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ARTICLE

Grow Big or Grow Home: A Two-Year Study on Economical & Sustainable Hydroponic Yield Facilitation

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2021 Canada-Wide Science Fair Senior Silver Excellence Medallion • 2021 NSERC Young Innovator Award • 2021 Western Manitoba Science Fair Gold Medallion • 2021 John Deere Canada 4-H Scholarship • 2021 TD 4-H Agriculture Scholarship • 2021 Youth Ag Summit Delegate • 2021 University of Manitoba President's Scholar • 2021 Bayer Fund Opportunity Scholarship

As Earth's population continues to grow, greater demands to produce quantities of food have been placed on the agricultural sector. Creative and innovative ways of optimizing food production are at the forefront of research into the future of agriculture. This research, based on earlier findings indicating that arugula growth is maximized through multi-brand fertilizer combination usage, seeks to further explore methods of manipulating hydroponic nutrients to maximize statistical gains in arugula crops while remaining economical. Analysis occurred by comparing relative growth rates of shoot heights, root lengths, and leaf areas among treatments, alongside multiple statistical analyses for biomass output including descriptive statistics, one-way ANOVA tests, and a Tukey HSD test. Nutrient usage in treatments over time and economical aspects were observed to further validate statistical results. Findings supported that a two-part treatment ($4.00\times10^{-6}m^3/m^3$ water of Advanced Nutrients brand macronutrients paired with $1.25\times10^{-6}m^3/m^3$ of High Output Garden brand micronutrients) consistently produced the greatest possible yields, ideal patterns in growth, and vigorous relative growth rates within the eight-week time frame. This nutrient input optimizes the biomass yield of hydroponically-produced arugula and costs six cents per liter of water, permitting environmental sustainability, economic efficiency, and food security. Two less sought-after treatments produced statistically similar biomass yields to the optimal treatment and has lower unit costs, but patterns in growth and overall plant health was not ideal (M1m2: $4.00\times10^{-6}m^3/m^3$ water of Advanced Nutrients brand macronutrients and $0.75\times10^{-6}m^3/m^3$ of High Output Garden brand micronutrients; M2m3: $3.00\times10^{-6}m^3/m^3$ water of Advanced Nutrients brand macronutrients and $1.25\times10^{-6}m^3/m^3$ of High Output Garden brand micronutrients).

As our world continues to expand, the pressure placed on all food production methods becomes greater. Our global population is expected to increase by approximately one-billion individuals come the year 2030, equating to about eight and a half billion earthly citizens (Worldometer, 2021). The global population is expected to reach nine billion by 2037 and ten billion by 2056. Every individual that makes up this population requires food and one in four are food insecure currently (Foley, J., n.d.). The increasing need for food availability pressures the agricultural industry across the globe to undergo any form of modernization for the sake of greater yield production and effective sustainable/regenerative practices. Arugula, Eruca vesicaria, is a favorable crop especially when paired with hydroponic agriculture. By manipulating the supplemented nutrients in hydroponic growth, the most optimal nutrient quantities can be found to grow greater yields, creating reliable food security, economic stability, and environmental sustainability; hydroponic usage can sustainably feed Earth's population (Sambo et al., 2019).

The research investigates if there is a combination between Advanced Nutrients brand macronutrients and High Output Garden brand micronutrients that create a two-part hydroponic fertilizer resulting in optimal nutrient concentrations for arugula lettuce to statistically produce a greater yield while simultaneously proving to be economically sound. It was concluded, in the first year of this study, that a viable method of hydroponic growth for leafy vegetables was to combine fertilizer components from different brands, where one combination outproduced all others (M1m1 equivalent: $4.00\times10^{-6}m^3/m^3$ water of Advanced Nutrients brand macronutrients and $1.00\times10^{-6}m^3/m^3$ of High Output Garden brand micronutrients). This experiment explores different concentration combinations of said fertilizer mix, a combination of Advanced Nutrients and High Output Garden, to identify the combination that statistically produces the greatest amount of fresh biomass by eight weeks of growth while proving to be the most economically efficient solution.

HYPOTHESIS:

It is hypothesized that if Advanced Nutrients macronutrients are diluted by 25% of the recommended ratio (the recommended ratio being $4.00\times10^{-6}m^3/m^3$ water) and High Output Garden micronutrients are concentrated by 25% of the recommended ratio (the recommended ratio being $1.00\times10^{-6}m^3/m^3$ water), then the resulting crop yield will be significantly larger than that of other tested treatments, and also prove to be the most economical option. The recommended ratio of Advanced Nutrients macronutrients to wa-

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ter is concentrated and costly in comparison to the recommended ratio of High Output Garden micronutrients. Combing these two components in the specified concentrations may suffice nutritional plant needs and remain economical. It is noted that this combination is similar to a 2.3-0.3-3.1 fertilizer mix.

PROCEDURE:

Due to prior experimentation, a space was already prepared for testing. A bleach solution was used to sterilize the $0.038m^3$ totes and lids, and netted pots for reuse. Following this, fertilizers and water were collected in accordance with transportation logistics. Water was measured out at $0.033m^3$ per every $0.038m^3$ tote. Totes were placed into three rows of ten, each row serving as a trial and each trial containing one of every treatment, where the Control treatment is distilled water. Fertilizer concentrations and combinations were mixed into totes within a trial via random assignment through Microsoft Excel, as deliberate placement may be a product of bias and treatment performance is potentially affected by location – placing a treatment in different locations within each trial of the entire test block minimizes data that reflects crop attributes based on location. T12 1.219m horticultural lights were changed to ensure adequate light output and were connected to a timer allowing power during twelve (12) hours of the day. Seeds were placed five (5) to a pot on vermiculite. Vermiculite facilitated seedling growth before roots became suspended in the treatment solution. Growth occurred for fifty-six (56) days before harvest.

Daily following seeding, pictures and observations of each treatment were taken. Parameters such as color, texture, and consistency amongst plants within the same test were noted. Additionally, developmental milestones were noted. Once weekly, shoot height, root length, and leaf length/width/area were noted, and water samples were taken in sterile 100mL specimen containers by removing one netted pot and allowing water to fill the container. Samples were frozen until nutrient content testing took place.

RESULTS:

The analysis of biomass used descriptive statistics to compare trial and treatment results. Mean weight and standard deviation values were examined and between identical treatments of different trials, remaining consistent. Plotting a box and whisker graph shows that treatment M1m3 has the highest mean overall with a small range, but this was not finite or predictive.

Inferential statistics were used to confirm that there were no differences in weight among identical treatments of separate trials. A one-way ANOVA test with an F-statistic of ($F_{2,87} = 4.858$, $p < 0.01$) was used within each of the ten treatments. An F-Statistic of ($F_{29,870} = 1.732$, $p < 0.01$) was used in a separate one-way ANOVA test comparing the ten treatments against each other, and the resulting F-value rejected the null hypothesis. Significant differences occurred among all treatments at a 99% confidence level, and a Post-Hoc test (Tukey HSD test) determined where variation occurred. The Tukey HSD test was used in lieu of multiple t-tests to mitigate the chance of type I error occurrence. How often the mean biomass weight of a given treatment was greater/less than that of a treatment statistically different from it was quantified.

Randomly selected arugula leaf areas from various treatments and different times of growth were calculated by hand, alongside the leaf width and length product. These values created a linear regression where the slope value was utilized to find general leaf area. The relative growth rate for each leaf set (cotyledons, firsts, seconds) was found in seven-day intervals. The measurements for weekly shoot heights and root lengths were uti-

Figure 3.1 Series: Area of Experimentation

Fig 3.11: Testing area before seeding

Fig. 3.12: Testing area at 8 weeks of growth (harvest)

Figure 3.1 Series: Testing area at different time of the growth period.

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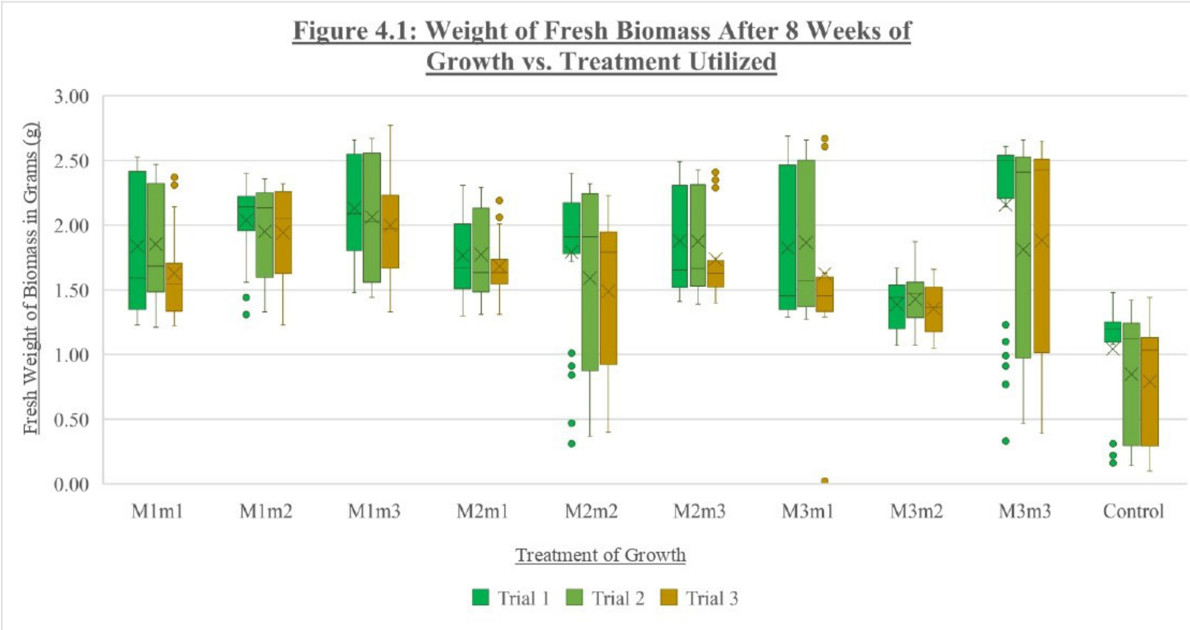

Figure 4.1: A box and whisker graph depicting the distribution of final biomass weights per treatment.

Figure 4.2 Series: Statistical Analysis

Fig. 4.21: ANOVA Table – All Treatments (Second ANOVA)

Source	D.F.	S.S.	M.S.	F-Statistic	F critical	p-value
Between	9	94.7806	10.5312	45.5798	2.42724121	1.1102×10^{-16}
Within	890	205.6338	0.231			
Total	899	300.4144				

Fig. 4.22: Tukey HSD Test Quantified Results – All Treatment Pairings

	M1m1	M1m2	M1m3	M2m1	M2m2	M2m3	M3m1	M3m2	M3m3	Cont.
M1m1										
M1m2										
M1m3										
M2m1										
M2m2										
M2m3										
M3m1										
M3m2										
M3m3										
Cont.										

Statistically greater than	2	3	6	2	1	2	2	1	4	0
Statistically less than	1	0	0	1	3	1	1	7	0	9
Not statistically different than	6	6	3	6	5	6	6	1	5	0

Figure 4.21: One-way ANOVA comparing all treatments (α=0.01).
Figure 4.22: A table quantifying the results of the Tukey HSD test (α=0.01).

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Figure 4.3 Series: Relative Growth Rates of Roots, Shoots, and Leaf Areas

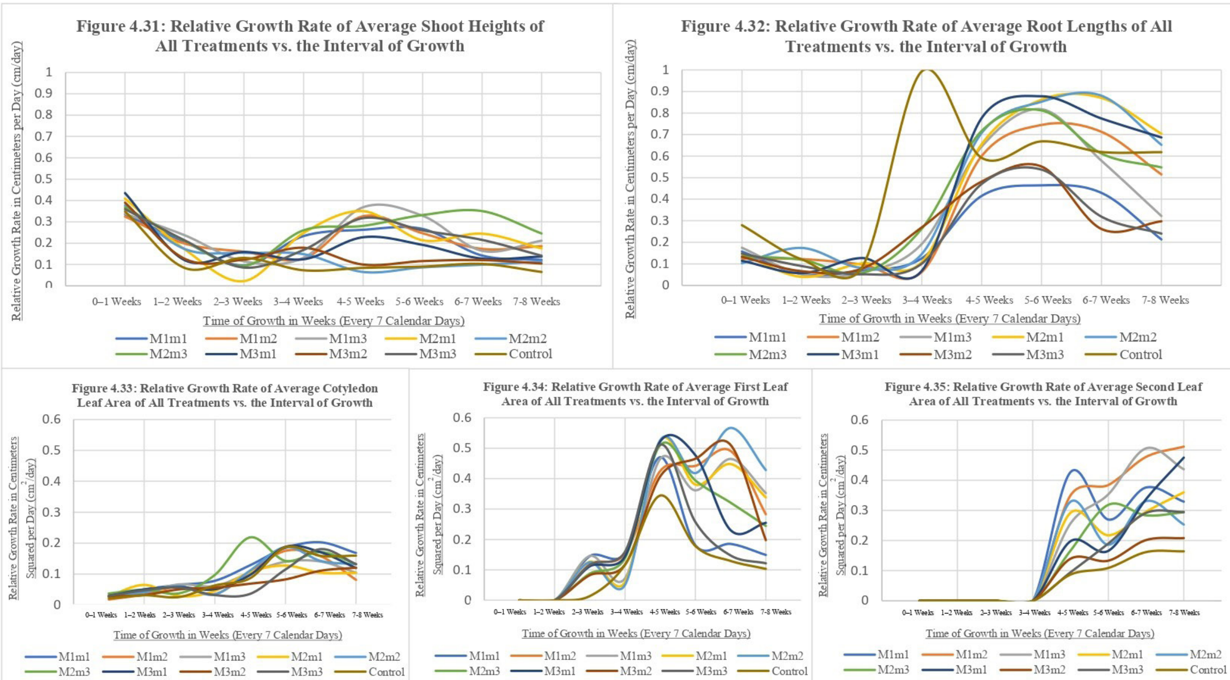

Figure 4.3 Series: Relative growth rates of shoot heights, root lengths, and leaf areas over the growth period.

Figure 4.4: Cost of Treatment Table

		Advanced Nutrients Macronutrients		
		M1 (100%)	*M2 (75%)*	*M3 (125%)*
High Output Garden Micronutrients	*m1 (100%)*	M1 = 4mL/L, $0.0468/L m1 = 1mL/L, $0.0118/L **Total:** **5ml/L, $0.0586/L**	M2 = 3mL/L, $0.0351/L m1 = 1mL/L, $0.0118/L **Total:** **4ml/L, $0.0469/L**	M3 = 5mL/L, $0.0585/L m1 = 1mL/L, $0.0118/L **Total:** **6ml/L, $0.0703/L**
	m2 (75%)	M1 = 4mL/L, $0.0468/L m2 = 0.75mL/L, $0.0089/L **Total:** **4.75ml/L, $0.0557/L**	M2 = 3mL/L, $0.0351/L m2 = 0.75mL/L, $0.0089/L **Total:** **3.75ml/L, $0.0440/L**	M3 = 5mL/L, $0.0585/L m2 = 0.75mL/L, $0.0089/L **Total:** **5.75ml/L, $0.0674/L**
	m3 (125%)	M1 = 4mL/L, $0.0468/L m3 = 1.25mL/L, $0.0148/L **Total:** **5.25ml/L, $0.0616/L**	M2 = 3mL/L, $0.0351/L m3 = 1.25mL/L, $0.0148/L **Total:** **4.25ml/L, $0.0499/L**	M3 = 5mL/L, $0.0585/L m3 = 1.25mL/L, $0.0148/L **Total:** **6.25ml/L, $0.0733/L**

Lowest Unit Price **Highest Unit Price**

Control M2m2 M2m1 M2m3 M1m2 M1m1 M1m3 M3m2 M3m1 M3m3

Figure 4.4: A table displaying the unit costs of all treatments excluding the control (distilled water).

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Figure 4.5 Series: Average Elemental Nutrients in Treatments Over Time

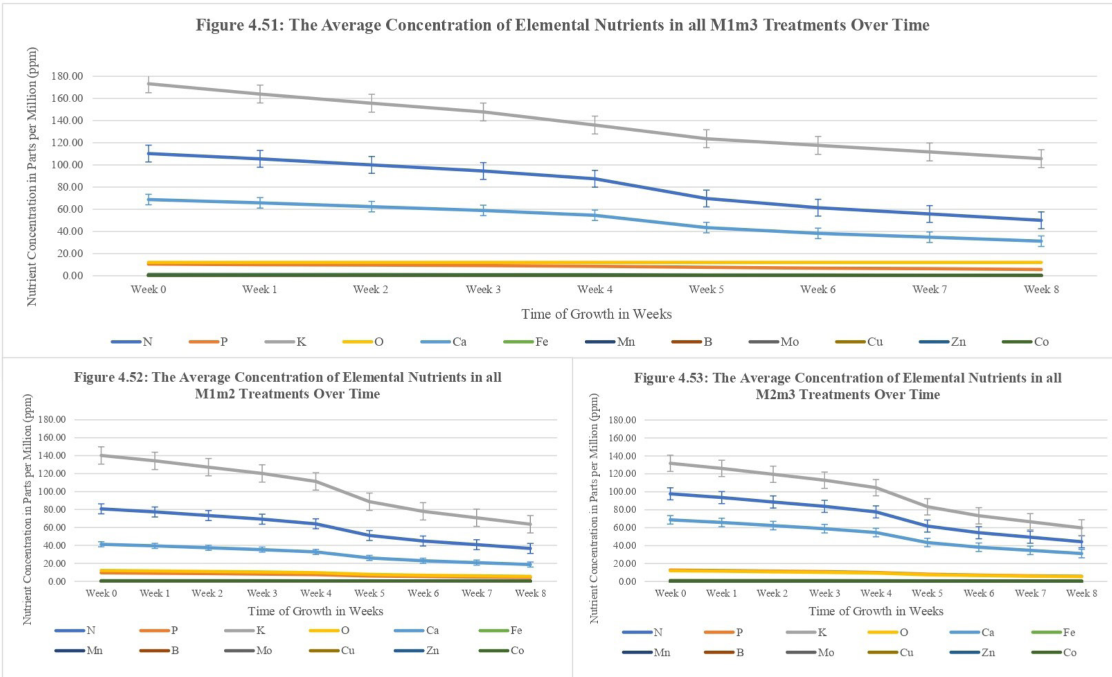

Figure 4.5 Series: The presence and usage of nutrients (N, P, K, O, Ca, Fe, Mn, B, Mo, Cu, Zn, Co) in treatments M1m3, M1m2, and M2m3 over the growth period.

lized to find relative shoot and root growth rates that would assist in determining the most favorable treatment by relating patterns in growth to a given treatment's biomass output and performance.

The M1m3 treatment does not have the lowest unit cost. However, the majority of cheaper treatments produced statistically inferior crops as seen in prior analysis, rendering them as undesirable regardless of their economic value in comparison to M1m3. Treatments M1m2 and M2m3 were noted to be statistically indifferent from M1m3 in biomass production based on the Tukey HSD test, and both treatments had lower unit costs.

Samples of treatment solutions taken during the growth period were accessed for further analysis. The fertilizers of the greatest producing treatment, M1m3, and the indifferent treatments, M1m2 and M2m3, were tested for a variety of macronutrients and micronutrients via a reagent-based testing solution. Potassium was found in the greatest quantities, in parts per million, amongst these top-production treatments.

DISCUSSION:

In viewing Figure 4.1, treatment M1m3 has the most consistent biomass output compared to other treatments that have more inconsistent, and somewhat unpredictable, yields. Without statistical analysis, treatment M1m3 appears to be favorable bearing a consistent range, high mean production weights, and consistency between trials. Though the ANOVA test that used an F-Statistic of ($F_{2,87} = 4.858$, $p < 0.01$) confirmed that variation between the trials of a given treatment was insignificant, an initial analysis favors treatment M1m3.

Cotyledon relative growth rates in most treatments were poor, but cotyledons will fall off plants once established explaining the decrease in growth after five weeks, as seen in Figure 4.33. The increased growth rate at week five for all leaf sets shows that this was the time of greatest growth, the final stage of maturation occurring at the ten-week point. Treatment M3m2 had a continually increasing growth rate beyond five weeks, for all leaf sets, which implies that more time is needed to produce optimal biomass deeming it an insufficient. All treatments, excluding M1m1 and M2m2, displayed an increasing growth rate of their second leaf set; treatments M1m1 and M2m2 failed to allow second leaves to grow properly by the eight-week point.

Relative shoot growth rates at week zero are high as growth is for root/shoot elongation during this interval, not leaf expansion. The peak of the root/shoot relative growth rates also occurred at the five-week point, excluding the M2m2, M3m2, and Control treatments; poor relative growth rates reflect in poor yield. The M1m3 treatment reached a peak at week five, allowing shoot heights of 0.133m by harvest. Relative growth rates of shoot heights and root lengths peaked at the five-week point in many treatments, excluding the M2m2, M3m2, and Control treatments with poor performance also reflected in other areas. Relative root growth rates of the Control treatment reached a peak

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Figure 6.1: N-P-K Content of Treatments

Treatment	M1m1	M1m2	M1m3	M2m1	M2m2	M2m3	M3m1	M3m2	M3m3	Control
(N-P-K) Equivalent	1.9-0.2-3.4	1.7-0.2-3.5	2.1-0.2-3.3	2.1-0.3-3.3	1.9-0.2-3.4	2.3-0.3-3.1	1.8-0.2-3.5	1.6-0.1-4.8	1.9-0.2-3.4	0.0-0.0-0.0

M1m1: *Advanced Nutrients* Macronutrients $4.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $1.00\times10^{-6}m^3$ solution/m3 water
M1m2: *Advanced Nutrients* Macronutrients $4.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $0.75\times10^{-6}m^3$ solution/m3 water
M1m3: *Advanced Nutrients* Macronutrients $4.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $1.25\times10^{-6}m^3$ solution/m3 water

M2m1: *Advanced Nutrients* Macronutrients $3.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $1.00\times10^{-6}m^3$ solution/m3 water
M2m2: *Advanced Nutrients* Macronutrients $3.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $0.75\times10^{-6}m^3$ solution/m3 water
M2m3: *Advanced Nutrients* Macronutrients $3.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $1.25\times10^{-6}m^3$ solution/m3 water

M3m1: *Advanced Nutrients* Macronutrients $5.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $1.00\times10^{-6}m^3$ solution/m3 water
M3m2: *Advanced Nutrients* Macronutrients $5.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $0.75\times10^{-6}m^3$ solution/m3 water
M3m3: *Advanced Nutrients* Macronutrients $5.00\times10^{-6}m^3$ solution/m^3 water, *High Output Garden* Micronutrients $1.25\times10^{-6}m^3$ solution/m3 water

Control: *Advanced Nutrients* Macronutrients $0.00m^3$ solution/m^3 water, *High Output Garden* Micronutrients $0.00m^3$ solution/m3 water

Figure 6.1: The N-P-K (nitrogen, phosphorus, potassium) content of all treatments and their respective concentrations in testing.

at four weeks of growth. The Control roots lengthened to obtain nutrients in preparation for week five, and the Control treatment does not increase relative shoot growth rate at the five-week point which may be due to root elongation efforts prior. Overall, treatment M1m3 showed the most desirable trends of growth without taking the statistical analysis of biomass into account, achieving the greatest shoot height, root length, leaf areas (aside from its cotyledons), and relative growth rates. The lack of cotyledon area may correlate to the immense biomass found in other leaf sets, where other treatments had larger cotyledons and smaller succeeding leaves.

In further analyzing the Tukey HSD test, as seen in Figure 4.22, it is noted that treatment M1m3 had a mean weight that was statistically greater than six of nine compared treatments. This was a greater quantity than any other treatment, only further confirming that treatment M1m3 was the greatest biomass producer seeing that it was statistically inferior to none and statistically indifferent to three (M1m2, M2m3, M3m3) treatments, which indicates that biomass production was comparable.

It was deduced that potassium was prevalent in top-producing treatments (M1m3, M1m2, M2m3) as it is an integral macronutrient for plant growth, relating to the movement of water and photosynthesis control. This is very important for growth in a system with constant water exposure, and ultimately led to the great biomass production of treatment M1m3. With 173.25ppm of usable potassium initially, treatment M1m3 produced greatly where other treatments waivered from this amount by ±15ppm resulting in inferior biomass output. Treatments M1m2 and M2m3 are feasible alternatives to M1m3 if required.

Future work related to this outcome may entail the further development of an arugula fertilizer, for biomass maximization and economic efficiency, that encompasses the nutrient parameters present in treatment M1m3. However, the fertilizer may be formulated with easily sourced and renewable materials to further enforce sustainability and accessibility. Beyond this, the development of sustainable, crop-specific, hydroponic fertilizers is a possibility as using identical fertilizer treatments for the growth of separate plant species may not yield comparable results in biomass output.

CONCLUSION:

In conclusion, the hypothesis was incorrect as the combination of Advanced Nutrients macronutrients diluted by 25% ($3.00\times10^{-6}m^3/m^3$ water) and High Output Garden micronutrients concentrated by 25% ($1.25\times10^{-6}m^3/m^3$ water), or the M2m3 treatment, failed to create an optimal nutrient solution for efficient arugula yield production. The M1m3 treatment, equating to a 2.1-0.2-3.3 fertilizer, statistically proved to produce the greatest amount of biomass and the related patterns in growth and observations strengthened this conclusion. Treatments M1m2 and M2m3 were not statistically different than M1m3 in biomass production, but their trends growth were not ideal; leaf areas by harvest were approximately $0.02m^2$ to $0.04m^2$ less than leaf areas of treatment M1m3 and they were ultimately insufficient. The nutrient solution of treatment M1m3 was further tested to deduce what contents led to its success, and high amounts of usable potassium resulted in ideal hydroponic growth, alongside comparable nitrogen levels.

This solution has never previously been implemented and is able to produce arugula crops that are equivalent, if not greater, in biomass yield and growth resiliency compared to conventional agriculture for six (6) cents per m^3 of water. Nutrient inputs in hydroponic systems are ratio based so this option remains feasible for many uses. With the economic efficiency, food security becomes more attainable. Hydroponic systems are closed and are not directly in contact with the environment, so this method of growing greater crops is environmentally sustainable, especially reducing the chances of fertilizer run-off causing eutrophication in nearby ecosystems. Overall, the results shown in this study demonstrate that using the M1m3 treatment for the production of hydroponic arugula lettuce, Eruca vesicaria, creates a growing environment with the greatest effectivity in terms of economics, environmental stewardship, and yield output. These results will aid in agricultural advancement – trailblazing a pathway towards a more sought-after, cost-effective, environmentally sustainable, and reliable method of food production.

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Emily is a high school graduate from Brandon, Manitoba, attending the University of Manitoba for a B.Sc. (Agroecology) degree. Agriculturally-oriented, she was a Canadian 2019 Global Youth Institute delegate, is a 4-H member, seasonally works for A.A.F.C., and is a Canadian 2021 Youth Ag Summit delegate. Displaying her food production/environmental sustainability research regionally, nationally, and internationally, she's received various high accolades from industry professionals. Additionally, she's an avid ringette player and manages a poultry business dedicated to breed preservation. Mitigating food insecurity/environmental degradation is her ultimate goal – she's excited to explore her future in post-secondary studies and Canadian agriculture!

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