Hydroponic and Soil-based Methods for Crop Production: Results from an Exploratory Research for Tomatoes, Lettuce, and Chicory.

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Introduction:

There are currently 7.8 billion people in the World, and by 2050 the population will increase to 9.1 billion. In an effort to fight the growing population, increasing global food demands, and supply chain bottlenecks, the agricultural industry must focus some of its energies on innovative farming methods to combat these concerns (1,2). The focus of our project was striving to answer the question of whether hydroponic-based methods produce a greater year-to-year yield compared to soil-based methods for tomatoes, lettuce/chicory. The article of which we obtained our data was chasing the answer of "To quantify crop yields of urban agriculture for a broad range of crops and explore differences in yields for distinct urban spaces and growing systems". In the article the authors investigated how growing crops using different methods and in different growing mediums would affect year-to-year yields. Another main point of the research was on urban agriculture and its effects on food security. Commonly discussed as a sustainable solution for dealing with gaps in the local food system, and proponents often highlight the many social, environmental, and economic benefits (3). This new methodology of farming goes about supporting the local food supply and applying more sustainable practices than conventional agriculture (4).

When doing our research, we used the data to focus on hydroponic and soil-based farming to see how it directly affected yields. Hydroponic farming has many different forms which can be used in urban environments, with that, hydroponic farming is a way to omit the soil and focus the health of the plant through providing it with a nutrient enriched water mixture. (5). Whereas soil-based agriculture depends on the soil where they can absorb different nutrients and grow in full health (6). The research demonstrated in this report will work to show how hydroponic urban agriculture could play an important role in providing food security through three high-value crops (7).

Methods:

To answer our research question, the first necessity was to identify our variables of interest. The independent variable is the growth method used, which is categorical. The dependent variable is the yield, which is a quantitative and continuous variable. Also, for our project, we are specifically interested in two types of vegetables which are tomato and lettuce/chicory.

We identified a dataset containing the necessary variables for this project. The data was obtained from a research article named, "How Much Food Can We Grow In Urban Areas? Food Production and Crop Yields of Urban Agriculture: A Meta-Analysis", carried out by Payen and colleagues and utilized as this project's primary data source (5). This dataset has 2063 total

observations and 15 variables. We tidied the database in Excel by dividing the dataset to keep only the subset of interest, which were tomatoes and lettuce/chicory, then by fixing the column names to be computer readable.

Overall, in our main spreadsheet, there were 553 observations in total and 4 variables including (a) *Crop_grown* which lists our vegetable subgroups of interest, (b) *Orientation* which lists either horizontal or vertical integration, (c) *Growing_methods* which lists either soil-based or hydroponics, and (d) *Yield* which lists the kg/m2/year of a specific crop grown.

Using the libraries tidyverse (8), patchwork (9), car (10), we wrote the R script to analyze the difference in yield depending on the method used for Tomatoes and lettuce/chicory. First, the libraries were imported, then the tidied data was imported as a .xlsx file into Posit Cloud. From there, we performed t-tests to see if the means between the different methods used were significantly different. To know which t-test to perform, we had to perform two steps beforehand. Therefore, for our two samples (Tomatoes and Lettuce/Chicory), we conducted: (1) a normality test to understand the distribution, (2) a test of homogeneity of variances.

To conclude, following our statistical analyses, we undertook an exploratory analysis that consists of capturing the yield that would be produced according to the orientation of tomatoes and lettuce/chicory from a specific method: the hydroponic method.

Results:

The results of the Shapiro-Wilk tests did not show evidence of non-normality (Tomatoes: $W = 0.99$, p-value = 0.83 | Lettuce/Chicory: $W = 0.99$, p-value = 0.28). Based on this outcome, Bartlett's test statistic was designed to test for equality of variances. The results indicate that there is a significant difference between the variances of the two groups (Tomatoes: $B = 259.95$, p-value < 2.2e-16 | Lettuce/Chicory: $B = 292.78$, p-value < 2.2e-16). Therefore, we ran the Welch t-test, which doesn't assume the equality of the two variances. The results of Welch's t-test indicated that the means are significantly different for the two types of vegetables (Tomatoes: $t(54) = 2.64$, p-value < 0.05 | Lettuce/Chicory: $t(241) = 4.85$, p-value < 0.001). Indeed, concerning tomatoes, we can see that in the graph A of Figure 1, the difference between the hydroponic method (yield mean= 15.93) and the soil-based method (yield mean= 6.14), is statistically different (Figure 1. A). Therefore, the hydroponic method generates a better yield than the soil-based method in a substantial way. Regarding Lettuce/chicory, we can see that in the graph B of Figure 1, the difference between the hydroponic method (yield mean= 7.13) and the soil-based method (yield mean= 2.58), is also statistically different (Figure 1. B). This leads us to the conclusion that the hydroponic method generates a better yield than the soil-based method for Lettuce/chicory. We can therefore conclude that the hydroponic method is the one that generates a better yield for our two groups of interest.

Finally, regarding our exploratory analyses, the results of our analyses indicate that, for tomatoes and for lettuce/chicory, there were a significant difference between the means concerning the selected orientation of vegetables (Tomatoes orientation: $t(45) = 2.64$, p-value < 0.05 | Lettuce/chicory orientation: $t(62) = -3.85$, p-value < 0.001). We can observe in the graph of figure 2 that the horizontal farming method (yield mean = 17.29) for tomatoes generates a greater yield than the vertical farming method(yield mean = 5.07) in a significant way (Figure 2). However, for the lettuce/chicory, the vertical farming method (yield mean = 15.42) generates more yield than the horizontal farming method(yield mean = 3.92). All R scripts relating to the t-test are presented in "Supporting Information".

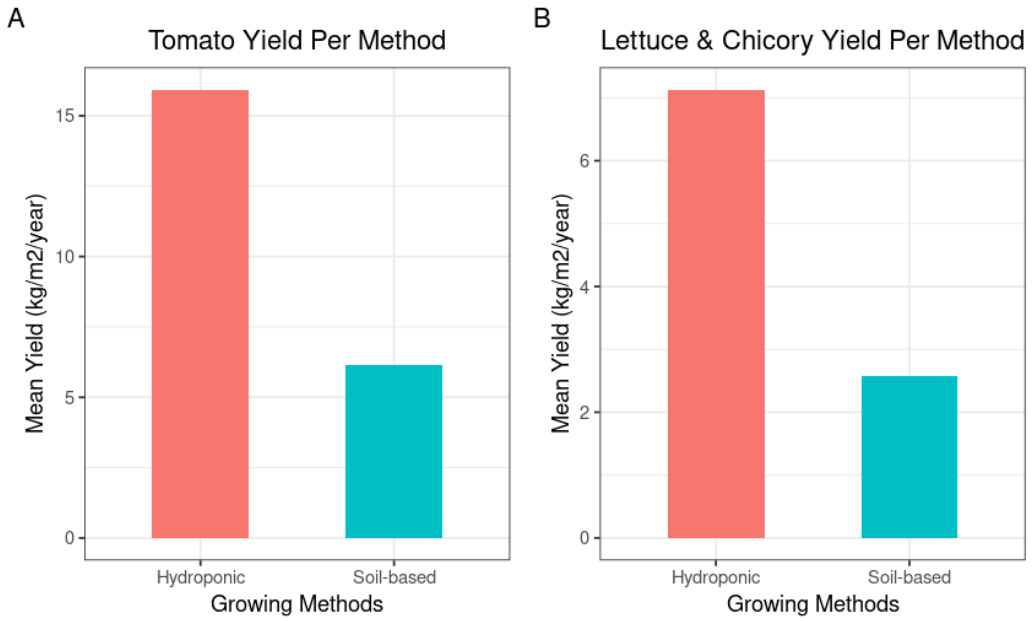

Figure 1. Yield obtained per growing methods for (A) Tomatoes (B) Lettuce and Chicory

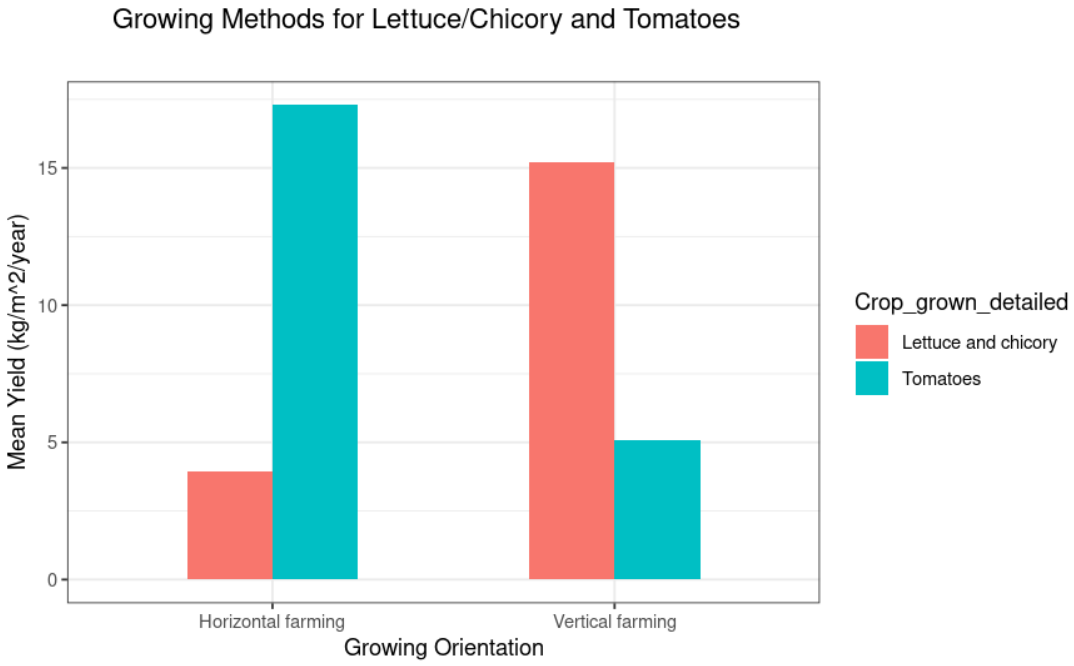

Figure 2. Average Yield obtained per orientation for vegetables (tomatoes and lettuce/chicory) from a hydroponic method

Discussion/Conclusion:

Overall, our hypothesis and prediction were supported by our analyses. Hydroponic grown tomatoes, lettuce/chicory had a statistically significant yield difference with compared to soil-based grown tomatoes and lettuce/chicory. For tomatoes and lettuce/chicory, there was an increase on average, of 160% and 176% respectively (figure 1). This proved to us, that for these analyzed crops, it is worth moving towards producing such crops in a hydroponic environment. To advance this research topic, we propose that additional crop yields be analyzed, and they be compared to resource cost consumption. For this quantitative analysis to be done, a cost-benefit-analysis of the overall-overhead must be completed to determine economic viability for each prospective crop.

Ultimately, the decision to begin moving a percentage of crop production to a modern urban-based agriculture environment will depend solely on the promise of acceptable profits a certain crop is capable of producing. Some crops cannot be stripped of their environment, therefore, as previously mentioned, modern urban-based agriculture is meant to complement traditional farming, not replace it.

Data:

https://github.com/Jefe238/Hydroponics.git

Supporting Information:

```
        Welch Two Sample t-test

data:  Tomatoes$Tomatoes_hydroponic and Tomatoes$`Tomatoes_soil-based`
t = 2.644, df = 54.221, p-value = 0.01069
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
  2.368219 17.219885
sample estimates:
mean of x mean of y
15.933333  6.139281


        Welch Two Sample t-test

data:  Orientation$`Tomatoes_Horizontal farming` and Orientation$`Tomaotes_Vertical farming`
t = 2.6408, df = 44.653, p-value = 0.01136
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
  2.898112 21.543202
sample estimates:
mean of x mean of y
17.291042  5.070385
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        Welch Two Sample t-test

data:  Lettuce$Lettuce_hydroponic and Lettuce$Lettuce_soil
t = 4.8499, df = 240.54, p-value = 2.22e-06
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 2.701321 6.396631
sample estimates:
mean of x mean of y
 7.129234  2.580259


        Welch Two Sample t-test

data:  Orientation$`Lettuce_Horizontal farming` and
Orientation$`Lettuce_Vertical farming`
t = -3.8507, df = 62.073, p-value = 0.0002812
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -17.46611  -5.52906
sample estimates:
mean of x mean of y
 3.924338 15.421926
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