Effects of pH Level, Temperature in Fish Tank, and Temperature in Grow Bed on the Growth of Nile Tilapia and Romaine Lettuce in an Automated Aquaponics System

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Abstract

This paper presents an experimental study to determine the effects of pH level, temperature of the tank, and temperature of the grow bed on the length of the Nile Tilapia and plant height of the Romaine Lettuce using the automated aquaponics system and to recommend optimal combination of identified factors to maximize their growth. A 2^3 Factorial Design with two replicates for sixteen runs was used to perform the experiment and the results were processed using the Minitab software. Measurement on the length of both the Nile tilapia and Romaine lettuce was done once a week. The experiment lasted for 112 days. The results indicated that the pH level, temperature in the fish tank, and temperature in the grow bed have great impact on both the growth in length of the Nile tilapia and Romaine lettuce. It was also found out that the two-way interaction between the temperature in fish tank and temperature in grow bed significantly impact the growth of Nile tilapia and Romaine lettuce, respectively. Using Tukey's test, it was also found out that the higher-level values of the pH level, temperature in fish tank, and temperature in grow bed showed significance when compared to other levels for a one factor, two-way interaction, and three-way interaction. Moreover, the optimal values of the pH level, temperature in fish tank, and temperature in grow bed for both the Nile tilapia and Romaine lettuce were (7.0 pH, 30°C, 27°C), (7.0 pH, 27°C, 27°C), and (7.0 pH, 30°C, 24°C).

Keywords: Automated aquaponics system, 2^3 Factorial Design, Nile tilapia and Romaine lettuce, pH level, temperature in fish tank and grow bed.

1. Introduction

Aquaponics is a sustainable technology that integrates the food production system by combining fish and hydroponic vegetable crops (Yep and Zheng, 2019). Generally, there are two types of setups used in the modern commercial aquaponics systems. These are the coupled aquaponic systems, consisting of one continuous system loop where the water has only one direction or outlet in each tank, and the decoupled aquaponic systems where it utilizes sub-loops within the system in which water can travel in more than one direction in some tanks (Masabni and Niu, 2021; Forchino et al, 2017). The setup of the aquaponic systems comprises mostly of the deep-water culture or floating raft technique, the media filled grow beds, or the nutrient film technique (Masabni and Niu, 2021; Goddek et al, 2016; Maucieri et al, 2018). Mauciere et al (2018) reviewed on hydroponics systems in aquaponic publications found that 43% used the media-based systems, 33% used deep well culture, 15% used the nutrient film technique, and 9% used other less common hydroponic systems.

One key challenge of the aquaponic systems is finding the appropriate fish-plant combinations adapted to local conditions without compromising yield (Knaus and Palm, 2017; Suhl et al., 2016). According to Love et al. (2014), 69% used Oreochromis niloticus (tilapia), 43% used ornamental fish and 25% used Siluriformes (catfish) in their commercial operations. On the other hand, in the study of Villaroel et al (2016) on the plant species used in aquaponics systems in Europe, 58% used herbs including basil, 47% used lettuce including green salads, and 32% used tomatoes being the major crops. Lettuce was precisely suggested by Rakocy (2012) as a good crop for aquaponics systems production due to its short production period of three to four weeks and because of a relatively low pest pressure.

Previous studies, to mention a few, developed automated aquaponic systems using the Internet of Things to monitor the pH level of water, temperature of tank, temperature of grow beds and other relevant parameter and measure the growth of fish and plants (Udanor et al., 2022; Ezzahoui et al., 2021; Lee and Wang, 2020; Valiente et al., 2018). The Internet of Things system used consists of microcontroller such as ESP-32 (Udanor et al, 2022), and a "ThinkSpeak", a cloud platform using WIFI (Lee and Wang, 2020; Valiente et al., 2018).

Statistical tests were also utilized in the aquaponic systems. Urrestarazu (2019) compared three different small-scale aquaponic systems (SAS) based on modified FAO's models using as a case study a joint production of lettuce (*Lactuca sativa* L.) and goldfish (*Carassius auratus*). He used one-way ANOVA (Analysis of Variance) to statistically compare the data using SPSS 24. Also, the normality of the data was determine using the Shapiro-Wilk test and if not normally distributed, a nonparametric ANOVA (Kruskal-Walli's test) had used them to confirm significant differences at $p < 0.05$. A post hoc analysis was also performed using the HSD Tukey test and the Games-Howell test (when variances were not equal). Suhl et al. (2016) developed the double recirculating aquaponic system (DRAPS) to investigate the tilapia and tomato production. The effect of nutrient solutions based on fish wastewater and fresh water on plant parameters, such as yield, leaf area, number of leaves, Chl NDI, and on internal fruit quality parameters, such as contents of dry matter, SSC, SAR, lycopene, and ß-carotene were analyzed using SPSS package version 19.0. A t-test was used to compare the mentioned investigation parameters of both treatments, after confirmed normal distribution by Kolmogorov-Smirnov test using $p < 0.05$. Otherwise, the non-parametric Mann-Whitney U Test was used.

Previous studies, however, did not investigate the effect of the pH level and temperature in the growth of fish and plant. Statistical test were basically one-way ANOVA and t-test. Therefore, to address these gaps, the study intends to use the setup of Valiente et al. (2018) as the automated aquaponic systems using the Internet of Things as a platform to measure the required parameters. The study conducted an experiment to determine the effects of pH level, temperature of the tank, and temperature of the grow beds on the growth of Nile tilapia and Romaine lettuce. The experimental design to be used is the 2^3 Factorial Design (Montgomery, 2013).

1.1 Objectives

The study aims to determine the effects of pH level, temperature of the tank, and temperature of the grow bed on the length of the Nile Tilapia and plant height of the Romaine Lettuce using the automated aquaponic system; to recommend optimal combination of pH level, temperature of tank, and temperature of grow bed to maximize the growth of Nile tilapia and Romaine lettuce.

2. Literature Review

Aquaponics combines the propagation of fish culture and plants in a single system to improve the performance of the growth of the fish and plant culture (Colt and Semmens, 2022). As reviewed by Colt et al. (2021, several design parameters used in the aquaponic systems include, among others, area and volume ratios for fish and plant, water flows, hydraulic detention times, loading rates, densities, and feed and nutrients loadings. Important metrics, to mention a few, also include growth rates, yield, productivity, and water use.

The common fish – plant combination used in the aquaponic systems was the Nile tilapia (Love et al., 2014) and lettuce (Villaroel et al., 2016) which was suggested by Rakocy (2012) as a good plant for the aquaponic systems due to its short production period. Furthermore, the automated aquaponic system was commonly used to monitor the design parameters used and the growth of the Nile tilapia and Romaine lettuce using the Internet of Things (Udanor et al., 2022; Ezzahoui et al., 2021; Lee and Wang, 2020; Valiente et al., 2018).

Statistical tests were also employed but majority of the studies used the Analysis of Variance (ANOVA) (Urrestarazu, 2019) and t-test (Suhl et al., 2016). In this study, a Factorial design, specifically the 2^3 Factorial design, was used to statistically determine the importance of the parameters such as pH level, temperature in fish tank, and temperature in grow bed. Factorial designs are widely used in industrial experiments involving several factors where the effects and interaction between factors are evaluated with respect to the response variable. (Montgomery, 2013).

3. Methods

The data collection method used by the researchers for the study is experimentation. It was used to determine the effect of pH level and temperature on the growth of Nile Tilapia and Romaine Lettuce in an automated aquaponics.

The following data gathering procedures were used to obtain the data presented.

1. Setup the Automated Aquaponics System. The study used the automated aquaponic system developed by Valiente et al. (2018).

2. Conduct an experiment using the 2^3 Factorial Design. This experiment requires 8 runs comprising of 8 treatment combinations with two replicates or a total of 16 runs. Table 1 shows the 8 treatment combinations with 16 runs of the 2^3 Factorial Design.

Table 1. Treatment Combinations of the 23 Factorial Design with 16 Runs

Run	Treatment Combination	pH Level	Temperature in Tank (°C)	Temperature in Grow Bed (°C)
1	(1)	6.5	27	24
2	A	7.0	27	24
3	B	6.5	30	24
4	AB	7.0	30	24
5	C	6.5	27	27
6	AC	7.0	27	27
7	BC	6.5	30	27
8	ABC	7.0	30	27
9	(1)	6.5	27	24
10	A	7.0	27	24
11	B	6.5	30	24
12	AB	7.0	30	24
13	C	6.5	27	27
14	AC	7.0	27	27
15	BC	6.5	30	27
16	ABC	7.0	30	27

Table 2 shows the values used as parameter of pH level and temperature of the tank and temperature of the Grow bed.

Table 2. Values of Parameters Used in the Experiment

Parameters	Low Value	High Value
pH Level	6.5	7.0
Temperature in Tank (°C)	27	30
Temperature in Grow Bed (°C)	24	27

These values of the parameters are within the acceptable range of values.

3. The experiment starts by setting the values of the parameters based on the sequence of the runs. The Nile Tilapia and Romaine Lettuces are placed in the automatic aquaponics system.

4. Measure the plant length from the bottom of the stem until the longest leaf at the end of seven (7) days. Record the height of the Romaine Lettuce in aquaponics.

5. Using a fish net, bring the fish close to the wall of the fish tank and measure its length using a measuring device at the end of seven (7) days. Record the length of the fish in aquaponics.

6. After the measurement of the Nile tilapia and Romaine lettuce at the end of seven days, repeat steps 3 up to 5 until the 16 runs are completed. The data gathering procedure lasted for 112 days.

7. The data were inputted in the Minitab software to run the 2^3 Factorial Design.

4. Data Collection

Below were the data collected from the experiment on the length of the Nile tilapia comprising of 16 runs. Table 3 shows the details.

Table 3. Data on the Length of the Nile Tilapia in 16 runs

Run	A	B	C	Treatment Combination	pH Level	Temperature in Tank (°C)	Temperature in Grow Bed (°C)	Length of Nile Tilapia (in cm.)
1	-	-	-	(1)	6.5	27	24	4.0
2	+	-	-	A	7.0	27	24	4.6
3	-	+	-	B	6.5	30	24	4.5
4	+	+	-	AB	7.0	30	24	4.8
5	-	-	+	C	6.5	27	27	4.5
6	+	-	+	AC	7.0	27	27	4.8
7	-	+	+	BC	6.5	30	27	4.8
8	+	+	+	ABC	7.0	30	27	4.8
9	-	-	-	(1)	6.5	27	24	4.0
10	+	-	-	A	7.0	27	24	4.4
11	-	+	-	B	6.5	30	24	4.4
12	+	+	-	AB	7.0	30	24	4.7
13	-	-	+	C	6.5	27	27	4.8
14	+	-	+	AC	7.0	27	27	4.9
15	-	+	+	BC	6.5	30	27	4.5
16	+	+	+	ABC	7.0	30	27	5.0

On the other hand, Table 4 presents the data collected from the experiment on the length of the Romaine lettuce with 16 runs.

Table 4. Data on the Length of the Romaine lettuce I 16 runs

Run	A	B	C	Treatment Combination	pH Level	Temperature in Tank (°C)	Temperature in Grow Bed (°C)	Length of Romaine Lettuce (in cm..)
1	-	-	-	(1)	6.5	27	24	5.5
2	+	-	-	A	7.0	27	24	5.7
3	-	+	-	B	6.5	30	24	5.7
4	+	+	-	AB	7.0	30	24	5.7
5	-	-	+	C	6.5	27	27	5.5
6	+	-	+	AC	7.0	27	27	5.7
7	-	+	+	BC	6.5	30	27	5.6
8	+	+	+	ABC	7.0	30	27	5.7
9	-	-	-	(1)	6.5	27	24	5.6
10	+	-	-	A	7.0	27	24	5.7
11	-	+	-	B	6.5	30	24	5.7
12	+	+	-	AB	7.0	30	24	5.7
13	-	-	+	C	6.5	27	27	5.5

14	+	-	+	AC	7.0	27	27	5.6
15	-	+	+	BC	6.5	30	27	5.6
16	+	+	+	ABC	7.0	30	27	5.7

5. Results and Discussion

5.1 Numerical Results

Table 5 presents the factor effects of the parameters used in the Nile Tilapia and Romaine lettuce experiment.

Table 5. Factor Effects of Parameters in the Nile Tilapia and Romaine Lettuce

Factors	Nile Tilapia		Romaine Lettuce	
	Effects	p-value	Effects	p-value
pH Level	0.3125	**0.002**	0.10000	**0.000**
Temperature in Fish Tank	0.1875	**0.024**	0.07500	**0.003**
Temperature in Grow Bed	0.3375	**0.001**	-0.05000	**0.022**
pH Level*Temperature in Fish Tank	-0.0375	0.593	-0.05000	**0.022**
pH Level*Temperature in Grow Bed	-0.0875	0.230	0.02500	0.195
Temperature in Fish Tank*Temperature in Grow Bed	-0.1625	**0.042**	-0.00000	1.000
pH Level*Temperature in Fish Tank*Temperature in Grow Bed	0.0625	0.380	0.02500	0.195

As presented in Table 5, the pH level, temperature in fish tank, and temperature in grow bed as linear factors showed significance, where the p-values are < 0.05. These factors indicated positive importance to the growth of the Nile tilapia. Also, the two-way interaction between temperature in fish tank and temperature in grow bed indicated significance with a p-value of 0.042, however, with negative importance to the growth of Nile tilapia as the response variable. Moreover, the pH level, temperature in fish tank, and temperature in grow bed showed positive importance. The values of these parameter ensure the growth and survival of the fish (El-Sherrif and El-Feky, 2009).

On the other hand, the pH level, temperature in fish tank, temperature in grow bed as linear factors, and two-way interaction between the pH level and temperature in fish tank showed significance with p-values ranging from 0.000 to 0.0022 which are below the p-value of 0.05. These linear factors and two-way interaction factors showed positive importance to the model, that is, as these parameters are increased, the growth of the Romaine lettuce will correspondingly increase.

The result of the Analysis of Variance of the Nile tilapia experiment is shown in Table 6.

Table 6. Analysis of Variance (ANOVA) Table of the Nile Tilapia Experiment

Source	**df**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	7	1.14438	0.163482	9.02	0.003
Linear	3	0.98688	0.328958	18.15	0.001
pH Level	1	0.39063	0.390625	21.55	**0.002**
Temperature in Fish Tank	1	0.14062	0.140625	7.76	**0.024**
Temperature in Grow Bed	1	0.45562	0.455625	25.14	**0.001**
2-Way Interactions	3	0.14188	0.047292	2.61	0.124
pH Level * Temperature in Fish Tank	1	0.00563	0.005625	0.31	0.593

pH Level * Temperature in Grow Bed	1	0.03062	0.030625	1.69	0.230
Temperature in Fish Tank*Temperature in Grow Bed	1	0.10563	0.105625	5.83	**0.042**
3-Way Interactions	1	0.01563	0.015625	0.86	0.380
pH Level*Temperature in Fish Tank * Temperature in Grow Bed	1	0.015 63	0.015625	0.86	0.380
Error	8	0.14500	0.018125		
Total	15				

Subjecting the data into inferential statistical test using Analysis of Variance (ANOVA), shown in Table 6, the results of the Nile tilapia experiment showed that the p-values of the linear factors such as pH level ($p = 0.002$), temperature in fish tank ($p = 0.024$), and temperature in grow bed ($p = 0.001$) were significant. This means that these factors greatly affect the growth of the Nile tilapia during the one-week period. Moreover, the p-value ($p = 0.042$) of the two-way interaction between temperature in fish and temperature in grow bed was statistically significant. It only indicated that the temperature levels used in this experiment for temperature in the fish tank of 27°C and 30°C and the temperature in grow bed of 24°C and 27°C were within the acceptable temperature for aquaculture species ranges between 25.5°C and ranges between 30.5°C. (Udanor et al., 2022)

Furthermore, the ANOVA results showed significance in the linear factors and in the two-way interaction factor, there is a need to determine which among the levels of these factors made great impact to the significance of the factor. The researcher used the Post Hoc analysis through the Tukey's Test to undertake a pairwise comparison between levels of the factors that were statistically significant. Table 7 presents the results of the Tukey's Test for the Nile tilapia experiment.

Table.7. Tukey's Test Results in the Nile Tilapia Experiment

Factor	**Value**	**Mean**	**Value**	**Mean**	**Difference of Means**	**P – value**
Linear						
pH Level	6.5	4.4375	7.0	4.7500	0.3125	**0.002**
Temperature in Fish Tank	27	4.5000	30	4.6875	0.1875	**0.024**
Temperature in Grow Bed	24	4.4250	27	4.7625	0.3375	**0.001**
2-way Interactions						
pH Level*Temperature in Fish Tank	7.0, 27	4.675	6.5, 27	4.325	0.3500	**0.026**
	7.0, 30	4.825	6.5, 27	4.325	0.5000	**0.003**
pH Level*Temperature in Grow Bed	6.5, 27	4.650	6.5, 24	4.225	0.4250	**0.009**
	7.0, 24	4.625	6.5, 24	4.225	0.4000	**0.013**
	7.0, 27	4.875	6.5, 24	4.225	0.6500	**0.001**
Temperature in Fish	27, 27	4.750	27, 24	4.250	0.5000	**0.003**
	30, 24	4.600	27, 24	4.250	0.3500	**0.026**

Tank*Temperature in Grow Bed	30, 27	4.775	27, 24	4.250	0.5250	**0.003**
3-way Interactions						
Difference of pH Level*Temperature in Fish Tank*Temperature in Grow Bed Levels	6.5, 27, 27	4.65	6.5, 27, 24	4.00	0.650	**0.017**
	6.5, 30, 27	4.65	6.5, 27, 24	4.00	0.650	**0.017**
	7.0, 27, 27	4.85	6.5, 27, 24	4.00	0.850	**0.003**
	7.0, 30, 24	4.75	6.5, 27, 24	4.00	0.750	**0.007**
	7.0, 30, 27	4.90	6.5, 27, 24	4.00	0.900	**0.002**

As shown in Table 7, pH level of 7.0 produced significantly higher length in the growth of Nile tilapia than using the 6.5 pH level. Since both pH levels were within the acceptable range, the higher pH level resulted to higher growth of the Nile tilapia. The same results were also found in the water temperature in the fish tank and grow bed. The higher temperature of 30°C for temperature in fish tank and 27°C for temperature in grow bed indicate a higher length of the Nile tilapia compared to the other temperature levels.

For the two-way interaction results of pH level and temperature in fish tank, only the interaction between 7.0 pH and both levels of temperature in fish tank were significant compared to the interaction between 6.5 pH level and 27°C temperature in fish tank. With respect to the interaction between pH level and temperature in grow bed, three interaction factors such as 6.5 pH level and 27°C temperature in grow bed, 7.0 pH level and 24°C and 27°C temperature in grow bed, respectively, were significant compared to the interaction between the 6.5 pH level and 24°C temperature in grow bed. For the interaction between the temperature in fish tank and temperature in grow bed, three two-way interactions were significant compared to other level combinations. These were the interaction between 27°C and 27°C, 30°C and 24°C, and 30°C and 27°C against the interaction between the 27°C and 24°C for the temperature in fish tank and temperature in grow bed, respectively.

Lastly, the three-way interactions showed that the higher-level values of the pH level, temperature in fish tank, and temperature in grow bed showed significance to the lower-level values of the combinations of the three factors.

On the other hand, Table 8 presents the results of the Analysis of Variance of the Romaine lettuce experiment.

Table 8. Analysis of Variance (ANOVA) Table of the Romaine Lettuce Experiment

Source	Df	Adj SS	Adj MS	F-Value	P-Value
Model	7	0.087500	0.012500	10.00	**0.002**
Linear	3	0.072500	0.024167	19.33	**0.001**
pH Level	1	0.040000	0.040000	32.00	**0.000**
Temperature in Fish Tank	1	0.022500	0.022500	18.00	**0.003**
Temperature in Grow Bed	1	0.010000	0.010000	8.00	**0.022**
2-Way Interactions	3	0.012500	0.004167	3.33	0.077
pH Level * Temperature in Fish Tank	1	0.010000	0.010000	8.00	**0.022**
pH Level * Temperature in Grow Bed	1	0.002500	0.002500	2.00	0.195
Temperature in Fish Tank*Temperature in Grow Bed	1	0.000000	0.000000	0.00	1.000
3-Way Interactions	1	0.002500	0.002500	2.00	0.195

pH Level*Temperature in Fish Tank * Temperature in Grow Bed	1	0.002500	0.002500	2.00	0.195
Error	8	0.010000	0.001250		
Total	15				

As shown in Table 8, the linear factors of pH level, temperature in fish tank, and temperature in grow bed significantly affect the growth of the Romaine lettuce during the experiment, with p-values of 0.000, 0.002, and 0.022, respectively which were less that p-value of 0.05. These results were also the same as that of the Nile tilapia. It is interesting to note that the two-way interaction between the pH level and temperature in fish tank was significant with a p-value of 0.022, below the p-value of 0.05. This proved that pH level and water temperature are critical in the growth of Romaine lettuce where the values of pH level of 6.5 and 7.0 were within the acceptable range.

To determine which levels of the factors and interaction of factors give significance to the model, a Post Hoc Analysis using the Tukey's Test was performed. Table 9 shows the results of the Tukey's Test.

Table 9. Tukey's Test Results in the Romaine Lettuce Experiment

Factor	Value	Mean	Value	Mean	Difference of Means	P – value
Linear						
pH Level	6.5	5.5875	7.0	5.6875	0.1000	**0.000**
Temperature in Fish Tank	27	5.600	30	5.675	0.0750	**0.003**
Temperature in Grow Bed	24	5.6625	27	5.6125	-0.0500	**0.022**
2-way Interactions						
pH Level*Temperature in Fish Tank	6.5, 30	5.650	6.5, 27	5.525	0.1250	**0.005**
	7.0, 27	5.675	6.5, 27	5.525	0.1500	**0.001**
	7.0, 30	5.700	6.5, 27	5.525	0.1750	**0.001**
pH Level*Temperature in Grow Bed	7.0, 24	5.700	6.5, 27	5.550	0.1500	**0.001**
	7.0, 27	5.675	6.5, 27	5.550	0.1250	**0.005**
Temperature in Fish Tank*Temperature in Grow Bed	30, 24	5.700	27, 27	5.575	0.1250	**0.005**
3-way Interactions						
Difference of pH Level*Temperature in Fish Tank*Temperature in Grow Bed Levels	6.5, 30, 24	5.70	6.5, 27, 24	5.55	0.1500	**0.035**
	7.0, 27, 24	5.70	6.5, 27, 24	5.55	0.1500	**0.035**
	7.0, 30, 24	5.70	6.5, 27, 24	5.55	0.1500	**0.035**
	7.0, 30, 27	5.70	6.5, 27, 24	5.55	0.1500	**0.035**
	6.5, 30, 24	5.70	6.5, 27, 27	5.50	0.2000	**0.007**
	7.0, 27, 24	5.70	6.5, 27, 27	5.50	0.2000	**0.007**
	7.0, 27, 27	5.65	6.5, 27, 27	5.50	0.1500	**0.035**
	7.0, 30, 24	5.70	6.5, 27, 27	5.50	0.2000	**0.007**
	7.0, 30, 27	5.70	6.5, 27, 27	5.50	0.2000	**0.007**

As presented in Table 9, the differences in the linear factors of pH level, temperature in fish tank, and temperature in grow bed showed significance with p-values of 0.000, 0.003, and 0.022, respectively, with p-value ≤ 0.05. The higher values (7.0 pH level, 30°C temperature in fish tank, and 27°C temperature in grow bed) of the levels in each factor resulted to higher growth in length of the Romaine lettuce during the experiment.

For the two-way interaction results of pH level and temperature in fish tank, the interaction between the 6.5 pH level and 27°C temperature in fish tank showed significance between the interaction of the 6.5 pH level and 27°C temperature in fish tank with a p-value of 0.005 ($p \leq 0.05$). On the other hand, the interaction between the 7.0 pH level and both levels (27°C and 30°C) of temperature in fish tank showed a higher result in the growth of the Romaine lettuce compared to the interaction between the interaction of 6.5 pH and 27°C temperature in fish tank with p-values of 0.001 ($p \leq 0.05$), respectively. With respect to the interaction between pH level and temperature in grow bed, the interaction between the 7.0 pH level and both the two-level values (24°C and 27°C) of temperature in grow bed resulted to higher growth in the length of Romaine lettuce compared to the interaction between the 6.5 pH level and 27°C temperature in grow bed, with p-values of 0.001 and 0.005 ($p \leq 0.05$), respectively. For the interaction between the temperature in fish tank and temperature in grow bed, only the interaction between 30°C temperature in fish tank and 24°C temperature in grow bed showed significance ($p = 0.005$) compared to the interaction between 27°C temperature in fish tank and 27°C temperature in grow bed.

Meanwhile, as shown in Table 9, nine three-factor interactions resulted to be significant. It indicated that the higher-value levels resulted to higher growth in length of the Romaine lettuce. Their p-values range from 0.007 to 0.035. The results of Tukey's Test revealed that the higher-level values of the linear factors, two-way interactions, and three-way interactions resulted to higher growth in the length of the Romaine lettuce.

5.2 Graphical Results

To test the normality of the data taken from the experiment, the standardized residuals of the data of the Nile tilapia and Romaine lettuce showed to be normally distributed as shown in Figures 1 and 2. The data indicated that the maximum standardized residual of the Nile tilapia and Romaine lettuce was ± 1.58 and ± 2.00, respectively which were within the ± 3 sigma. The results indicated that the data are normally distributed (Montgomery, 2013

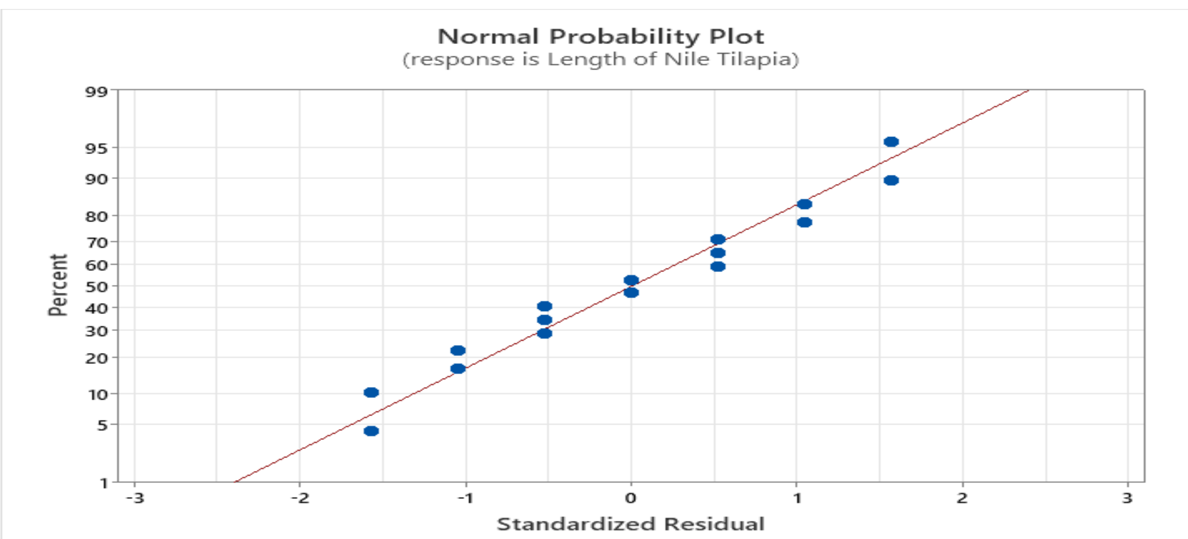

Figure 1. Normal Probability Plot of the Nile Tilapia

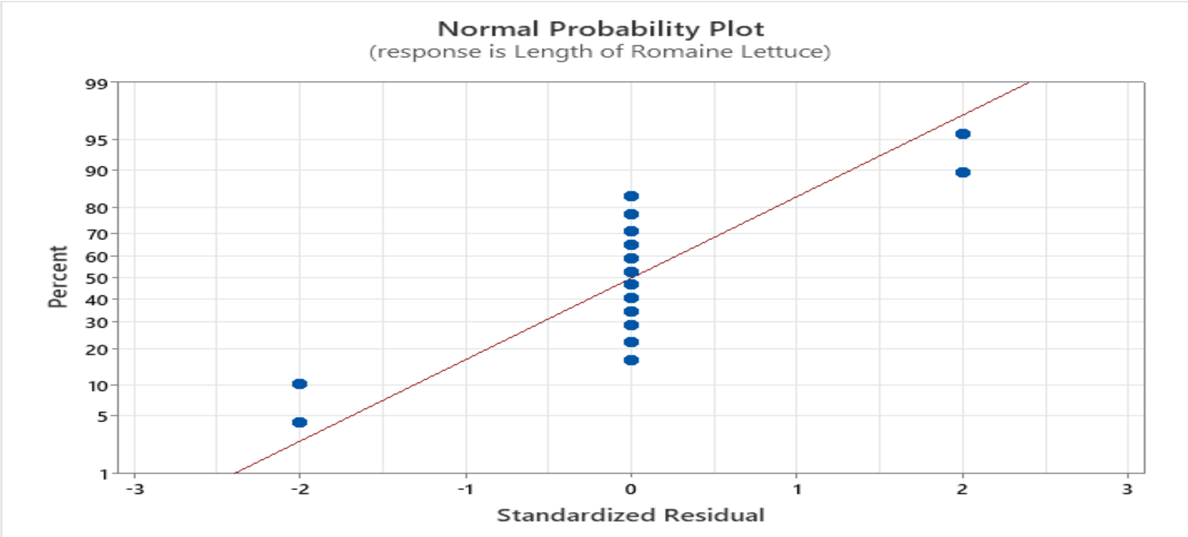

Figure 2. Normal Probability Plot of the Romaine Lettuce

5.3 Proposed Improvements

Based on the discussion of the results, Table 10 shows the optimal 3-way interaction of factors such as pH level, temperature in fish tank, and temperature in grow bed that will give optimal growth in length of Nile tilapia comprising of five treatment combinations and for the Romaine lettuce with five treatment combinations on individual basis. All these treatment combinations are statistically significant and were grouped in one category. This means, regardless of the actual values of means of growth in length of Nile tilapia and Romaine lettuce, they are considered as statistically the same.

Table 10. Optimal Values of pH Level, Temperature in fish tank, and Temperature in grow bed of the Nile Tilapia and Romaine Lettuce on Individual Basis

Nile Tilapia			Romaine Lettuce		
pH Level	Temperature in Fish Tank	Temperature in Grow Bed	pH Level	Temperature in Fish Tank	Temperature in Grow Bed
7.0	30	27	7.0	30	27
7.0	27	27	7.0	30	24
7.0	30	24	7.0	27	27
6.5	30	27	7.0	27	24
6.5	27	27	6.5	30	24

However, the setup of the automated aquaponics system combined both the Nile tilapia and the Romaine lettuce in same values of pH level, temperature in fish tanks, and temperature in grow bed, the common combination of these treatments was considered as basis for the optimal combination of values for the pH level, temperature in fish tank, and temperature in grow bed as shown in Table 11.

Table 11. Optimal Combined Values of pH Level, Temperature in fish tank, and Temperature in grow bed of the Nile Tilapia and Romaine Lettuce

Nile Tilapia and Romaine Lettuce		
pH Level	Temperature in Fish Tank	Temperature in Grow Bed
7.0	30	27
7.0	27	27
7.0	30	24

Any of the three combinations of pH level, temperature in fish tank, and temperature in grow bed result to an optimal growth of Nile tilapia and Romaine lettuce.

5.4 Validation

Table 12 shows the validation of using the original data of the three-factor combinations of the length of Nile tilapia and Romaine lettuce compared with the optimal data.

Table 12. Paired t- test between the Original Data and Optimal Data of the Length of Nile Tilapia and Romaine Lettuce

Subject	Mean		P-Value
	Original Data	Optimal Data	
Nile Tilapia	4.5938	4.8500	0.002
Romaine Lettuce	5.6375	5.7000	0.007

The validation as shown in Table 12 indicated that using the optimal values of the three-way interactions between the pH level, temperature in fish tank, and temperature in grow bed proved to provide significant increase in the length of Nile tilapia and Romaine lettuce with p-value of 0.002 and 0.007, respectively.

6. Conclusion

The results of the experiment using the 2^3 Factorial Design showed that the pH level, temperature in fish tank, and temperature in grow bed significantly affect the growth of the Nile tilapia and Romain lettuce during the one-week duration of the experiment per treatment combinations. Furthermore, there are also two-way interactions and three-ways interactions of the factors that showed significant results. Moreover, the data of the experiment were subjected to a normality test using the standardized residuals indicating to be less than ±3 sigma which means that the data are normally distributed.

After determining significant factors from the ANOVA results for both the Nile tilapia and Romaine lettuce, the Tukey's test was employed to determine which among the levels of the factors showed significance. As found out from the Tukey's test the higher-level values were significant for the linear factors of the pH level, temperature in the fish tank, and temperature in grow bed. These are the 7.0 pH, 30°C temperature in fish tank, and 27°C temperature in grow bed The higher-value levels were also manifested in the two-way interaction of factors, and three-way interaction of factors.

Lastly, three three-way interactions of factors were found to be optimal values for both the Nile tilapia and the Romaine lettuce. Any of this combination of values of the three factors can be used in the actual implementation of growing Nile tilapia and Romaine lettuce using the automated aquaponics system. The optimal values of the pH level, temperature in fish tank, and temperature in grow bed were also determined. Three treatment combinations were identified as the optimal values of the pH level, temperature in tank, and temperature in grow bed that will give optimal growth in length of the Nile tilapia and Romaine lettuce, namely, the (7.0 pH, 30°C, 27°C), (7.0 pH, 27°C, 27°C), and (7.0 pH, 30°C, 24°C).

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