water for lettuce growth in hydroponics. Positive results in root health.	No solar energy used; focused on hydroponic system only. Gap: No field application or acidic water study.
5	E. Yuliana et al. (2020)	Application of Electrolysis for Irrigation	Investigated alkaline water for irrigation with slight crop improvement.	Weak pH control; no long-term analysis. Gap: No study on acidic water, or electrolysis from variable electrolytes.
6	B. Nugraha (2022)	Smart Electrolysis System with IoT	Developed a smart system to monitor voltage and current in electrolysis using Android-based tools.	System-focused; no water quality or agricultural testing. Gap: No application on soil or plants.
7	Y. Prasetyo (2020)	Effect of Voltage on Electrolysis Output	Showed how voltage affects the pH and TDS of produced water.	Used only tap water; no use-case in agriculture. Gap: No renewable energy source; limited water types.
8	I. M. Ayu (2022)	NaCl-based Electrolyzed Water for Soil Treatment	Demonstrated pH control of soil with NaCl electrolyzed water.	No solar integration; limited scale. Gap: No exploration of other electrolytes; acidic water not considered.
9	E. Kurniawan et al. (2020)	Electrolysis and Galvani Cell for Power Storage	Studied electrolysis with seawater for electric power using solar panels.	Not focused on water reuse; only electricity generation. Gap: No application

				to agriculture or fertilizer replacement.
10	R. A. Putri et al. (2023)	Electric Current Controller for Portable Ionizer	Developed automatic control system for alkaline water generation with safety features.	Household use only; no integration with renewable sources. Gap: No connection to agriculture.
11	E. Kurniawan et al. (2018)	Alkaline & Acidic Water via Solar Electrolysis	Produced high-pH and low-pH water using solar cells and mineral water.	Cost and material availability issues. Gap: No follow-up study on soil or crop response.
12	A. Jaiswal et al. (2023)	Design of Water Ionizer	Designed a water ionizer combining RO and electrolysis, focusing on human health.	No agricultural relevance; energy-intensive. Gap: No solar use, no soil analysis.
13	L. Rizki et al. (2021)	Household Alkaline Water Device	Demonstrated household alkaline water production device with good pH output.	Inaccurate pH tools; limited to RO water. Gap: No agricultural application; no acidic water.
14	T. LeBaron et al. (2022)	Electrolyzed–Reduced Water for Health	Reviewed biological safety and effectiveness of electrolyzed water.	Human-health focused; lacking environmental application. Gap: No agriculture, no system integration.
15	C. Guno & C. Agaton (2022)	Solar Irrigation System Study	Socioeconomic and environmental review of solar irrigation in agriculture.	No focus on water chemistry or electrolysis. Gap: No exploration of alkaline/acidic water integration.

CHAPTER III
SYSTEM MODEL

3.1. System Proposed Model

This subchapter describes the system model used in this thesis research. The system to be used in this thesis is an electrolyzer or commonly called PWI (Portable Water Ionizer). Figure 3.1 shows the block diagram of the system model of the production of alkaline and acid water by electrolysis method using Solar Cell Modules (SCM). Start from user insert the water in several types into the system and the system get input power from SCM, until the system produces alkaline and acidic water both on cathode and anode sides. For more details regarding each part of system proposed model, it will be explained in the next section.

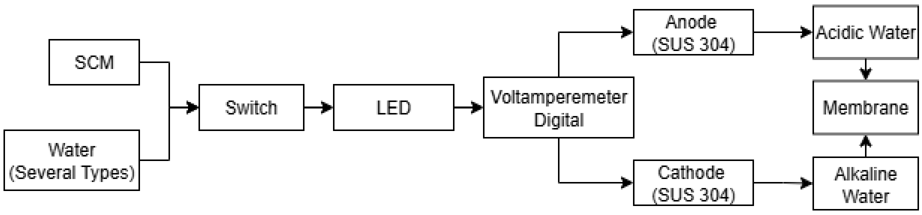


Figure 3. 1 System model of production alkaline and acid water by Electrolysis Method Using Solar Cell Modules

Table 3. 1 Component Specification of System

Component Name	Amount	Spesification	Price/Pcs (IDR) from e-commerce
Baut SUS 304	2 Pcs	M8 x 160 mm	15.000 – 30.000
Solar Cell Module (SCM)	1 Pcs	Polycrystalline (20 wp)	200.000 – 300.000
Container Cathode (plastic)	1 Pcs	Plexiglass (15x5x20 cm)	20.000 – 50.000
Container anode (bottle)	1 Pcs	1,5 L	16.500
DPDT Toogle Switch	1 Pcs	6 pin	5.000 – 15.000
Board (perfboard)	1 Pcs	4x6 cm	2.000 – 5.000
Cable Jumper	1 Pcs	Female to female (15cm)	7.900
Cable Jumper	1 Pcs	Male to male (15cm)	13.500
Cable	3 meters	1x1,5mm	3.000 – 6.000
LED	2 Pcs	Clear RGB 5mm Auto Disco	1.000 – 3.000
Voltamperemeter Digital	1 Pcs	30VDC 10A	25.000 – 50.000

3.1.1. Input System

Based on Figure 3.1, the system's electrical power supply will come entirely from the Solar Cell Module (SCM), which functions as the main and independent energy source for the electrolysis setup. For the water supply, it is divided into two streams. The first stream for system performance measurement will use raw tap water and is categorized into five different types of solutions: raw water (without added salts), and four electrolyte solutions made by dissolving approximately ±20 grams of NaCl, KCl, KIO3, or NH4Cl in 1 liter of pure water. The second stream uses the same types of solutions and salt mass but with a water volume of 7.5 L to produce water that will be sprayed onto the soil and plants. Conditioning the solutions by mixing several types of salts with water results in different solution concentrations for each solution.

The solution concentrations (1 liter water) for NaCl, KCl, KIO3, and NH4Cl solutions are as follows:

1. NaCl Solution (Sodium Chloride)
   - Molar Mass (Mr) of NaCl = 23 + 35.45 = 58.45 g/mol
   - Moles = Mass / Mr = 20 g / 58.45 g/mol = 0.342 mol
   - Molarity = Moles / Volume (L) = 0.342 mol / 1 L = 0.342 M

2. KCl Solution (Potassium Chloride)
   - Molar Mass (Mr) of KCl = 39.10 + 35.45 = 74.55 g/mol
   - Moles = Mass / Mr = 20 g / 74.55 g/mol = 0.268 mol
   - Molarity = Moles / Volume (L) = 0.268 mol / 1 L = 0.268 M

3. KIO_3 Solution (Potassium Iodate)
   - Molar Mass (Mr) of KIO_3 = 39.10 + 126.90 + (3 * 16.00) = 214.00 g/mol
   - Moles = Mass / Mr = 20 g / 214.00 g/mol = 0.093 mol
   - Molarity = Moles / Volume (L) = 0.093 mol / 1 L = 0.093 M

4. NH_4Cl Solution (Ammonium Chloride)
   - Molar Mass (Mr) of NH_4Cl = 14.01 + (4 * 1.01) + 35.45 = 53.50 g/mol
   - Moles = Mass / Mr = 20 g / 53.50 g/mol = 0.374 mol
   - Molarity = Moles / Volume (L) = 0.374 mol / 1 L = 0.374 M

5. Percentage Concentration Salt to Solution (%) (Applicable to all salt solutions)

This method calculates concentration by comparing the mass of the salt to the total mass of the solution (salt + water). This requires assuming the density of water is 1 g/mL.

- Mass of Salt: 20 g
- Mass of Water: Given a volume of 1 L (1.000 mL) and assuming a density of 1 g/mL, the mass is 1.000 g.
- Total Solution Mass: Mass of Salt + Mass of Water = 20g + 1.000g = 1.020g

% = (Mass of Solute / Total Solution Mass) x 100%
% = (20 g / 1.020 g) x 100% = 0.0196 x 100% = 1.96 %
Therefore, the concentration for all prepared salt solutions is 1.96 %.

The selection of these salts is based on their affordability and availability, aligning with the practical needs of agricultural applications. These solutions play a key role in enhancing electrical conductivity by increasing ion concentration, thus improving the efficiency of electrolysis. The system also incorporates a 1:4 water ratio between the anode and cathode containers and utilizes a gauze membrane as a separator to facilitate ion exchange during operation.

3.1.2. Electrolysis Process

In a 24% electrolysis cell, the cathode holds a negative charge, while the anode is positively charged, based on the direction of electric current flow. The essential components of an electrolysis cell include a substance that can ionize, electrodes, and a power source (such as a battery). Electric current flows from the battery's negative terminal to the negatively charged cathode. This current causes the solution to ionize, producing cations and anions. At the cathode, cations undergo reduction, while the anode facilitates oxidation reactions [4].

During electrolysis, direct current (DC) is applied to the electrodes, causing the electrolyte's compounds to dissociate into ions, leading to redox reactions and the production of gas. In this reaction, oxygen atoms form negatively charged ions (OH-), and hydrogen atoms become positively charged ions (H+). At the negative pole, H+ ions are drawn to the cathode, where they combine to form hydrogen gas, which emerges as bubbles at the cathode. Similarly, OHions combine at the anode, producing oxygen gas in bubble form [13].

The electrolysis of water splits water (H2O) into oxygen (O2) and hydrogen gas (H2) as an electric current pass through it. At the cathode, two water molecules accept two electrons, forming H2 and hydroxide ions (OH-). Concurrently, at the anode, two other water molecules split into oxygen gas (O2), release four H+ ions, and send electrons to the cathode. The H+ and OHions combine, creating more water molecules. The overall balanced reaction for water (H_2O) electrolysis can be represented as Equation 2.6.

3.1.3. Output System

The input to the system uses resources from SCM sources, have output which is alkaline water and acidic water. Alkaline water will be produced on the cathode (-) side and acidic water will be produced on the anode (+) side. Actually, in addition to producing alkaline water and acidic water, the system also produces hydrogen gas that will propagate on the membrane used. However, there are no additional components in the system to accommodate the hydrogen gas. Thus, this output system will be used for agriculture, namely as a substitute for maintaining soil into optimal conditions by the research focus.

3.2. Flowchart System

Figure 3.2 shows the flowchart of the system used in this study. It can be seen that the system starts with the user entering water in several conditions (with a mixture of electrolyte solution or without electrolyte solution) according to the desired condition by the user. Then, the system is also given a power input that comes from SCM. Then, the user sets the switch from the PWI, for example, if the user sets the switch direction to the left then the left electrode will become the anode (+) and the right electrode becomes the cathode (-), and vice versa. Then after setting the electrode, the electrolysis process will take place which will produce alkaline and acid-electrolyzed water as the output that will be needed to be applied to agriculture.

Then, as a protection measure or to increase the service life of the PWI system, the electrode protection process is added. This is because the electrode used is not a pure inert electrode (SUS 304) which on the positive electrode (anode) will experience an oxidation reaction and over time will experience corrosion. To overcome this can be done by changing the electrodes used to inert electrodes that can resist corrosion and do not affect the electrolysis reaction process. However, the cost of using inert electrodes is expensive so innovation is needed to maintain the durability of the electrodes used. Therefore, innovation is needed in the electrode protection process. This electrode protection can be done by changing the polarity of the system (adjusting the switch to the opposite direction) which will cause the cathode which initially thickened due to the metal deposits from the electrolysis reaction to undergo oxidation and corrosion so that it returns to its original form. Meanwhile, the anode, which initially experienced oxidation and corrosion, will experience thickening by changing the polarity of the system. By using this flowchart, it is expected that the system can produce alkaline and acid-electrolyzed water as the output that will be needed to be applied to agriculture and increase the lifetime of the system.

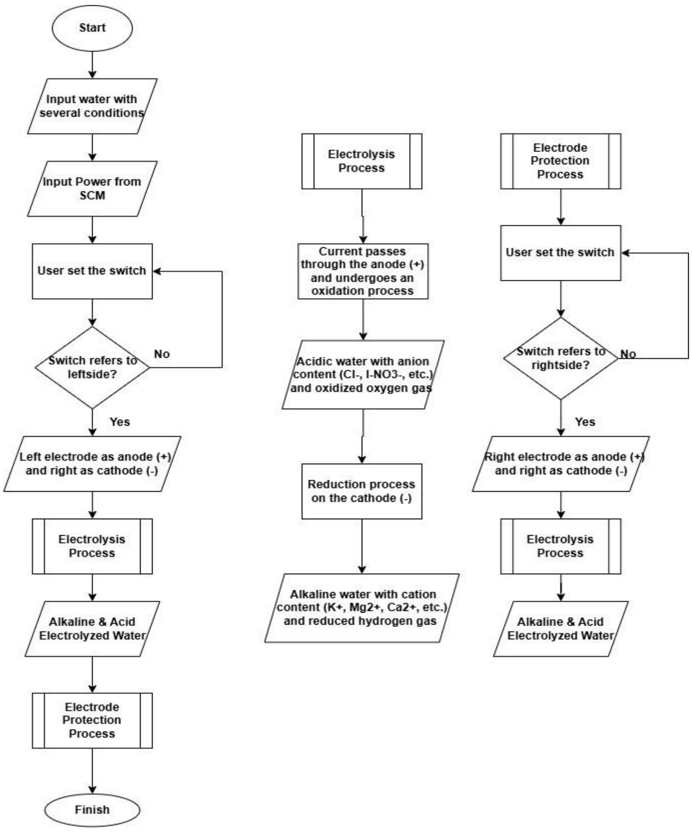


Figure 3. 2 Flowchart System Production of Acidic and Alkaline Water Through Water Ionization by Electrolysis Method Using SCM Source

3.3. Scenario Proposed Model

This section outlines the scenarios that will be employed in this study. This study will be divided into three scenarios, namely preparation, data collection, and analysis. Detailed explanations of each scenario will be provided in the following sections.

3.3.1 Preparation Scenario

Figure 3.3 illustrates the scenario of the preparation process, which begins with the construction of a PWI system that will serve as a tool for producing electrolyzed water, which will then be utilized in agriculture. This includes preparing the growing medium, planting, and placing samples to facilitate measurements and analysis of the growth of each plant (water spinach, red spinach, and green spinach) under various irrigation conditions (P1 = Acidic; P2 = Neutral (without electrolysis process); P3 = Alkaline).

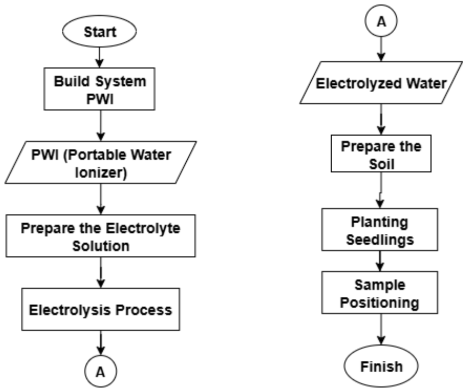


Figure 3. 3 Preparation Scenario Flow

3.3.2 Data Collection Scenario

Figure 3.4 shows the scenario of the measurement/data collection process in this study. It begins with the collection of energy parameter data (voltage and current) from the PWI system, followed by the collection of plant parameter data (plant height, leaf length, and sum of leaves). The duration of measurement for each parameter varies. For energy parameters, measurements were taken over 5 days from 10:00 AM to 3:00 PM to determine the daily energy used during the optimal output period of the SCM. For electrolyzed water parameters, measurements were also taken over 5 days, with 5 measurements for each condition (P1 = Acidic; P2 = Neutral (without electrolysis process); P3 = Alkaline). Soil measurements were conducted over 30 days with a 2-day interval. Finally, plant parameter measurements were conducted over 40 days with a 2-day interval.

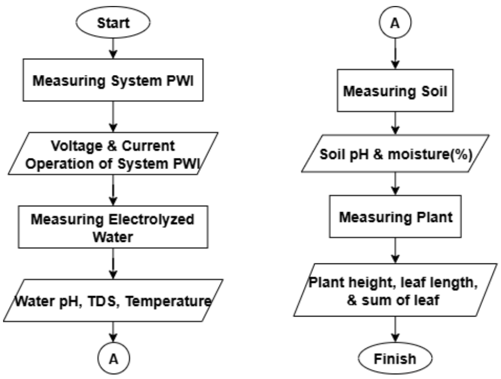


Figure 3. 4 Data Collection Scenario Flow

3.3.3 Analysis Scenario

Figure 3.5 shows the scenario of the analysis process in this study. It begins with obtaining data based on the results of data collection, then preparing and processing the data. If the data is valid, the next step is to visualize the data, which will then be analyzed. To enhance the validity of the analysis, statistical analysis is added, particularly focusing on energy parameters, with the aim of addressing the question of whether there is an effect of solution type on the measured energy parameters (voltage, current, and energy). This statistical analysis consists of two stages: conducting assumption tests, which include two steps (normality test and homogeneity test), and parametric or non-parametric tests (depending on the results of the assumption tests). Based on this process, conclusions will be drawn from the analysis results to address the research objectives.

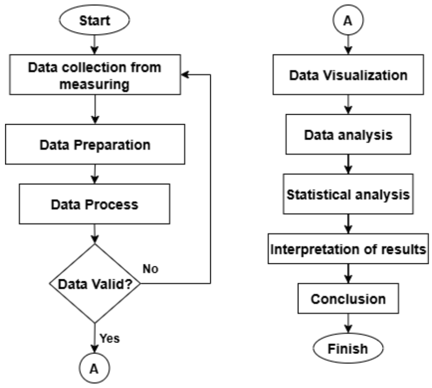


Figure 3. 5 Analysis Scenario Flow

3.4. Performance Parameter

To conduct an analysis related to the production of alkaline water and acidic water in the system and test the effectiveness and efficiency of utilizing the system output in agriculture, it is necessary to measure several parameters. These parameters range from parameters in the input and output water of the system to parameters in plants and growing media. The following parameters are measured as performance parameters in the study:

3.4.1 PH (Potential (Hydrogen)

Acidity refers to the level of acidity and basicity of a solution, commonly known as pH (hydrogen potential). pH is a measure of acidity that indicates how acidic or basic a solution is. The pH scale ranges from 1 to 14, with a value of 7 being neutral; solutions with a pH below 7 are acidic, while those above 7 are basic or alkaline. Acids and bases are widely used in material processing, both in industrial sectors and in everyday life. In the chemical industry, acidity is a key factor in raw material processing, determining the quality of production outputs, and in waste management to prevent environmental pollution. In agriculture, understanding acidity levels is essential for soil management. pH measurement is based on the principle of electrochemical potential between the solution inside the glass electrode (glass membrane) and the solution outside the electrode. This enables a thin layer of glass to interact with hydrogen ions, which are small and highly reactive. The glass electrode measures the electrochemical potential of hydrogen ions, while a reference electrode is used to balance the electrical circuit. This device does not measure current, but only voltage [38]. Figure 6 show the PH (Potential Hydrogen) measurement using "PH meter digital" by Meditech.

Figure 3. 6 PH Meter by Mediatech

3.4.2 TDS (Total Dissolved Solid)

Total dissolved solids (TDS) refer to the measure of inorganic salts and small quantities of organic substances dissolved in water. The main components typically include cations like calcium, magnesium, sodium, and potassium, along with anions such as carbonate, bicarbonate, chloride, sulfate, and nitrate [39]. The concentration of ionized TDS in a liquid affects the liquid's electrical conductivity. The higher the concentration of ionized TDS in water, the greater the solution's electrical conductivity. Meanwhile, TDS concentration is also influenced by temperature [40]. The greater the conductivity value indicates the more minerals contained in the water. The correlation between TDS and conductivity is expressed in the following equation [41]:

$$TDS = EC \tag{3.1}$$

Where:
Total Dissolved Solid (TDS): part per million (ppm)
Electrical Conductivity (EC): (μS/cm)

Figure 3.7 show the TDS measurements using the "TDS Meter" by Meditech. The results of the measurements will then be analyzed to see changes in the value of TDS in water at the input and output of the system both on the anode side and the cathode side.

Figure 3. 7 TDS Meter by Mediatech

3.4.3 Soil Moisture (%)

Soil moisture represents the water volume held in soil pores above the groundwater level and is essential for supporting plant physiological activities such as germination, root respiration, and microbial metabolism. This parameter is highly dynamic, influenced by evapotranspiration, rainfall infiltration, and mulching practices, which directly affect crop performance. Studies have shown that mulching significantly improves soil moisture retention by reducing evaporation and promoting stable water distribution in the root zone [42], [43]. Such findings are aligned with the need to maintain optimal soil moisture levels, especially for moisture-sensitive crops like chili, which typically require 60–70% field capacity [3]. Figure 3.8 shows soil moisture variations across different media, measured using a 3-Way Soil Meter, highlighting the importance of substrate selection for water retention in sustainable cropping systems.

Figure 3. 8 Soil Measurement using ”3 Way Soil Meter”

3.4.4 Electrical Power (Watt)

In the International System (SI), the unit of electrical power is Watt, which is defined as the change in energy per unit time through voltage and current. The amount of power in watts absorbed by a load at any time is equal to the product of the voltage (volts) at the load and the current (amperes) flowing through it. Electrical power is divided into three types: active power, reactive power, and real power [44]. Here the equation used in this study to get electrical power of system:

$$P = V \times I \quad (3.2)$$

Where:

P : Power (Watt);

V : Voltage (Volt);

I : Current (Ampere);

In this study, because the power source used is SCM which has DC current, it is assumed that all the power available is real power. This is because DC power sources do not have a phase angle or voltage and current are in the same phase. So, the calculation formula that will be used is equation 3.2.

3.5. Statistical Analysis

The final step in this study was to perform statistical tests on the measurement data obtained, in this case voltage, current, and energy measurements from the system. This was done to determine whether there was a significant effect between the types of solution and the three parameters using the one-way ANOVA (Analysis of Variance) method. The following are the statistical analysis steps performed:

3.5.1 Normality Test

This test evaluates whether the data distribution within each group approximates a normal distribution. The steps for testing normality are as follows:
1. Conduct the Shapiro-Wilk test on each group's data.
2. If p-value > 0.05, the data can be considered normally distributed [35].

3.5.2 Homogeneity Test

The homogeneity of variance test is used to verify whether the variances across different groups are equal. The steps for the homogeneity test are as follows:
1. Calculate the absolute deviations for each observation from its group median.
2. If the p-value > 0.05, the data satisfies the assumption of homogeneity [35], [36].
3. If the p-value is less than 0.05, then proceed with a non-parametric test.

3.5.3 One-Way ANOVA (Analysis of Variance) Test

ANOVA is a statistical method used to test for significant differences between the means of three or more independent groups. The steps for the One-Way ANOVA test are as follows:
1. Compute group and overall means.
2. Calculate SS and derive MS for both between and within groups.
3. Calculate the F-value and compare it with the critical value or p-value.
4. If $p < 0.05$, it indicates a statistically significant difference among groups [35], [36].

CHAPTER IV
RESULTS AND ANALYSIS

4.1 System Testing Design

Figure. 4.1 shows the implementation of system testing scheme. The system will be given a power input from the positive SCM which will then enter the PWI through the electrode. This electrode will precisely enter through the anode as the positive pole, and flow through the cathode as the negative pole and back to the negative source. Then, the system input voltage and current were measured using a DC Voltamperemeter and validated using a digital multimeter measuring instrument. Voltage is measured by stringing in parallel between the measuring instrument and the positive source and positive PWI, while the current is measured by stringing in series the measuring instrument with the negative source and negative PWI. The measurement results of this system will then be included in the energy & system efficiency analysis section.

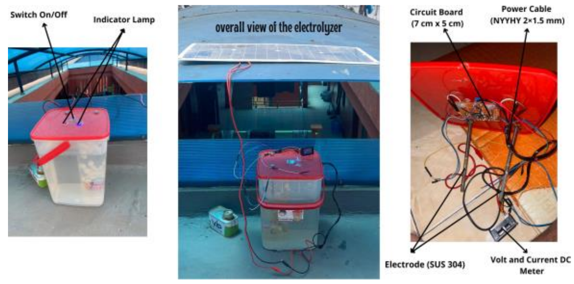


Figure 4. 1 Overall View of The System Testing Scheme

4.2 Power Utilization Measurement

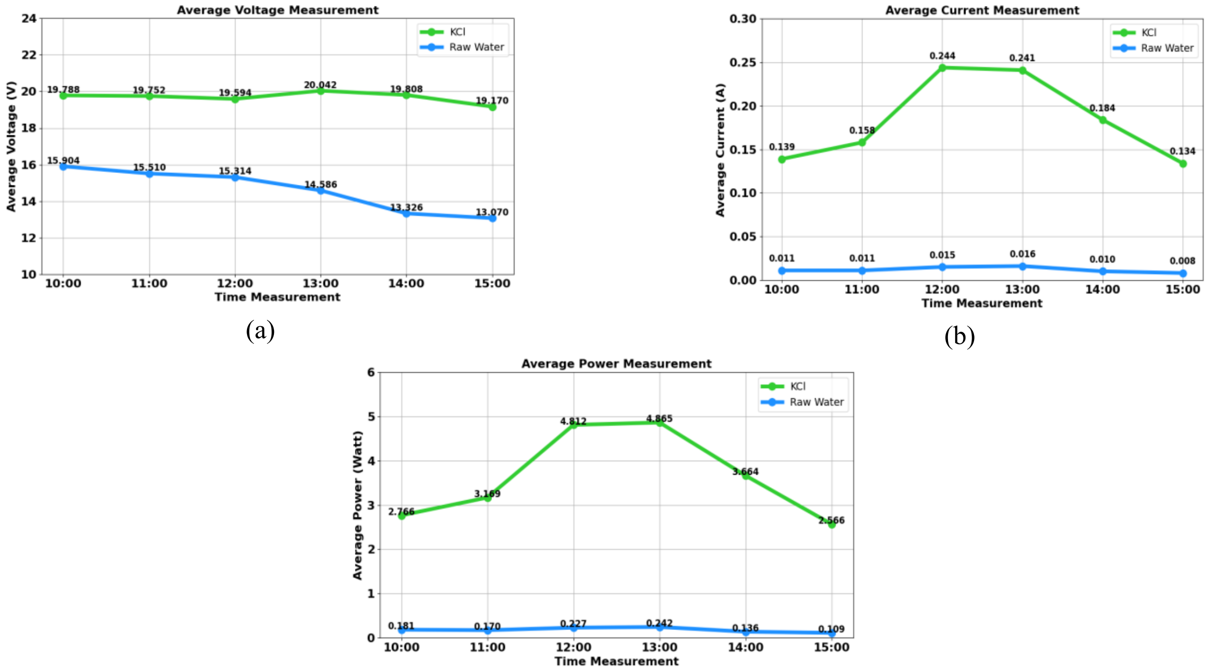
Figure 4.2 shows the system measurements during electrolysis using either an electrolyte solution, such as KCl, or no electrolyte (raw water). The results show that the current measured in the system with electrolyte solution produces a larger current than without electrolyte, as well as a larger power measurement. Strong electrolytes such as NaCl and KCl increase solar electrolysis efficiency by improving ion transport, reducing internal resistance, and minimizing voltage losses [37]-[39]. Trinh et al. [40] and Cheng et al. [41] further confirmed that conductivity governs performance in solar-assisted systems. The poor results of the raw water are in agreement with the findings by Kissaoui et al. [42], who highlighted low conductivity as a limiting factor in sustainable electrolysis applications. These results reinforce the value of high-conductivity electrolytes in maximizing solar-powered energy conversion. For more detail about the result of system measurement, can be seen on the appendix.

Based on the calculation of Power Utilization Index (PUI), it is found that the PUI of KCl system results in 18.20% which is much greater than the PUI of raw water system, which is 0.90%. So, it can be concluded that the system will be much more effective when electrolyzing using an electrolyte solution such as KCl compared to no electrolyte solution (raw water).

Power Utilization Index (PUI):

PUI (KCl) **= (Pactual / Pmpp) × 100%**
= (3.64 W / 10.51 W) × 100%
= 34.63 %

PUI (Raw Water) **= (Pactual / Pmpp) × 100%**
= (0.18 W / 10.51 W) × 100%
= 1.71 %



(a) (b) (c)

Figure 4. 2 System Measurement Result (With Load (PWI)) of With and Without Electroliyte Solutions: (a)Voltage; (b) Current; (c) Power

4.3 Electrolysis Hydrogen (H_2) Production

Based on equations 2.1, 2.2, and 2.4, the amount of hydrogen gas can be calculated for each type of solution. The analysis and calculation related to the amount of hydrogen gas formed while the system is working for each type of solution are attached below.

4.3.1 Calculating the molar gas volume

Assumed Conditions: The study was conducted from 10:00 to 15:00 WIB, so the following room conditions can be assumed:

- Temperature (T): 30°C (equivalent to 30 + 273.15 = 303.15 K)
- Pressure (P): 1 atm (standard atmospheric pressure near sea level)

Based on equation 2.1 and these assumptions, the molar volume of gas for all types of solutions is as follows:

$$Vm = \frac{RT}{P} = \frac{0.08206 \times 303.15}{1} \approx 24.88 \text{ L/mol}$$

4.3.2 Hydrogen (H_2) Production (maximum)

1. Hydrogen (H_2) Production for NaCl Solution

Based on table A.2, the following is the amount of hydrogen gas formed when the system works for NaCl solution is as follows:
Current (I): 0,233 A (daily current maximum)
Time (t): 5 hours = 18.000 s
Total Electric Charge (Q): Q = I × t = 0,233 A × 18.000 s = 4.194 C
Mol Elektron (n_{e^-}): n_{e^-} = Q / F = 4.194 / 96.485 = 0,0435 mol

The ratio of e^- and mol H_2 (n H_2) is 2:1, based on the reaction at the cathode $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Thus, we obtain:
nH_2 = mol electrons / 2 = 0.0435 / 2 = 0.0217

VH_2 = moles of H_2 × Molar Gas Volume
VH_2 = 0.0217 mol × 24.88 L/mol (temperature 30°C and 1 atm)
VH_2 = 0.539 liters of H_2

2. Hydrogen (H_2) Production for KCl Solution

Based on table A.2, the following is the amount of hydrogen gas formed when the system works for KCl solution is as follows:
Current (I): 0,224 A (daily current maximum)
Time (t): 5 hours = 18.000 s
Total Electric Charge (Q): Q = I × t = 0,224 A × 18.000 s = 4.032 C
Mol Elektron (n_{e^-}): n_{e^-} = Q / F = 4.032 / 96.485 = 0,0418 mol

The ratio of e^- and mol H_2 (n H_2) is 2:1, based on the reaction at the cathode $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Thus, we obtain:
nH_2 = mol electrons / 2 = 0.0418 / 2 = 0.0209

VH_2 = moles of H_2 × Molar Gas Volume
VH_2 = 0.0209 moles × 24.88 L/mol (temperature 30°C and 1 atm)
VH_2 = 0.519 liters of H_2

3. Hydrogen (H_2) Production for KIO_3 Solution

Based on table A.2, the following is the amount of hydrogen gas formed when the system works for KIO_3 solution is as follows:
Current (I): 0,208 A (daily current maximum)
Time (t): 5 hours = 18.000 s
Total Electric Charge (Q): $Q = I \times t$ = 0,208 A × 18.000 s = 3.744 C
Mol Elektron (n_{e^-}): $n_{e^-} = Q / F$ = 3.744 / 96.485 = 0,0388 mol

The ratio of e^- and mol H_2 (n H_2) is 2:1, based on the reaction at the cathode $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Thus, we obtain:
nH_2 = mol electrons / 2 = 0.0388 / 2 = 0.0194

VH_2 = moles of H_2 × Molar Gas Volume
VH_2 = 0.0194 moles × 24.88 L/mol (temperature 30°C and 1 atm)
VH_2 = 0.483 liters of H_2

4. Hydrogen (H_2) Production for NH_4Cl Solution

Based on table A.2, the following is the amount of hydrogen gas formed when the system works for NH_4Cl solution is as follows:
Current (I): 0,216 A (daily current maximum)
Time (t): 5 hours = 18.000 s
Total Electric Charge (Q): $Q = I \times t$ = 0,216 A × 18.000 s = 3.888 C
Mol Elektron (n_{e^-}): $n_{e^-} = Q / F$ = 3.888 / 96.485 = 0,0403 mol

The ratio of e^- and mol H_2 (n H_2) is 2:1, based on the reaction at the cathode $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Thus, we obtain:
nH_2 = mol electrons / 2 = 0.0403 / 2 = 0.0202

VH_2 = moles of H_2 × Molar Gas Volume
VH_2 = 0.0202 moles × 24.88 L/mol (temperature 30°C and 1 atm)
VH_2 = 0.502 liters of H_2

5. Hydrogen (H_2) Production for Raw Water Solution

Based on table A.2, the following is the amount of hydrogen gas formed when the system works for Raw Water solution is as follows:
Current (I): 0,014 A (daily current maximum)
Time (t): 5 hours = 18.000 s

Total Electric Charge (Q): $Q = I \times t = 0{,}014\ A \times 18.000\ s = 252\ C$
Mol Elektron (n_{e^-}): $n_{e^-} = Q / F = 252\ / 96.485 = 0{,}0026$ mol

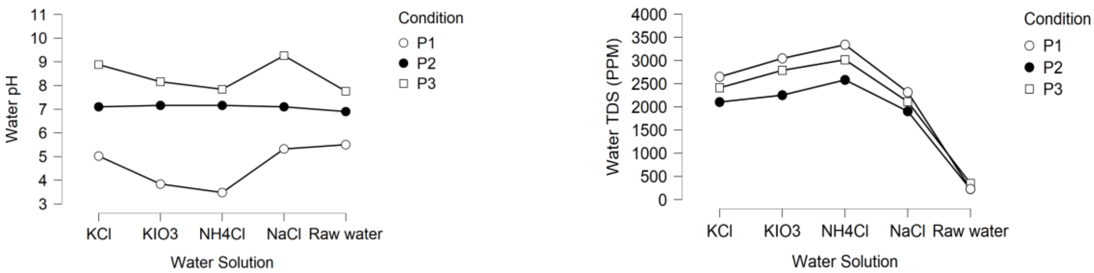
The ratio of e^- and mol H_2 (n H_2) is 2:1, based on the reaction at the cathode $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Thus, we obtain:
nH_2 = mol electrons / 2 = 0.0026 / 2 = 0.0013

VH_2 = moles of H_2 × Molar Gas Volume
VH_2 = 0.0013 moles × 24.88 L/mol (temperature 30°C and 1 atm)
VH_2 = 0.032 liters of H_2

Based on these calculations, it can be seen that each type of solution produces different amounts of hydrogen gas. Therefore, it can be concluded that solutions with strong electrolyte mixtures, such as NaCl and KCl, will produce more hydrogen gas than solutions without electrolyte mixtures, such as raw water. This indicates that the level of ionic conductivity in the solution affects the rate of hydrogen gas production during the electrolysis process. However, there are other factors besides the type of solution, one of which is the concentration of the solution.

4.4 Water Measurement

Figure 4.3 reveals that the pH and TDS behaviors of five electrolytic solutions across electrochemical zones show consistent trends, with NaCl reaching the highest alkalinity under cathodic conditions (pH 9.26) and NH_4Cl exhibiting the strongest acidification under anodic conditions (pH 3.48), in line with Madeira's findings on ion mobility and electrostatic interactions [45]. Neutral pH stabilization for NaCl and KCl (~7.0–7.2) under P2 supports the ionic strength plateau effect described by Urtnasan and Wang, where high ion concentrations limit further pH shift [46]. The TDS increase observed in both P1 and P3 also aligns with Kucernak et al., who documented ionic release due to electrochemical stress [47]. These patterns suggest that alkaline-treated waters like NaCl under P3 may be beneficial for soil pH correction, while NH_4^+-based treatments require caution due to excessive acidification potential.

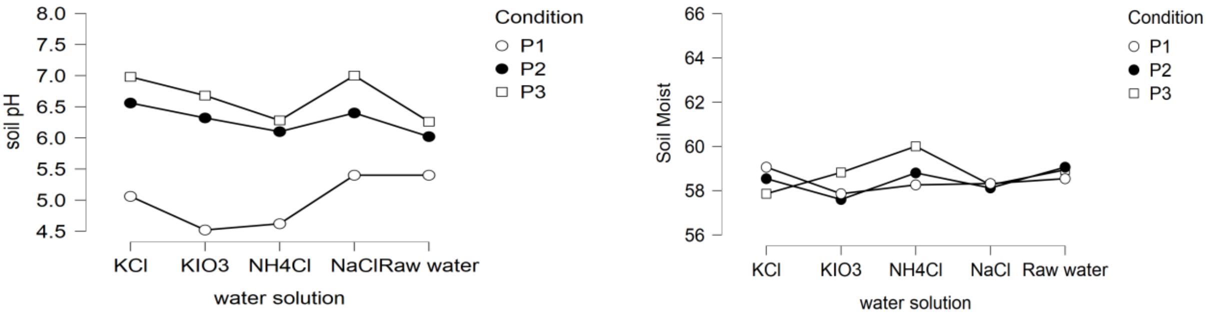


(a) (b)

Figure 4. 3 Water Measurement result (a) pH; (b) TDS (ppm)

4.5 Soil Measurement

Figure 4.4 demonstrates that soil pH stabilized according to irrigation type over 30 days: P1 remained acidic (≤5.5), P2 moderately suitable (6.0–6.6), and P3 reached optimal levels (6.3–7.0). These outcomes corroborate findings from Singh et al. who demonstrated that alkaline or partially neutralized irrigation water gradually raises acidic soil pH into a crop-favorable range (pH 6.5–7.5) during long-term application across diverse soil profiles [48]. Furthermore, Minhas et al. affirmed that alkalinity-induced pH adjustment is linearly related to irrigation pH and shows resilience against seasonal fluctuations when amendments (e.g., gypsum) are employed [49]. Despite varying water chemistries (acidic, alkaline, electrolytic), all treatments maintained consistent soil moisture content (58%–60%), primarily governed by irrigation timing and volume rather than solution composition. This pattern aligns with the findings of Sheoran et al. who reported moisture retention within 55%–60% across alkali irrigation trials when frequency and evapotranspiration were controlled [50]. Therefore, based on these soil measurements, it has been proven that water with a high pH can help balance soil pH, which is beneficial for plants, especially those using acidic growing media such as organic soil. However, the conditioning of soil, particularly acidic organic soil, still needs to be adjusted further to the optimal pH and moisture range for each plant to be grown.



(a) (b)

Figure 4. 4 Soil Measurement result (a) pH ; (b) Moisture(%)

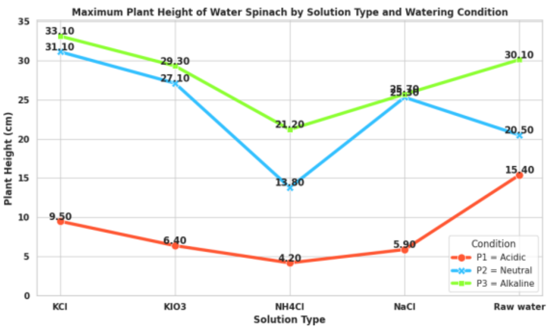
4.6 Plant Measurement

The plant measurements were conducted repeatedly over 40 days, from February 12, 2025, to March 22, 2025. The plant was devided into three way of watering such as P1 = Acidic water (Anode), P2 = Neutral (without electrolysis), and P3 = Alkaline water (Cathode). As a result, measurement data were obtained for each plant under each condition and for each type of solution, with 20 measurements taken (plant measurements were conducted every two days). The total number of data points obtained is 300, as attached in the appendix. The plant measurements were divided into three processes: preparation, measurement, and documentation of results. All plant measurement data and research documentation can be viewed in the appendix. For further details regarding the analysis of the measured plant results (water spinach, red spinach, and green spinach), please refer to the subsequent section.

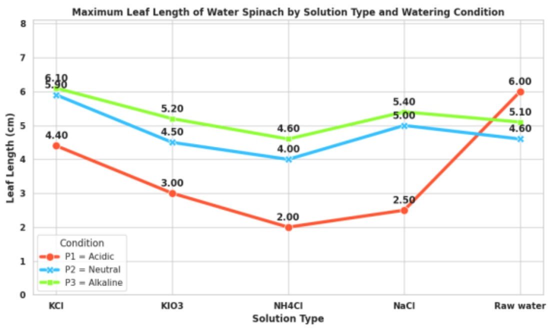
4.6.1 Water Spinach Measurement

Figure. 4.5 and 4.6 present the maximum observed values for water spinach growth under various treatments, showing that potassium chloride (KCl) under alkaline conditions (P3) resulted in the most optimal growth, with a maximum plant height of 33.1 cm, leaf length of 6.1 cm, and 12 leaves. This effect suggests that potassium supports plant tissue formation and stimulates chlorophyll synthesis and water transport in plants [51]. In comparison, raw water and KIO_3 under alkaline conditions (P3) also yielded competitive results, with raw water reaching 30.1 cm in height and KIO_3 supporting up to 11 leaves. This indicates the potential of both treatments as effective options in nutrient-supplemented or base-neutral irrigation regimes. Conversely, treatment with NH_4Cl (ammonium chloride) resulted in the lowest growth, with plant height of 5.415 cm, leaf length of 1.638 cm, and number of leaves of 3.567. The negative effects of NH_4Cl use are supported by the findings of Whangchai et al. (2014), who showed that high concentrations of ammonium ions (NH_4^+) can reduce root and leaf growth and cause nutrient imbalance in aquatic plants like water spinach [52]. These findings are reinforced by the study of Fan et al. (2024), who observed that in a controlled environment, the application of ammonium-based fertilizers had a detrimental effect on chlorophyll content and the nitrogen-to-potassium ratio (N: K) in spinach and water spinach plants, particularly under high humidity conditions [10].

From a statistical distribution perspective, plant height in KCl treatments exhibited high variability (SD = 10.29) and a moderate right-skewed distribution (skewness = 0.61), reflecting heterogeneous responses among plants. This trend was similarly observed in leaf length (SD = 2.04; skewness = –0.03) and number of leaves (SD = 3.58; skewness = 0.23). In contrast, NH_4Cl treatments showed lower SD in height (5.99) and higher skewness in leaf traits (leaf count skewness = 0.38), implying more constrained and less favorable growth. Raw water also displayed favorable skewness values (–0.07 for leaf length), indicating more symmetric distribution and reliable growth. These findings suggest that neutral KCl irrigation enhances growth with some biological variability, while raw water remains a consistent and economical option. However, the use of NH_4Cl and NaCl should be avoided due to their limiting effects on plant morphology and potential disruption of nutrient uptake [10], [52].



(a)



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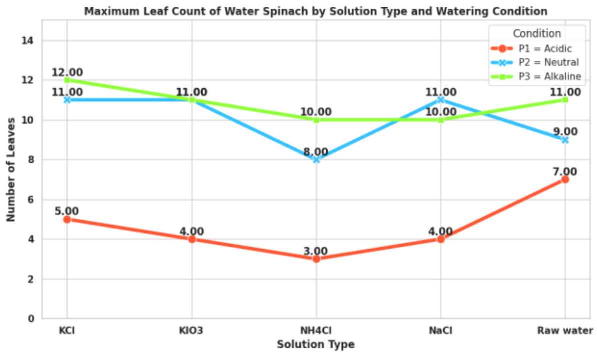


(c)

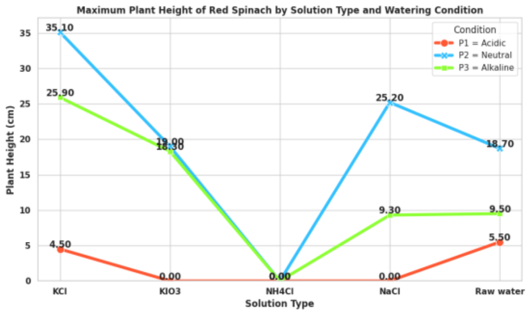
Figure 4. 5 Water Spinach Measurement Result: (a) Plant Height; (b) Leaf Length; (c) Sum of Leaf

Figure 4. 6 Photo of the tallest water spinach plant (KCL P3) vs. the shortest (Raw water P2)

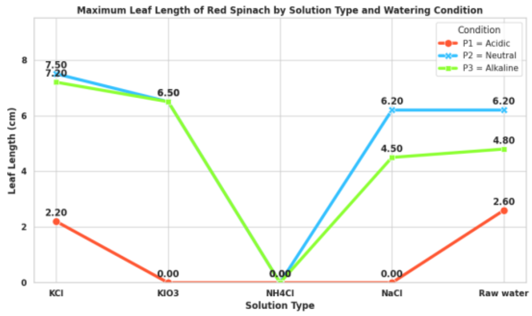
4.6.2 Red Spinach Measurement

Figure 4.7 and 4.8 shows the result of red spinach that exhibited the highest growth under potassium chloride (KCl) treatment at neutral pH conditions (P2), reaching a maximum plant height of 35.1 cm, leaf length of 7.5 cm, and 14 leaves. This finding is consistent with those of Rambe et al. who demonstrated that potassium plays a crucial role in cell expansion and photosynthetic efficiency, particularly at neutral soil pH, which optimizes potassium availability [7]. Notably, the distribution of the growth data for KCl treatment shows high variability (SD = 8.49) and a moderate right-skew (skewness = 1.48), indicating heterogeneous responses among the plant population, potentially due to genotypic variation in potassium uptake efficiency [8]. Raw water treatment under P2 also demonstrated promising results with 18.7 cm in height and 10 leaves, alongside relatively lower variation (SD = 4.79, skewness = 1.29), supporting its feasibility as a low-cost irrigation alternative.

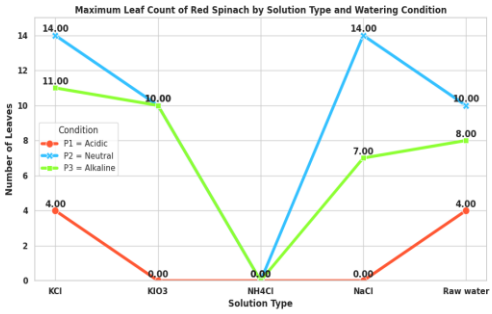
Meanwhile, treatments with NH_4Cl and KIO_3 did not yield significant growth, with zero values observed across all growth parameters. This effect is likely due to ammonium toxicity, which inhibits root development and photosynthetic activity, as well as the inefficiency of iodate in acidic environments, as reported by Fan et al. and Akamine et al. [10][9]. Sodium chloride (NaCl) was similarly ineffective in acidic environments but provided some growth under neutral and alkaline conditions, with a maximum height of 25.2 cm at P2. However, NaCl-treated plants showed higher skewness (1.83) and variability (SD = 5.68), reflecting stress-induced growth inconsistencies. These findings suggest that KCl at neutral pH remains the most effective treatment, while NH_4Cl and KIO_3 are unsuitable for red amaranth cultivation due to their phytotoxic effects. In the absence of KCl, raw water under neutral conditions may serve as a reliable and sustainable substitute.



(a)



(b)



(c)

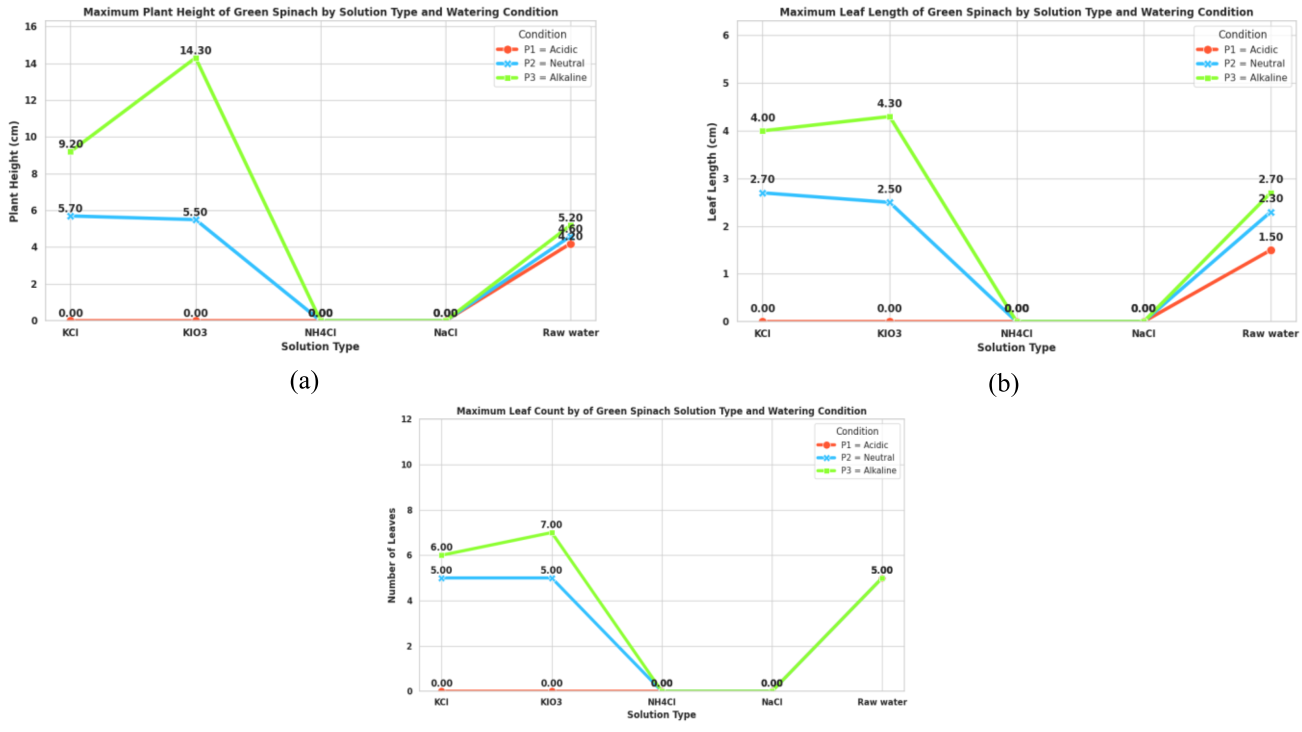
Figure 4. 7 Red Spinach Measurement Result: (a) Plant Height; (b) Leaf Length; (c) Sum of Leaf

Figure 4. 8 Photo of the tallest water spinach plant (KCl P2) vs. the shortest (KIO3 P3)

4.6.3 Green Spinach Measurement

Figure 4.9 and 4.10 shows the experimental results indicate that treatment with potassium iodate (KIO_3) under alkaline conditions (P3) led to the most favorable growth of green spinach plants, achieving maximum plant height of 14.3 cm, leaf length of 4.3 cm, and leaf count of 7, exceeding all other treatments. The enhanced growth is likely associated with the physiological role of iodate ions (IO_3^-), which are known to influence plant hormonal regulation particularly auxin activity under basic pH environments. Smoleń et al. [53] demonstrated that iodate supplementation can improve nutrient uptake, chlorophyll concentration, and overall plant development, especially when applied in neutral to alkaline soils. In addition, iodate has been linked to improved nitrogen transport efficiency and cellular osmotic balance. The data from KIO_3-treated green spinach also showed high variability (SD = 3.84 for height) and a right-skewed distribution (skewness = 1.39), indicating individual differences in iodine uptake or response to treatment. The positive impact of KIO_3 under alkaline conditions is attributed to its chemical stability at high pH, preventing reduction to less bioactive iodide forms and enhancing auxin-related cell elongation pathways [53], [54].

In contrast, treatments involving NaCl and NH_4Cl showed no measurable growth (height = 0 cm; SD = 0) across all watering conditions, likely due to the toxic effects of Na^+ and NH_4^+ ions on plant physiology. This observation is supported by Fan et al. [10], who reported that ammonium-based treatments resulted in decreased chlorophyll content, protein synthesis, and biomass accumulation in leafy vegetables. Meanwhile, KCl and raw water showed moderate growth results, with KCl under alkaline conditions (P3) reaching 9.2 cm in height and raw water under P3 producing the highest leaf count among non-iodate treatments (6 leaves). The consistent leaf production and near-symmetric distribution of raw water (skewness = –0.07) suggest that it remains a stable and low-cost alternative. Thus, combining KIO_3 with alkaline irrigation (P3) is recommended as the optimal agronomic strategy for cultivating green spinach, whereas NH_4Cl and NaCl should be avoided due to their toxic effects. If KIO_3 is not available, raw water remains a viable low-cost alternative under neutral pH conditions, albeit with reduced efficacy.



(a)

(b)

(c)

Figure 4. 9 Green Spinach Measurement Result: (a) Plant Height; (b) Leaf Length; (c) Sum of Leaf

Figure 4. 10 Photo of the tallest Green Spinach plant (KIO3 P3) vs. the shortest (KCl P3)

4.7 Statistical Analysis

The analysis was conducted using JASP software. Total data that gain by measuring the system are 30 data for each type of solution and each parameter for a total of 450 data. Then, the data was organized into average current, voltage, and energy for each day to reduce bias so that there were 5 data for each type of solution and eachn parameter for a total of 75 data. The data was then analyzed with univariate ANOVA for each dependent variable. To determine how the type of solution affects the parameters of current (A), voltage (V), and energy (Wh). Shapiro-Wilk and Levene tests were performed to verify assumptions. Although homogeneity violations were found, the ANOVA results can still be interpreted but a non-parametric test, Kruskal-Wallis, was also conducted as a comparison to ensure the validity of the results. For more details, there is an explanation below.

4.7.1 Effect of solution type on voltage

The effect of solution type on voltage will be explained in detail in the next section. It consists of the results of assumption tests (normality test and homogeneity test) and ANOVA test using the JASP application, which is then analyzed to obtain conclusions on whether the solution type as an independent variable has a significant effect on the dependent variable, in this case, the voltage parameter in the system used.

A. Normality Test

Hypothesis: H0 = Data is normally distributed; H1 = Data is not normally distributed.

Table 4. 1 Descriptive Statistic of Voltage Parameter

Descriptive Statistics

	Average Voltage (V)				
	KCl	**KIO3**	**NH4Cl**	**NaCl**	**Raw water**
Total Data	30	30	30	30	30
Data Valid	5	5	5	5	5
Missing	0	0	0	0	0
Mean	19.692	19.450	19.556	19.796	14.618

Descriptive Statistics

	Average Voltage (V)				
	KCl	KIO3	NH4Cl	NaCl	Raw water
Std. Deviation	1.022	1.026	1.016	1.008	0.354
Shapiro-Wilk	0.873	0.879	0.876	0.897	0.895
P-value of Shapiro-Wilk	0.278	0.306	0.291	0.392	0.382

Based on the normality test steps in chapter 3, to check whether the data is normally distributed or not, focus on the p-value of Shapiro Wilk where if the p-value> 0.05, then the data is normally distributed and can proceed to the next assumption test. Table 4.1 shows that the p-value of Shapiro wilk > 0.05 for all types of solutions. This means H0 can be accepted so that it is concluded that the data is normally distributed, and can proceed to the next test.

B. Homogenity Test

Hypothesis: H0 = Data is homogeneous; H1 = Data is not homogeneous.

Table 4. 2 Assumptions Checks of Voltage Parameter

Test for Equality of Variances (Levene's)

F	df1	df2	p
3.301	4.000	20.000	0.031

Based on the homogeneity test steps in Chapter 3, to check whether the data is homogeneous or not is to test the assumptions using the assumption checks feature in JASP which uses the Levene method. Based on Table 4.2, the p-value <0.05 is obtained, where if the p-value <0.05, then the H0 hypothesis cannot be accepted so it is concluded that the data is not homogeneous, and if it is continued in the next test. Then it must use the Non-parametric test method in this case the Kruskal Wallis Test and cannot use parametric tests such as One Way ANOVA.

C. Non-parametric Test (Kruskal Wallis Test)

Hypothesis: H0 = Solution type has a significant effect on Voltage; H1 = Solution type has no significant effect on Voltage.

Table 4. 3 Non-Parametric Test of Voltage Parameter

Kruskal-Wallis Test

Factor	Statistic	df	p
Type of Solution	12.847	4	0.012

Based on the significance test steps in Chapter 3, to check whether H0 is acceptable or not is to focus on the p-value of the non-parametric test, in this case, the Kruskal-Wallis Test method. If the p-value <0.05, it can be concluded that H0 is acceptable or the independent variable affects the dependent variable. Table 4.3 shows that the p-value of the Kruskal Wallis test <0.05 for the type of solution. So, H0 can be accepted (type of solution has a significant effect on the voltage).

4.7.2 Effect of solution type on current

The effect of solution type on current will be explained in detail in the next section. It consists of the results of assumption tests (normality test and homogeneity test) and ANOVA test using the JASP application, which is then analyzed to obtain conclusions on whether the solution type as an independent variable has a significant effect on the dependent variable, in this case, the current parameter in the system used.

A. Normality Test

Hypothesis: H0 = Data is normally distributed; H1 = Data is not normally distributed.

Table 4. 4 Descriptive Statistic of Current Parameter

Descriptive Statistics

	Average Current (A)				
	KCl	**KIO3**	**NH4Cl**	**NaCl**	**Raw water**
Total Data	30	30	30	30	30
Data Valid	5	5	5	5	5
Missing	0	0	0	0	0
Mean	0.182	0.166	0.174	0.190	0.012
Std. Deviation	0.033	0.036	0.036	0.032	0.002
Shapiro-Wilk	0.905	0.955	0.927	0.922	0.863
P-value of Shapiro-Wilk	0.437	0.775	0.573	0.543	0.238

Based on the normality test steps in chapter 3, to check whether the data is normally distributed or not is to focus on the p-value of Shapiro Wilk where if the p-value> 0.05, the data is normally distributed and can proceed to the next assumption test. Table 4.4 shows that the p-value of Shapiro wilk > 0.05 for all types of solutions. This means that H0 can be accepted so that it is concluded that the data is normally distributed, and can proceed to the next test.

B. Homogenity Test

Hypothesis: H0 = Data is homogeneous; H1 = Data is not homogeneous.

Table 4. 5 Assumptions Checks of Current Parameter

Test for Equality of Variances (Levene's)

F	df1	df2	p
1.062	4.000	20.000	0.401

Based on the homogeneity test steps in Chapter 3, to check whether the data is homogeneous or not, is to test the assumptions using the assumption checks feature in JASP which uses the Levene method. Based on table 4.5, the p-value> 0.05 is obtained, then the H0 hypothesis can be accepted so it is concluded that the data is homogeneous and can continue the parametric test in this case using One Way ANOVA.

C. Parametric Test (One Way ANOVA)

Hypothesis: H0 = Solution type has a significant effect on Current; H1 = Solution type has no significant effect on Current.

Table 4. 6 Parametric Test of Current Parameter

ANOVA - Current (A)

Cases	Sum of Squares	df	Mean Square	F	p
Type of Solution	0.112	4	0.028	29.602	< .001
Residuals	0.019	20	9.466e -4		

Note. Type III Sum of Squares

Based on the significance test steps in Chapter 3, to check whether H0 is acceptable or not is to focus on the p-value points of the parametric test, in this case, the One Way ANOVA method. If the p-value <0.05, it can be concluded that H0 is acceptable or the independent variable affects the dependent variable. Table 4.6 shows that the p-value of One Way ANOVA < 0.05 for the type of solution. This means H0 can be accepted so it can be concluded that the type of solution has a significant effect on the current.

4.7.3 Effect of solution type on Energy

The effect of solution type on energy will be explained in detail in the next section. It consists of the results of assumption tests (normality test and homogeneity test) and ANOVA test using the JASP application, which is then analyzed to obtain conclusions on whether the solution type as an independent variable has a significant effect on the dependent variable, in this case, the energy parameter in the system used.

A. Normality Test

Hypothesis: H0 = Data is normally distributed; H1 = Data is not normally distributed.

Table 4. 7 Descriptive Statistic of Energy Parameter

Descriptive Statistics

	Average Energy (Wh)				
	KCl	**KIO3**	**NH4Cl**	**NaCl**	**Raw water**
Total Data	30	30	30	30	30
Data Valid	5	5	5	5	5
Missing	0	0	0	0	0
Mean	18.204	16.278	17.160	19.084	0.172
Std. Deviation	3.948	4.159	3.920	4.007	0.027
Shapiro-Wilk	0.977	0.963	0.980	0.967	0.870
P-value of Shapiro-Wilk	0.920	0.827	0.937	0.858	0.267

Based on the normality test steps in chapter 3, to check whether the data is normally distributed or not is to focus on the p-value of Shapiro Wilk where if the p-value> 0.05, the data is normally distributed and can proceed to the next assumption test. Table 4.7 shows that the p-value of Shapiro wilk > 0.05 for all types of solutions. This means that H0 can be accepted so that it is concluded that the data is normally distributed, and can proceed to the next test.

B. Homogenity Test

Hipotesis: H0 = Data homogen; H1 = Data tidak homogen.

Table 4. 8 Assumptions Checks of Energy Parameter

Test for Equality of Variances (Levene's)

F	df1	df2	p
1.479	4.000	20.000	0.246

Based on the homogeneity test steps in Chapter 3, to check whether the data is homogeneous or not, is to test the assumptions using the assumption checks feature in JASP which uses the Levene method. Based on table 4.5, the p-value> 0.05 is obtained, then the H0 hypothesis can be accepted so it is concluded that the data is homogeneous and can continue the parametric test in this case using One Way ANOVA.

C. Parametric Test (One Way ANOVA)

Hypothesis: H0 = Solution type has a significant effect on stress; H1 = Solution type has no significant effect on stress.

Table 4. 9 Parametric Test of Energy Parameter

ANOVA - Energy (Wh)

Cases	Sum of Squares	df	Mean Square	F	p
Type of Solution	1248.683	4	312.171	24.272	< .001
Residuals	257.226	20	12.861		

Note. Type III Sum of Squares

Based on the significance test steps in Chapter 3, to check whether H0 is acceptable or not is to focus on the p-value points of the parametric test, in this case, the One Way ANOVA method. If the p-value <0.05, it can be concluded that H0 is acceptable or the independent variable affects the dependent variable. Table 4.9 shows that the p-value of One Way ANOVA < 0.05 for the type of solution. This means H0 can be accepted so it can be concluded that the type of solution has a significant effect on the energy.

CHAPTER V
CONCLUSION

5. 1 Conclusion

Based on the results of the experiment and data analysis, the following conclusions can be drawn from the study:

1. **The system will be much more effective to utilize the power when electrolyzing using an electrolyte solution such as KCl compared to no electrolyte solution (raw water).** The results show that the current measured in the system with electrolyte solution produces a larger current than without electrolyte, as well as a larger power measurement. Based on the calculation of Power Utilization Index (PUI), it is found that the PUI of KCl system results in 34.63 % which is much greater than the PUI of raw water system, which is 1.71%.
2. **Hydrogen (H_2) Production varies depending on the concentration and type of solution.** NaCl and KCl achieved the highest Hydrogen (H_2) Production (0.539 L & 0.519 L) due to its conductivity and concentration. Meanwhile, raw water obtained the lowest hydrogen (H2) production (0.032 L). **This indicates solutions with strong electrolyte mixtures, such as NaCl and KCl, will produce more hydrogen gas than solutions without electrolyte mixtures, such as raw water.**
3. **Electrolysis process significantly affects pH and TDS water values, which in turn influence soil responses**. Under alkaline conditions (P3), NaCl produces the highest pH (9.26), while under acidic conditions NH_4Cl has the lowest pH (3.48). These pH values especially alkaline conditions (P3) linearly affect soil pH, increasing soil pH to the optimal range of 6.0 – 7.0. Soil moisture remains stable (58–60%) regardless of solution type, indicating minimal effects on water retention.
4. **Plant growth performance varies depending on plant species, solution type, and irrigation conditions**. KCl under alkaline conditions (P3) was most effective for water spinach (maximum height: 33.1 cm), KCl under neutral conditions (P2) supported the best growth of red spinach (maximum height: 35.1 cm), and KIO_3 under alkaline conditions (P3) showed the best results for green spinach (maximum height: 14.3 cm). Conversely, NaCl and NH_4Cl caused stunted or zero growth due to ion toxicity. In conclusion, **the combination of KCl or KIO_3 solutions with alkaline irrigation conditions is highly recommended for sustainable agricultural strategies, provided that the growing medium is acidic or neutral under normal soil conditions**. Meanwhile, NH_4Cl and NaCl are not suitable due to their toxic effects and lower electrolysis efficiency.
5. **Statistical Analysis Validates Electrical Parameter Differences**. Normality tests (Shapiro-Wilk) confirmed that all electrical parameter data (voltage, current, energy) were normally distributed. However, Levene's test indicated non-homogeneous variance for voltage data. Thus, Kruskal-Wallis was applied for voltage, while one-way ANOVA was used for current and energy. **Both tests showed that the type of solution significantly affects all electrical parameters ($p < 0.05$)**.

5. 2 Future Works

To improve and extend the findings of this research, the following recommendations are proposed for future studies:

1. **Expand the analysis of electrolysis efficiency beyond hydrogen production.** Future works should explore other electrochemical outputs, such as nutrient enhancement potential, especially for agricultural applications or anything else.
2. **Investigate long-term soil and plant responses.** This study was limited to a 30–40 day observation period. Longer trials are needed to assess sustainability, potential soil mineral depletion, or pH overcompensation over time.
3. **Test with varying concentrations of electrolyte solutions and volumes.** This study used a fixed concentration of 20 g/1 L. Variations in salt concentration may affect both energy performance and plant responses.
4. **Incorporate more diverse crop types and soil textures.** The current research focused on water spinach and spinach variants grown in similar soil media. Further studies could assess the applicability of this technique across other plant species and farming environments.
5. **Include economic feasibility analysis.** Compare alkaline water irrigation with conventional farming in terms of cost, yield improvement, and soil optimization to evaluate its real-world applicability.
6. **Optimize system integration using automated solar tracking and real-time pH control.** Improvements in solar harvesting and controlled water delivery could increase system efficiency and usability in practical field applications.

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APPENDICES

A. System Measurement Result

Table A. 1 System Measurement Result of Comparison System With and Without Electrolyte Solution

Time Measurement	With Load PWI (09/02/2025 – 13/02/2025)											
	Voltage (V)		Average Voltage (V)		Current (A)		Average Current (A)		Power (watt)		Average Power (Watt)	
	KCl	Raw Water	KCl	Raw Water	KCl	Raw Water	KCl	Raw Water	KCl	Raw Water	KCl	Raw Water
	18,370	15,700			0,128	0,012			2,351	0,188		
	20,490	16,280			0,136	0,012			2,787	0,195		
10:00	17,850	15,020	19,788	15,904	0,133	0,013	0,139	0,011	2,374	0,195	2,766	0,183
	21,820	16,210			0,152	0,01			3,317	0,162		
	20,410	16,310			0,147	0,01			3,000	0,163		
	18,172	15,300			0,133	0,012			2,417	0,184		
	18,490	15,700			0,139	0,012			2,570	0,188		
11:00	20,870	15,430	19,752	15,510	0,164	0,014	0,158	0,012	3,423	0,216	3,169	0,170
	22,760	15,340			0,205	0,014			4,666	0,215		
	18,470	15,780			0,150	0,007			2,771	0,110		
	18,820	15,350			0,137	0,012			2,578	0,184		
	18,870	15,340			0,255	0,016			4,812	0,245		
12:00	21,140	15,120	19,594	15,314	0,260	0,015	0,244	0,015	5,496	0,227	4,812	0,227
	20,070	15,420			0,305	0,02			6,121	0,308		
	19,070	15,340			0,265	0,011			5,054	0,169		
	18,870	15,420			0,116	0,015			2,189	0,231		
	19,930	14,790			0,266	0,02			5,301	0,296		
13:00	21,590	15,410	20,042	14,586	0,279	0,02	0,241	0,016	6,024	0,308	4,865	0,242
	19,880	14,740			0,259	0,016			5,149	0,236		
	19,940	12,570			0,284	0,011			5,663	0,138		
	19,720	14,500			0,173	0,013			3,412	0,189		
	18,780	13,450			0,131	0,007			2,460	0,094		
14:00	21,890	12,450	19,808	13,326	0,194	0,012	0,184	0,010	4,247	0,149	3,664	0,136
	19,870	12,780			0,273	0,012			5,425	0,153		
	18,780	13,450			0,148	0,007			2,779	0,094		
	17,300	14,740			0,110	0,008			1,903	0,118		
	18,600	13,020			0,147	0,007			2,734	0,091		
15:00	21,920	12,310	19,170	13,070	0,127	0,01	0,134	0,008	2,784	0,123	2,566	0,109
	19,560	12,260			0,150	0,01			2,934	0,123		
	18,470	13,020			0,134	0,007			2,475	0,091		

Table A. 2 System Measurement Result of All Solution

Measurement to-	Time Measurement	Voltage (V)					Daily Voltage (V)					Current (A)					Daily Current (A)				
		NaCl	KCl	KIO3	NH4Cl	Raw Water	NaCl	KCl	KIO3	NH4Cl	Raw Water	NaCl	KCl	KIO3	NH4Cl	Raw Water	NaCl	KCl	KIO3	NH4Cl	Raw Water
1	10.00	18,45	18,37	18,17	18,28	15,7	18,630	18,542	18,282	18,397	15,168	0,13	0,13	0,11	0,12	0,012	0,141	0,133	0,108	0,124	0,012
	11:00	18,22	18,17	17,92	18,02	15,3						0,14	0,13	0,11	0,12	0,012					
	12:00	18,91	18,82	18,62	18,69	15,35						0,15	0,14	0,11	0,13	0,012					
	13:00	18,90	18,87	18,56	18,62	15,42						0,13	0,12	0,10	0,11	0,015					
	14:00	19,83	19,72	19,50	19,64	14,5						0,18	0,17	0,16	0,17	0,013					
	15:00	17,47	17,30	16,92	17,13	14,74						0,12	0,11	0,06	0,10	0,008					
2	10.00	20,61	20,49	20,20	20,38	16,28	19,397	19,193	18,913	19,058	14,763	0,14	0,14	0,12	0,13	0,012	0,189	0,179	0,164	0,169	0,012
	11:00	18,68	18,49	18,23	18,35	15,7						0,15	0,14	0,13	0,13	0,012					
	12:00	19,15	18,87	18,71	18,80	15,34						0,27	0,26	0,24	0,25	0,016					
	13:00	20,12	19,93	19,71	19,87	14,79						0,28	0,27	0,24	0,25	0,02					
	14:00	18,94	18,78	18,27	18,46	13,45						0,14	0,13	0,12	0,13	0,007					
	15:00	18,88	18,60	18,36	18,49	13,02						0,16	0,15	0,13	0,13	0,007					
3	10.00	17,92	17,85	17,59	17,69	15,02	20,963	20,877	20,615	20,728	14,290	0,16	0,13	0,15	0,13	0,013	0,233	0,193	0,208	0,184	0,014
	11:00	20,93	20,87	20,60	20,74	15,43						0,21	0,16	0,19	0,16	0,014					
	12:00	21,21	21,14	20,90	20,96	15,12						0,32	0,26	0,29	0,25	0,015					
	13:00	21,67	21,59	21,30	21,42	15,41						0,27	0,28	0,24	0,27	0,02					
	14:00	21,99	21,89	21,60	21,75	12,45						0,29	0,19	0,25	0,18	0,012					
	15:00	22,06	21,92	21,70	21,81	12,31						0,16	0,13	0,13	0,12	0,01					
4	10.00	21,93	21,82	21,60	21,75	16,21	20,738	20,660	20,437	20,522	14,458	0,14	0,15	0,13	0,15	0,01	0,199	0,224	0,178	0,216	0,014
	11:00	22,87	22,76	22,40	22,45	15,34						0,17	0,21	0,15	0,20	0,014					
	12:00	20,12	20,07	19,96	20,02	15,42						0,26	0,31	0,24	0,30	0,02					
	13:00	19,93	19,88	19,62	19,73	14,74						0,29	0,26	0,26	0,25	0,016					
	14:00	19,96	19,87	19,65	19,73	12,78						0,20	0,27	0,18	0,26	0,012					
	15:00	19,62	19,56	19,39	19,45	12,26						0,14	0,15	0,11	0,14	0,01					
5	10.00	20,47	20,41	20,21	20,26	16,31	19,253	19,190	19,003	19,072	14,412	0,15	0,15	0,13	0,14	0,01	0,195	0,188	0,171	0,178	0,009
	11:00	18,55	18,47	18,33	18,40	15,78						0,16	0,15	0,13	0,14	0,007					

	12:00	19,11	19,07	18,82	18,89	15,34						0,27	0,27	0,25	0,25	0,011					
	13:00	19,98	19,94	19,75	19,84	12,57						0,29	0,28	0,26	0,27	0,011					
	14:00	18,85	18,78	18,54	18,62	13,45						0,16	0,15	0,13	0,14	0,007					
	15:00	18,56	18,47	18,37	18,42	13,02						0,14	0,13	0,13	0,13	0,007					

B. Soil Measurement Result

Table A. 3 Soil Measurement Result (Ph and Moisture) in 30 Days in Condition (P1, P2, & P3)

Measurements were taken with a frequency of every 2 days (measurements from February 12, 2025 - March 12, 2025).																
Measurement to-	Date	pH														
		NaCl			KCl			Raw Water			KIO3			NH4Cl		
		P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
1	12-Feb-25	5,7	5,3	5,4	5,3	5,5	5,3	5,2	5,2	5,5	5,6	5,3	5,4	5,6	5,3	5,2
2	14-Feb-25	5,6	5,5	5,7	5,2	5,7	5,7	5,2	5,4	5,7	5,3	5,6	5,6	5,3	5,4	5,4
3	16-Feb-25	5,5	5,7	5,9	5,1	5,9	6,0	5,3	5,6	5,8	5,4	5,8	5,8	5,2	5,5	5,6
4	18-Feb-25	5,4	5,8	6,2	5,2	6,1	6,2	5,4	5,7	6,0	5,1	5,9	6,1	5,0	5,7	5,9
5	20-Feb-25	5,4	6,0	6,5	5,1	6,3	6,5	5,5	5,8	6,1	4,9	6,1	6,3	4,8	5,9	6,0
6	22-Feb-25	5,3	6,2	6,7	5,0	6,4	6,7	5,4	6,0	6,0	4,8	6,3	6,6	4,5	6,0	6,1
7	24-Feb-25	5,4	6,3	7,0	5,0	6,6	7,0	5,5	6,0	6,2	4,6	6,4	6,6	4,2	6,2	6,3
8	26-Feb-25	5,3	6,5	7,2	5,1	6,7	7,2	5,5	6,1	6,2	4,3	6,5	6,9	4,1	6,3	6,5
9	28-Feb-25	5,3	6,6	7,3	5,0	6,9	7,3	5,4	6,2	6,4	4,1	6,5	7,1	4,1	6,2	6,5
10	02-Mar-25	5,4	6,8	7,5	4,9	7,0	7,5	5,5	6,1	6,5	4,0	6,5	7,2	4,0	6,4	6,6
11	04-Mar-25	5,3	7,0	7,8	5,0	7,0	7,8	5,5	6,3	6,7	4,1	6,7	7,3	4,1	6,4	6,8
12	06-Mar-25	5,4	6,9	7,7	5,1	7,1	7,7	5,3	6,3	6,6	4,1	6,7	7,4	3,9	6,5	6,6
13	08-Mar-25	5,3	7,1	7,8	5,0	7,0	7,7	5,5	6,5	6,7	3,9	6,8	7,5	3,8	6,6	6,8
14	10-Mar-25	5,3	7,1	7,9	5,0	7,1	7,8	5,5	6,6	6,8	3,9	6,7	7,3	3,9	6,6	6,9
15	12-Mar-25	5,3	7,1	7,9	5,0	7,1	7,8	5,5	6,6	6,7	3,9	6,8	7,2	3,8	6,7	6,9

Measurement to-	Date	Moist (%)														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
1	12-Feb-25	45	45	42	49	43	44	43	48	45	44	47	49	42	42	49
2	14-Feb-25	50	49	53	51	48	44	49	51	50	52	46	44	47	45	52
3	16-Feb-25	52	56	55	55	54	51	56	54	59	58	57	54	55	52	55
4	18-Feb-25	55	54	58	60	60	59	58	55	61	58	55	59	60	60	57
5	20-Feb-25	59	60	60	62	62	62	60	62	61	59	58	62	62	61	60
6	22-Feb-25	64	63	62	64	64	63	62	64	64	60	62	64	64	65	62
7	24-Feb-25	61	59	59	60	59	61	59	58	58	57	60	62	62	64	63
8	26-Feb-25	62	62	60	62	62	61	62	61	62	61	62	63	64	65	65
9	28-Feb-25	61	59	59	59	58	60	58	58	59	57	60	63	64	61	62
10	02-Mar-25	64	61	61	59	58	60	57	58	58	57	56	58	57	59	58
11	04-Mar-25	60	61	60	60	61	61	62	62	61	60	60	62	59	61	62
12	06-Mar-25	56	56	54	55	57	54	57	58	55	56	54	54	52	56	58
13	08-Mar-25	61	62	63	62	63	61	65	66	63	62	61	61	60	62	66
14	10-Mar-25	62	62	64	64	64	63	65	66	64	63	63	63	62	64	66
15	12-Mar-25	63	63	64	64	65	64	65	65	64	64	63	64	64	65	65

C. Plant Measurement Result

Table A. 4 Water spinach Measurement Result in 40 Days in Condition (P1, P2, & P3)

Measurements were taken with a frequency of every 2 days (measurements from February 12, 2025 - March 22, 2025).																
Measurement to-	Date	P1														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	0,5	0,2	2	0,6	0,2	2	0,7	0,2	2	0,5	0,2	2	0,4	0,1	2
4	18/02/2025	1	0,3	2	1,2	0,4	2	1,4	0,4	2	1,2	0,3	2	0,8	0,2	2
5	20/02/2025	2,2	0,8	2	2,4	0,7	2	2,8	0,8	2	2,4	0,8	2	1,5	0,5	2
6	22/02/2025	3,1	1,5	2	3,6	1,4	3	3,4	1,3	3	3,1	1,5	2	2,6	0,8	3
7	24/02/2025	4,2	2	3	4,6	2	3	4,2	1,7	4	4,2	2	3	3,5	1,5	3
8	26/02/2025	4,9	2	3	5,3	2,4	4	5,6	2,1	4	4,9	2	3	4,2	2	3
9	28/02/2025	5,3	2,3	4	6,3	2,6	4	6,4	2,5	5	5,6	2,3	4	4,2	2	3
10	02/03/2025	5,9	2,5	4	7,2	3,1	4	7,2	3	5	5,9	2,5	4	4,2	2	3
11	04/03/2025	5,9	2,5	4	8,3	3,5	4	8,4	3,5	6	6,4	3	4	0	0	0
12	06/03/2025	0	0	0	8,9	3,9	4	9,8	3,8	6	6,4	3	4	0	0	0
13	08/03/2025	0	0	0	9,3	4,2	5	11,2	4,3	6	0	0	0	0	0	0
14	10/03/2025	0	0	0	9,5	4,4	5	12,6	4,9	6	0	0	0	0	0	0
15	12/03/2025	0	0	0	9,5	4,4	5	14	5,4	7	0	0	0	0	0	0
16	14/03/2025	0	0	0	0	0	0	15,4	6	7	0	0	0	0	0	0
17	16/03/2025	0	0	0	0	0	0	15,4	6	7	0	0	0	0	0	0
18	18/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	20/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	22/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Measurement to-	Date	P2														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	0,8	0,2	2	1,1	0,5	2	0,7	0,2	2	0,6	0,2	2	0,5	0,1	2
4	18/02/2025	1,5	0,5	2	2,2	0,7	2	1,4	0,4	2	1,2	0,4	2	1	0,3	2
5	20/02/2025	3,1	1	3	4,4	1,3	4	2,8	0,8	3	2,4	0,7	2	1,9	0,7	2
6	22/02/2025	4,2	1,4	4	6,6	2	4	4,2	1,5	4	3,6	1,5	4	2,8	1	3
7	24/02/2025	6,3	1,9	5	8,8	2,4	4	5,3	2,1	5	4,8	1,9	4	3,7	1,3	4
8	26/02/2025	7,9	2,2	5	11	2,8	5	6	2,5	4	7,9	2,1	5	4,5	1,6	4
9	28/02/2025	9,6	2,4	6	13,2	3,1	6	7,2	2,5	5	9,3	2,3	6	5,8	1,9	5
10	02/03/2025	11,2	2,6	6	15,4	3,5	6	8,4	2,7	5	11,2	2,6	6	6,9	2,2	5
11	04/03/2025	12,8	2,9	7	17,6	3,8	7	9,6	3	5	12,8	2,6	7	7,3	2,6	6
12	06/03/2025	14,1	3,2	7	19,8	4,1	7	10,8	3,3	6	14,1	3,1	7	8,5	3,1	6
13	08/03/2025	15,5	3,5	8	21,2	4,3	8	12	3,4	6	16	3,3	8	9,5	3,5	6
14	10/03/2025	16,2	3,7	8	22,9	4,5	9	13,2	3,7	7	17,6	3,6	8	11	3,8	7
15	12/03/2025	18,2	3,9	9	24,2	4,8	9	14,4	3,7	7	19,2	3,9	9	12,1	3,6	7
16	14/03/2025	19,8	4,2	9	26,4	5,1	9	15,6	4	7	20,8	4,2	9	13	3,8	8
17	16/03/2025	20,9	4,6	10	28,8	5,1	9	16,8	4,2	8	22,4	4,2	10	13,8	4	8
18	18/03/2025	22,1	4,6	10	29,5	5,5	10	17,7	4,5	8	23,9	4,5	10	13,8	4	8
19	20/03/2025	23,7	5	11	31,1	5,9	11	19,3	4,6	9	25,7	4,5	11	0	0	0
20	22/03/2025	25,3	5	11	31,1	5,9	11	20,5	4,6	9	27,1	4,5	11	0	0	0

Measurement to-	Date	P3														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	1	0,3	2	0,9	0,3	2	0,9	0,3	2	0,8	0,2	2	0,7	0,2	2
4	18/02/2025	1,9	0,6	2	1,8	0,5	2	1,8	0,6	2	1,5	0,5	2	1,4	0,4	2
5	20/02/2025	3,3	1,3	3	3,6	1,1	3	3,7	1,2	3	3,2	1	3	2,8	0,8	2
6	22/02/2025	4,5	2	4	5,4	1,6	4	5,4	1,9	4	4,8	1,4	4	4,2	1,5	4
7	24/02/2025	6,4	1,9	5	7,2	2,2	5	7,2	2,4	5	5,9	2,4	5	5,3	2,1	4
8	26/02/2025	7,9	2,4	5	9	2,7	5	9,2	2,7	6	7,2	2,7	6	6	2,5	5
9	28/02/2025	9,6	2,9	6	10,8	3,2	6	10,8	2,9	6	8,5	2,9	6	7,3	2,5	5
10	02/03/2025	11,1	3,4	6	12,6	3,5	6	12,5	3,2	7	9,9	3,2	7	8,4	2,7	6
11	04/03/2025	12,5	3,8	7	14,4	3,8	7	14,4	3,6	7	10,9	3,6	7	9,5	3	6
12	06/03/2025	14,4	4,3	7	16,2	4,1	7	16,3	3,9	8	12,5	3,9	8	10,8	3,3	6
13	08/03/2025	16,2	4,5	7	18,1	4,3	8	18,1	4	8	14,6	4	8	12,2	3,4	7
14	10/03/2025	17,6	4,8	8	19,8	4,5	8	19,8	4,3	8	16,7	4,3	9	13,2	3,7	7
15	12/03/2025	19,2	5	8	21,6	4,8	9	21,5	4,5	9	19	4,5	9	14,4	3,7	8
16	14/03/2025	20,8	5,3	9	23	5,1	10	23,4	4,7	9	20,7	4,8	10	15,6	4	8
17	16/03/2025	22,4	5,3	9	25,2	5,3	10	25,2	4,9	10	22,2	5	10	16,8	4,2	9
18	18/03/2025	24,1	5,4	9	26,1	5,6	10	27,2	5,1	10	25,7	5,2	11	17,7	4,5	9
19	20/03/2025	25,7	5,4	10	28,7	5,9	12	28,9	5,1	10	27,1	5,2	11	19,9	4,6	10
20	22/03/2025	25,7	5,4	10	33,1	6,1	12	30,1	5,1	11	29,3	5,2	11	21,2	4,6	10

Table A. 5 Red Spinach Measurement Result in 40 Days in Condition (P1, P2, & P3)

Measurements were taken with a frequency of every 2 days (measurements from February 12, 2025 - March 22, 2025).																
Measu rement to-	Date	P1														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	0	0	0	0,5	0,2	2	0	0	0	0	0	0	0	0	0
4	18/02/2025	0	0	0	1	0,5	2	0,5	0,2	2	0	0	0	0	0	0
5	20/02/2025	0	0	0	1,5	0,7	2	1	0,5	2	0	0	0	0	0	0
6	22/02/2025	0	0	0	2	1	2	1,5	0,7	2	0	0	0	0	0	0
7	24/02/2025	0	0	0	2,6	1,2	2	2	1	2	0	0	0	0	0	0
8	26/02/2025	0	0	0	3,2	1,5	3	2,6	1,2	2	0	0	0	0	0	0
9	28/02/2025	0	0	0	3,9	1,9	3	3,2	1,5	3	0	0	0	0	0	0
10	02/03/2025	0	0	0	4,5	2,2	4	3,9	1,9	3	0	0	0	0	0	0
11	04/03/2025	0	0	0	4,5	2,2	4	4,7	2,2	4	0	0	0	0	0	0
12	06/03/2025	0	0	0	0	0	0	5,5	2,6	4	0	0	0	0	0	0
13	08/03/2025	0	0	0	0	0	0	5,5	2,6	4	0	0	0	0	0	0
14	10/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	12/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	14/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	16/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	18/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	20/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	22/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Measurement to-	Date	P2														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	0	0	0	0,5	0,1	2	0,3	0,1	2	0,3	0,1	2	0	0	0
4	18/02/2025	0,5	0,2	2	1,1	0,5	2	0,8	0,3	2	0,6	0,2	2	0	0	0
5	20/02/2025	1,2	0,5	2	2	0,9	2	1,8	0,7	2	1,4	0,5	2	0	0	0
6	22/02/2025	2,4	0,7	2	3,2	1,5	3	2,4	1,1	3	2,5	1,1	3	0	0	0
7	24/02/2025	3,2	1,4	3	4,1	2	3	3,3	1,5	3	3	1,5	3	0	0	0
8	26/02/2025	4	2	3	5	2,4	5	4,1	1,7	4	3,7	1,9	4	0	0	0
9	28/02/2025	5	2,5	4	6,3	3	6	4,9	2,2	4	4,5	2	4	0	0	0
10	02/03/2025	6,1	3	4	7,9	3,4	6	6	2,6	6	5,3	2,5	5	0	0	0
11	04/03/2025	7	3,4	5	8,8	4	7	7	2,9	6	6	2,9	6	0	0	0
12	06/03/2025	7,9	3,5	7	10	4,3	7	8,1	3,2	7	6,8	3,5	6	0	0	0
13	08/03/2025	8,1	3,7	7	11,4	4,9	9	9,2	3,6	7	7,5	4,2	7	0	0	0
14	10/03/2025	9,2	4	8	13	5,2	9	10	4,2	7	8,3	5	7	0	0	0
15	12/03/2025	10,1	4,5	9	15,4	5,8	11	11	4,7	8	9,2	5	8	0	0	0
16	14/03/2025	12,6	4,9	10	18	6,1	11	12,5	5,2	8	10,5	5,5	8	0	0	0
17	16/03/2025	15,3	5,2	10	21,3	6,6	13	14,6	5,5	9	12	5,9	9	0	0	0
18	18/03/2025	17,9	5,9	12	25,7	7,1	13	16	5,5	9	14,1	6,1	9	0	0	0
19	20/03/2025	22,1	5,9	12	30,1	7,5	14	17,8	5,9	10	16	6,1	10	0	0	0
20	22/03/2025	25,2	6,2	14	35,1	7,5	14	18,7	6,2	10	19	6,5	10	0	0	0

Measurement to-	Date	P3														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	0	0	0	0,4	0,1	2	0,3	0,1	2	0,5	0,1	2	0	0	0
4	18/02/2025	0,5	0,2	2	0,9	0,3	2	0,6	0,2	2	1,1	0,3	2	0	0	0
5	20/02/2025	1,2	0,4	2	1,8	0,7	2	1,2	0,4	2	1,9	0,7	2	0	0	0
6	22/02/2025	1,8	0,7	2	2,6	1,3	3	1,8	0,7	2	2,4	1,1	3	0	0	0
7	24/02/2025	2,5	1,1	3	3,8	1,6	3	2,4	1	3	3,2	1,4	3	0	0	0
8	26/02/2025	3,4	1,5	3	4,5	2,1	4	3	1,4	3	4	1,7	4	0	0	0
9	28/02/2025	4	1,9	3	5,4	2,6	5	3,6	1,7	4	4,9	2	4	0	0	0
10	02/03/2025	4,6	2,2	4	6,6	3,1	6	4,2	2	4	5,9	2,5	6	0	0	0
11	04/03/2025	5,4	2,5	4	7,4	3,8	6	4,8	2,3	5	6,7	3	6	0	0	0
12	06/03/2025	6,2	2,9	5	8,5	4,2	6	5,4	2,6	5	7,5	3,4	7	0	0	0
13	08/03/2025	6,9	3,3	5	9,4	4,5	6	6,2	3	6	8,3	4	7	0	0	0
14	10/03/2025	7,3	3,5	6	10,6	5	7	7	3,4	6	9	4,4	7	0	0	0
15	12/03/2025	8,3	3,9	6	12	5,5	7	7,8	3,8	7	9,6	4,9	8	0	0	0
16	14/03/2025	8,9	4,3	6	14,5	6	8	8,5	4,3	7	10,5	5,2	8	0	0	0
17	16/03/2025	9,3	4,5	7	16,9	6,4	9	9,5	4,8	8	12,6	5,7	9	0	0	0
18	18/03/2025	9,3	4,5	7	18,2	6,9	9	9,5	4,8	8	14,7	6,1	9	0	0	0
19	20/03/2025	0	0	0	22,4	6,9	11	0	0	0	16,2	6,1	10	0	0	0
20	22/03/2025	0	0	0	25,9	7,2	11	0	0	0	18,3	6,5	10	0	0	0

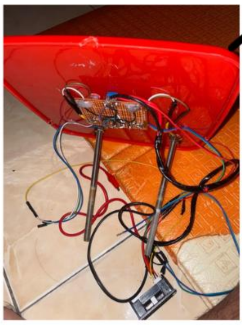
Table A. 6 Green Spinach Measurement Result in 40 Days in Condition (P1, P2, & P3)

Measurements were taken with a frequency of every 2 days (measurements from February 12, 2025 - March 22, 2025).																
Measurement to-	Date	P1														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	18/02/2025	0	0	0	0	0	0	0,3	0,1	2	0	0	0	0	0	0
5	20/02/2025	0	0	0	0	0	0	0,7	0,2	2	0	0	0	0	0	0
6	22/02/2025	0	0	0	0	0	0	1	0,5	2	0	0	0	0	0	0
7	24/02/2025	0	0	0	0	0	0	1,2	0,6	2	0	0	0	0	0	0
8	26/02/2025	0	0	0	0	0	0	1,5	0,8	3	0	0	0	0	0	0
9	28/02/2025	0	0	0	0	0	0	1,8	1	3	0	0	0	0	0	0
10	02/03/2025	0	0	0	0	0	0	2,2	1,1	3	0	0	0	0	0	0
11	04/03/2025	0	0	0	0	0	0	2,5	1,3	4	0	0	0	0	0	0
12	06/03/2025	0	0	0	0	0	0	2,9	1,5	4	0	0	0	0	0	0
13	08/03/2025	0	0	0	0	0	0	3,2	1,6	4	0	0	0	0	0	0
14	10/03/2025	0	0	0	0	0	0	3,6	1,7	5	0	0	0	0	0	0
15	12/03/2025	0	0	0	0	0	0	3,9	2	5	0	0	0	0	0	0
16	14/03/2025	0	0	0	0	0	0	4,2	2,3	5	0	0	0	0	0	0
17	16/03/2025	0	0	0	0	0	0	4,6	2,3	6	0	0	0	0	0	0
18	18/03/2025	0	0	0	0	0	0	4,6	2,3	6	0	0	0	0	0	0
19	20/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	22/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Measurement to-	Date	P2														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	18/02/2025	0	0	0	0,4	0,2	2	0,3	0,1	2	0,2	0,2	2	0	0	0
5	20/02/2025	0	0	0	0,8	0,5	2	0,6	0,2	2	0,5	0,5	2	0	0	0
6	22/02/2025	0	0	0	1,3	0,7	2	1,1	0,5	2	0,9	0,7	2	0	0	0
7	24/02/2025	0	0	0	1,8	0,9	2	1,5	1	2	1,2	0,9	2	0	0	0
8	26/02/2025	0	0	0	2,2	1	2	1,9	1,2	2	1,6	1	3	0	0	0
9	28/02/2025	0	0	0	2,6	1,2	3	2,1	1,4	3	2	1,2	3	0	0	0
10	02/03/2025	0	0	0	3	1,4	3	2,7	1,6	3	2,3	1,4	3	0	0	0
11	04/03/2025	0	0	0	3,5	1,8	3	3,2	1,9	3	2,7	1,8	3	0	0	0
12	06/03/2025	0	0	0	3,9	2	4	3,5	2,2	4	3,2	2	4	0	0	0
13	08/03/2025	0	0	0	4,2	2,2	4	3,9	2,2	4	3,8	2,2	4	0	0	0
14	10/03/2025	0	0	0	4,6	2,4	4	4,3	2,3	4	4,2	2,4	4	0	0	0
15	12/03/2025	0	0	0	5	2,5	5	4,7	2,5	4	4,7	2,4	5	0	0	0
16	14/03/2025	0	0	0	5,4	2,5	5	5,2	2,7	5	5,2	2,5	5	0	0	0
17	16/03/2025	0	0	0	5,7	2,7	5	5,2	2,7	5	5,5	2,5	5	0	0	0
18	18/03/2025	0	0	0	5,7	2,7	5	5,2	2,7	5	5,5	2,5	5	0	0	0
19	20/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	22/03/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Measurement to-	Date	P3														
		NaCl			KCl			Raw water			KIO3			NH4Cl		
		Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf	Plant Height (Cm)	Leaf Length (cm)	Sum of Leaf
1	12/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14/02/2025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	16/02/2025	0	0	0	0	0	0	0	0	0	0,5	0,1	2	0	0	0
4	18/02/2025	0	0	0	0,3	0,1	2	0,3	0,1	2	1,1	0,3	2	0	0	0
5	20/02/2025	0	0	0	0,7	0,2	2	0,5	0,1	2	1,9	0,5	2	0	0	0
6	22/02/2025	0	0	0	1,2	0,5	2	0,8	0,2	2	2,5	1	2	0	0	0
7	24/02/2025	0	0	0	1,4	0,9	2	1,3	0,5	2	3,4	1,1	3	0	0	0
8	26/02/2025	0	0	0	2	1,2	2	1,5	0,5	3	4,3	1,4	3	0	0	0
9	28/02/2025	0	0	0	2,2	1,2	3	1,9	0,7	3	5	1,7	3	0	0	0
10	02/03/2025	0	0	0	2,6	1,4	3	2,2	0,9	4	5,6	2	4	0	0	0
11	04/03/2025	0	0	0	3	1,5	3	2,5	1,1	4	6,2	2,2	4	0	0	0
12	06/03/2025	0	0	0	3,5	1,8	4	3	1,3	4	7	2,5	4	0	0	0
13	08/03/2025	0	0	0	4	2	4	3,5	1,4	4	7,9	2,7	5	0	0	0
14	10/03/2025	0	0	0	4,6	2,2	4	4	1,5	5	8,7	2,9	5	0	0	0
15	12/03/2025	0	0	0	5,1	2,5	5	4,2	1,5	5	9,6	3,1	5	0	0	0
16	14/03/2025	0	0	0	5,5	2,7	5	4,2	1,5	5	10,5	3,4	6	0	0	0
17	16/03/2025	0	0	0	6	2,9	5	0	0	0	11,3	3,7	6	0	0	0
18	18/03/2025	0	0	0	7,2	3,1	6	0	0	0	12	3,9	6	0	0	0
19	20/03/2025	0	0	0	7,9	3,6	6	0	0	0	12,8	4,2	7	0	0	0
20	22/03/2025	0	0	0	9,2	4	6	0	0	0	14,3	4,3	7	0	0	0

D. Documentation Activity



Build System PWI

Prepare the electrolyte solution

Electrolysis process

Electrolyzed water

Preparation Documentation

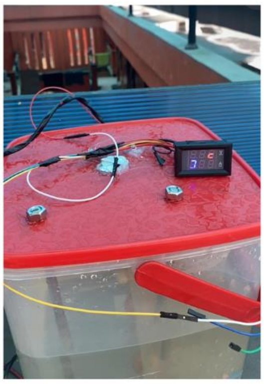
Prepare the soil

Planting Seedlings

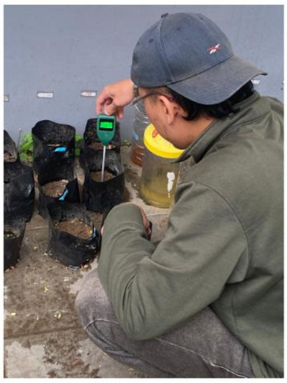
Sample Positioning

Finished

Water Measurement



PWI System Measurement



Soil Measurement

Data Collection Documentation

Red Spinach Measurement

Kale Measurement

Green Spinach Measurement