# <u>Grow Big or Grow Home: An Economical Way to Facilitate Greater Hydroponic Yields Sustainably</u>

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## Introduction:

As our world continues to expand, the pressure placed on food production becomes greater and greater. In fact, our population is currently growing at a rate of 1.08%, which is less than years in the past decade, but still allows an average yearly increase of approximately eighty-two (82) million people (Worldometers, 2019). By the year 2037, which was once believed to be 2050, about nine million people will need to be fed, which is minimalistic compared to the 2050 projection of ten billion (Foley, J., n.d.). The increasing need for crops and their yields requires agriculture itself to undergo innovation, or to be led in a different direction that can also be considered sustainable, despite the lack of it in this day and age. Without sustainability, continued degradation of the environment will cause yields to wither substantially, regardless of how unsustainable a practice is.

Many crops are uselessly grown as their beneficial properties are virtually useless for humans; only animals may benefit. If a crop that exhibited various important benefits for human health and wellbeing were to be grown with the implementation of more sustainable or ecologically friendly growing methods, a viable solution can be worked and built upon for correcting food insecurity, maintaining soil health, protecting water sources, and retaining any biodiversity. Arugula is a quickly maturing crop with many advantageous properties. Pairing such a crop with a sustainable alternative in comparison to conventional agricultural endeavors allows the genetic potential of the crop to be reached. Further advancing the methodology behind *hydroponics* would entail the manipulation of supplementation, or fertilizers quantities. If a fertilizer is manipulated enough in experimentation, the ideal ratio of nutrients can be found for the development of a robust and consistent yield in all operations, which increases the reliability of food security, economic stability, environmental sustainability, as well as the intensity of the agroecology being exercised. Overall, hydroponic gardening could become a strategy for sustainably feeding Earth's rising population (Sambo et al., 2019).

The research question asks if there a specific pairing between the macronutrient and micronutrient components of two-part hydroponic fertilizer brands in varying concentrations that could result in the ideal ratios of all nutrients, allowing arugula lettuce to statistically produce a greater yield, and also prove to be economically sound. Various prices of nutrient solutions will fluctuate based on demand. Perhaps the solution in growing is not to use the most expensive, or least expensive two-part formula, but one part from each brand or the same brand in different concentrations. They can be combined to create a separate fertilizer that will allow a greater yield upon maturity.

It is hypothesized that the macronutrient blend from High Output Garden fertilizer brand combined with the micronutrient blend from General Hydroponics fertilizer brand in the recommended concentration will statistically produce the largest possible crop (by weight) for the lowest possible cost. High Output Garden nutrient blends are seen on the hydroponic market for extremely low costs compared to other competitors. General Hydroponics, however, is marketed at a relatively higher price. The combination of macronutrients and micronutrients from only High Output Garden results in a relatively concentrated solution of guaranteed nutrients, even when selected in a recommended formula ratio. The micronutrient blend from General Hydroponics provides identical nutrients to High Output Garden, but in a weaker recommended concentration. In addition to this, General Hydroponics produces crops within a small range of weight deviation, proving to be reliable. Compared to all other fertilizer options, the hypothesized solution contains the highest variety of guaranteed micronutrients, as well as the most reasonable proportions in the recommended concentration of both macronutrients and micronutrients for the lowest feasible cost.

**Procedure:**

*Part 1: Assembling/preparing the testing area*

Due to prior experimentation, a space was already cleared and prepared in the lower level of the house. Tupperware totes, lighting fixtures, aeration supplies, vermiculite, netted pots, and supplies that aided in observation remained. Other materials were kept in a drier and cooler place, such as reagents. Due to methodology changes, previous 68L Tupperware totes were exchanged for 38L totes. Lids from the prior experiment were sterilized with a bleach solution, along with netted pots for reuse. Sterilization occurred three times to ensure no cross contamination. Following this, fertilizers and water were collected in accordance with logistics. Water was measured out at 33L per every 38L tote, while fertilizer concentrations and combinations were mixed into randomly assigned totes. Vermiculite was scooped into netted pots and placed in the pre-existing holes drilled into the tote lids. The T12 48" horticultural lights were changed immediately after this to ensure that the maximum number of lumens was cast upon the testing area, and were connected to the same automatic timer which allowed power during twelve (12) hours of the day. Seeds were counted out and placed five (5) to a pot. The aeration tubing was inspected for any damage or imperfections in sealing, and all ends with an air stone were secured to their designated Tupperware tote ensuring no movement or entanglement of multiple air hoses. To isolate the testing area, a section of galvanized Paige wire fencing was secured to surrounding walls and other supports, where one end allowed access. The vermiculite absorbed enough nutrient solution to facilitate the germination and development of seedlings before their roots became suspended. The plants grew for the next fifty-six (56) days.

*Part 2: Data Collection*

For each day following the date of seeding, pictures of each test were taken. Written observations were taken at 7:00 p.m. every day to coincide with the pictures. Observations include a variety of parameters such as color, texture, height, volume, width, stem thickness, leaf length, and consistency amongst plants within the same test. In addition to that, seed germination rates and developmental milestones were accounted for along with daily observations. Once weekly, or on days which are a multiple of seven (7) in regards to the days of the experiment timeframe, 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 testing of nitrogen, phosphorus, potassium, calcium, magnesium, oxygen, copper, silicon, and pH could take place.

Water samples were kept following testing. Plant heights were measured and an average height per pot was formulated. Upon the completion of fifty-six (56) growing days, crops were harvested in full and weighed immediately after the removal of excess water on any roots. Plants from each test were kept separate. Following this, plants were stored in a cool, dry place as it could have been decided that biomass should undergo testing for nutrients.

*Part 3: Turnaround between growth phases*

All biomass was harvested on a Saturday, and all new growth phases began on the Sunday immediately following. After biomass was harvested, it was removed from the testing area. Lids of testing containers were removed and set aside for sterilization, and vermiculite from netted pots was collected, sterilized, and left in a secure place for the time being, while pots had the same sterilization. Any components of the aeration system that came in contact with the nutrient solutions were removed and sterilized before returning. A submersible utility pump was placed into each tote to relocate the solutions outside into a reservoir. Each testing container was sterilized without relocation. New distilled water was brought in and measured out exactly like the time previous. After a bleach-based sterilization, lids and pots returned to the testing area and were placed on their respective containers. A new set of fertilizer concentrations previously determined was assigned at random to each test container, and was then measured out and implemented. At the same time, inert vermiculite was placed in pots, and pots were placed into the holes that are drilled into lids. Lights were inspected and replaced if the amount lumens being cast was not ideal. Seeds were sown once again on Sunday, and a new growth phase began. Only two turnarounds occurred during the timeframe of this project.

**Result Interpretation and Data Analysis:**

To begin analyzing data, biomass weights were plotted on bar graphs with error bars in order to compare and contrast weights to form conclusions. The weights alone revealed little about results, but percent deviation produced by individual fertilizer combination tests varied, ranging between as low as 13.5% and as high as 76.0%. However, the majority of percent deviations for any given test remained between 25.0% and 40.0%. In comparison to the control test (General Hydroponics macronutrients and micronutrients in the recommended concentration), only about 5% of all tests were able to prove that their percent deviations surpassed it in reliability and consistency.

An ANOVA test (f-test) that encompassed all samples and observations was performed, using the F-statistic of ($F_{80,2000} = 1.28$, $p < 0.05$). The numerator and denominator of the degrees of freedom were found by subtracting one from the total number of groups being tested (k-1, numerator), and subtracting the total number of groups being tested from the total number of data points (N-k, denominator). The F value of this ANOVA test was greater than the critical F value of 1.28, thus disproving the null hypothesis. Further ANOVA tests were run in an attempt to isolate where the variation causing acceptance of the alternate hypothesis originated. The subsequent tests of smaller sets of samples, subsets of the original ANOVA test, had F-statistics of ($F_{25,800} = 1.51$, $p < 0.05$), ($F_{8,260} = 1.98$, $p < 0.05$), and ($F_{2,90} = 3.11$, $p < 0.05$), depending on the chosen sets of data being tested, also disproved the null hypothesis.

With further ANOVA tests not providing concise conclusions, the same data sets were compared by using t-tests for independent means, using the T-statistic of 2.000. The degrees of freedom was found by adding the number of components within each data set being compared and then subtracting two ($n_1+n_2-2$), and the alpha value was lowered in comparison to the previous ANOVA tests in order to reduce the likelihood of receiving a false positive during testing ($\alpha = 0.025$, 2.5%). Every possible pair of data sets were compared against each other to either prove or disprove a null hypothesis. Concise conclusions regarding statistical significance could now be finalized based upon the results of the t-tests. For each data set, the amount of times that $\mu 1 > \mu 2$, $\mu 1 < \mu 2$, and $\mu 1 = \mu 2$ were counted and compared to the same occurrences of all other data sets. It had been previously decided that a given data set ($\mu_1$) with the greatest number of tests that resulted in the scenario of $\mu 1 > \mu 2$ would prove to be the most statistically significant for biomass production overall, without pricing involved. In using these parameters, Advanced Nutrients in the recommended macronutrient concentration and High Output Garden in the recommended concentration had the scenario of $\mu 1 > \mu 2$ occur the most in comparison to all other data sets; seventy-nine (79) out of eighty (80) tests. This would not have been concluded from the bar graphs prior.

The most cost-effective fertilizer combination was High Output Garden macronutrient and micronutrient components both in a weak concentration. However, this combination had the ideal scenario of $\mu 1 > \mu 2$ occur only nine (9) out of eighty (80) times. Overall, fertilizer combinations that had one part from the High Output Garden brand were generally the lowest for unit pricing, and Advanced Nutrients components caused pricing to rise. General Hydroponics components did not cause a large fluctuation in pricing. When the fertilizer combination that statistically proved to be the greatest biomass producer is compared to the combination that it was indifferent to, it is observed that the greatest producer has a lower unit price than the compared combination. All subsequent combinations were observed to have comparable costs but lesser biomass outputs by weight. In no scenario did other possible combinations prove to be effective for biomass production. Therefore, this proves that the fertilizer combination that is able to consistently produce the most biomass also proved to be the most cost effective, having a wholesale price of roughly \$0.05 per L of water (\$1.79 for experimentation within 33L of water).

Analyses of specified components within the water revealed that greater quantities of each nutrient caused the demise of crop development, with some nutrients being more essential than others in hydroponic development of arugula. The most crucial components tested appeared to be phosphorus, calcium, potassium, and nitrogen, though magnesium, silicon, and copper also aided in development. Being crucial to the development and growth of arugula, it can be concluded that arugula mainly consists of the minerals that are nitrogen (nitrate), calcium, and potassium. All nutrients within the water appeared to have an individual threshold for where growth would begin to slow or fail, with the "crucial" nutrients having smaller thresholds. The optimal areas in which these nutrients should exist are as follows: 100ppm nitrogen, 2ppm phosphorus, 190ppm potassium, 220ppm calcium, 0.1 > ppm magnesium, 12ppm oxygen, 1ppm silicon, 0.25ppm copper, and a pH of approximately six (6). The "crucial" nutrients could waiver from these amounts by approximately 10ppm, and other nutrients hardly appeared to fluctuate, but crops could still produce larger outputs of biomass under these parameters.

**Conclusions:**

In conclusion, the initial hypothesis was incorrect as the combination of the combination of High Output Garden in the recommended macronutrient concentration and General Hydroponics in the recommended micronutrient concentration was not able to produce the most biomass for the lowest cost. Though both brands utilized have low unit prices compared to a variety of other available options, the associated biomass that was harvested proved to be statistically less than at least one other fertilizer combination. Despite the concentrations of given nutrients appearing to be relatively manageable, they proved to be crossing over the determined threshold, which overall lead to the unproductivity of growth and development, even with the higher mean weight of associated crops. Proving to determining and subsequently remain within the nutrient threshold, the recommended concentration of Advanced Nutrients macronutrients and the recommended concentration of High Output Garden micronutrients produced the highest statistical biomass yield, and also proved to have the most efficient cost for growing. Though the combination described in the initial hypothesis had a lower unit price for fertilizer, it was determined that it would not be economical to use consistently in the future in comparison to the greatest biomass producer, which had a comparable unit cost. Thus, it is easily said that greater concentrations of nutrients will eventually be harmful for plant growth, but the point in where that would happen was not determined. With the gathered results and observations, it has been proved that there is a threshold for which quantities nutrients should be found in for optimal growth and harvest, while the measurement of pH does not affect final outputs. Additionally, it has been proved that exceeding these quantities, regardless of brand, will be detrimental to plant growth.

In knowing the range in which nutrients must exist instead of a rough, recommended amount, a variety of applications can be practiced. Aside from proving that there are other ways to supply crops contrary to what a company advises, this low-cost combination of fertilizer that is seemingly unconventional can be used in both cash crop operations, or hydroponics at home. Growing a larger yield for a fraction of the usual price will pay off over time, and feed more people in comparison to already existent fertilizers that are cost inefficient, often more than triple the cost of the greatest producing fertilizer discovered. This allows for greater food security as well as higher profitability for the same, if not smaller, space and time commitment. Hydroponic systems already accelerate crop development. Therefore, in using a statistically consistent and high-value producing fertilizer to grow crops, more consumable goods become available, meaning that importation of goods may become counterintuitive, possibly lowering harmful emissions from transportation. The ability to replicate the collected results based on statistical analyses shows that the most cost effective and greatest fertilizer for biomass production can serve as a long-term sustainable solution to food insecurity, the rehabilitation of the environment, and making hydroponic growing accessible to all through the lowering of cost. In food security, the reliability and consistency of yields proves to be viable. In environmental rehabilitation, no erosion of soil will occur from tillage, and no runoff into water sources will occur from excess fertilization. In cost efficiency, there is no need to purchase hydroponic fertilizers that provide substandard yields for a high price. Overall, the discovery of an optimal hydroponic fertilizer will reflect positively on agricultural advancement and development by creating a more sought-after way of producing cost-effective, sustainable, and reliable food for any individual to utilize.

## Appendix A: References


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