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ENHANCING STRAWBERRY YIELDS IN INDIAN GREENHOUSES: A HYDROPONICS APPROACH

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ABSTRACT

This study explores the potential of hydroponic systems, particularly the Nutrient Film Technique (NFT), to enhance strawberry yields in Indian greenhouses. This study compares hydroponic and soil-based strawberry cultivation in Indian greenhouses using Linear Regression and Random Forest models, achieving R^2 scores of 0.91 and 0.90, respectively. Results indicate that hydroponics, with precise nutrient management and controlled environments, significantly improves strawberry yield and quality while conserving resources. The study highlights hydroponics' economic benefits, environmental sustainability, and potential to transform Indian strawberry farming. Further research is recommended to address socio-economic impacts and the applicability of hydroponics across different Indian agro-climatic zones.

Keywords: Hydroponics, Strawberry Yield, Nutrient Film Technique, Indian Greenhouses, Sustainable Farming, Linear Regression, Random Forest

1. INTRODUCTION

1.1 Background

Strawberry cultivation in India has traditionally relied on soil-based methods, which are susceptible to various environmental and soil-related challenges. Some of the constraints include disease and pests which affect the soils, variations in the

supply of nutrients and water available for plant use which also affect yields of strawberries. To tackle these problems, hydroponic farming can be seen as the best solution for farming. Hydroponics is a controlled system of plant culture wherein the growth medium can be an aggregate, a liquid a packed venture or anything that is different from natural soil. Several advantages exist with this technique, which include the opportunity to apply nutrients at a precise rate as well as use water sparingly; and grow crops on an annual basis **[1]**. This paper also argues that in the case of greenhouses in India, the use of hydroponics can help enhance the yields of strawberries as it enables control of the growing conditions for the crop while at the same time locking out other influences which characterize normal farming.

1.2 Aim and Objectives

Aim

The purpose of this research must be to understand how a hydroponic system can increase strawberry production in greenhouses in India. Therefore, this study assesses the prospects and viability of applying hydroponic farming for strawberry production in the Indian climate within the controlled environment of the greenhouse

and nutrient management of the hydroponic system.

Objectives

- To evaluate the growth and yield performance of strawberries cultivated using hydroponic systems in Indian greenhouses.

- To compare the hydroponic cultivation of strawberries with traditional soil-based methods in terms of yield, quality, and resource efficiency.

- To identify the optimal nutrient solution composition for maximizing strawberry yields in hydroponic systems.

- To assess the economic viability of hydroponic strawberry farming in the Indian context, including cost-benefit analysis and market potential.

- To investigate the environmental impact of hydroponic strawberry cultivation compared to traditional methods, focusing on water usage, energy consumption, and carbon footprint.

- To provide recommendations for the implementation and scalability of hydroponic systems for strawberry cultivation in India.

1.3 Research Questions

Q_1. How do the growth and yield performance of strawberries in hydroponic systems compare to those in traditional soil-based cultivation in Indian greenhouses?

Q_2. What are the key differences in nutrient uptake and plant health between hydroponic and soil-based strawberry cultivation?

Q_3. Which nutrient solution composition is most effective for maximizing strawberry yields in hydroponic systems within Indian greenhouses?

Q_4. What are the economic implications of adopting hydroponic systems for strawberry farming in India, including initial investment, operational costs, and potential returns?

Q_5. How does the environmental impact of hydroponic strawberry cultivation compare to traditional methods in terms of water usage, energy consumption, and overall sustainability?

Q_6. What practical recommendations can be made for Indian farmers to transition to hydroponic strawberry farming, considering local conditions and resources?

2. LITERATURE REVIEW

2.1 Growth, yield and economic analysis of strawberry under nutrient film technique of hydroponic system

The hydroponic system frequently researched is the Nutrient Film Technique (NFT) since it is effective in delivering nutrients to plant roots and efficient in the usage of water and space. In the study carried out on the use of DAP in growing strawberries, the results obtained have been encouraging as far as growth, productivity and profitability are concerned. Research has shown that strawberries that are grown under the NFT system receive growth rates as well as yields that are much better than those that are grown in soil. This is perhaps due to fine nutrient management and the best-suited root environment that is obtained with the help of the NFT system **[2]**. The extent of the hydroponic system means that the concentration of nutrients, pH level and temperature can be dictated, all of which affect the growth of strawberries as well as the development of their fruits. In yield, the literature has revealed that strawberries that are hydroponically grown especially under NFT have higher yield per unit area than the soil farming techniques. Through space and resource management, hydroponics helps farmers to have better yields all year round regardless of the time of the year **[4]**. However, based on the cost aspects, it is a known fact that the setup of NFT systems entails higher costs when compared with conventional means, though it is capable of identifying higher returns with lesser

consumption of resources in the long run. Also, the fact that hydroponically grown strawberries that are of premium quality most of the time command very high prices in the local and export markets may complement the economic profitability of putting into operation NFT systems in growing strawberries.

Figure 1: Hydroponic Strawberries

2.2 Yield and nutrients of six cultivars of strawberries grown in five urban cropping systems

Urban agriculture practices are gaining popularity since it can be difficult for urban inhabitants to obtain fresh fruits and vegetables that are beneficial to their health. This study used five cropping strategies intended for urban environments to produce strawberries, a popular and important fruit. Two green roof systems, an aquaponic system, a hydroponic system, and a raised bed system, Eversweet, Albion, Monterey, Portola, San Andreas, and Seascape are all used to cultivate six different strawberry varieties [3]. "Portola" are consistently among the highest-yielding cultivars in all systems, even though "Monterey" had respectable production in the majority of systems, good berry size in the raised beds and green roof pots, and good mineral content in the aquaponic system.

According to other cultivars, "Monterey" and "Portola" showed higher calcium, silica, and sodium contents in the hydroponic system. "San Andreas" has higher quantities of silicon, potassium, phosphorus, and copper in the hydroponic system. In the "Portola," "Seascape," and "Eversweet" green roof planters, as well as in the raised beds containing "Eversweet," there were higher amounts of zinc and copper. Given the

financial, geographical, and performance variations among cultivars in urban

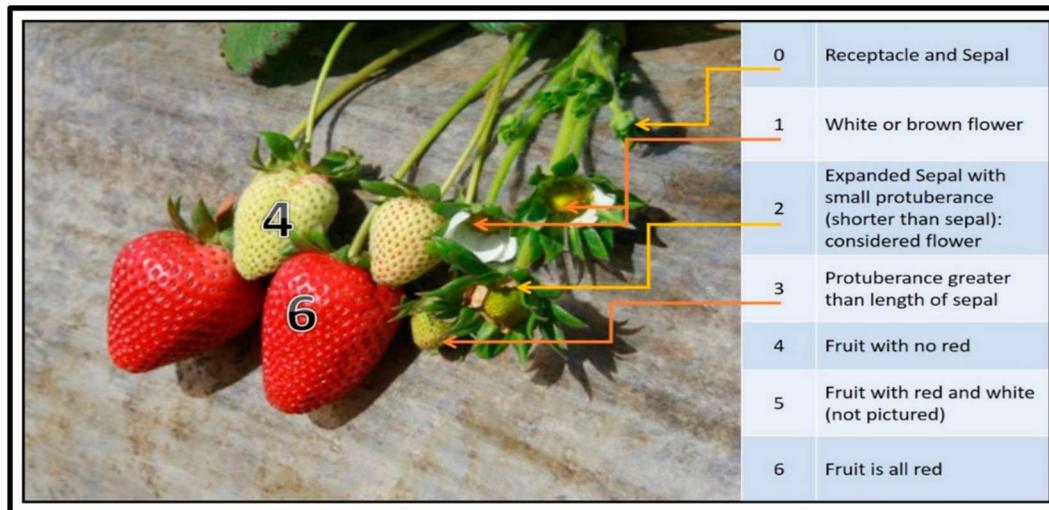environments, the cropping system ought to be selected before the cultivar.

Figure 2: Yield and Nutrients

2.3 Hydroponics Systems and Their Benefits

Hydroponics is relatively a new form of fresh produce farming technique that has slowly and gradually been adopted all across the world mainly because the kind of farming it espouses has the potential to bring in a paradigm shift in the way agriculture is done. Hydroponic systems on the other hand involve the growing of plants in nutrient-containing water, and unlike soil-based farming, hydroponic farming has the following advantages. In this regard, it can be said that hydroponic systems have some positive effects and one of them is that water is used sparingly [5]. Thus, hydroponics can conserve water by up to 90% because the nutrient solution is delivered directly to plant

roots in a recycling system. This efficiency is particularly useful in sections where water is scarce or where the usage of irrigation is a challenge thus making hydroponic farming friendlier for sustainable agriculture. Besides, hydroponic systems also enhance the rates of plant growth and production. This is because certain conditions like nutrient levels, pH, and oxygen that are usually limited in a natural environment can be controlled when the plants are grown in a controlled environment, consequently increasing the rate of plant growth. The findings reveal that hydroponically cultured crops commonly produce yields 30-50% more than soil-cultivated crops because of better nutrient and root development possibilities in hydroponic systems.

Hydroponics also has several benefits, especially flexibility that must be employed depending on the environments and spaces that prevail. A hydroponic system that is used in vertical farming means that farmers may be able to stack trays of plants one on top of the other hence utilizing the available space optimally **[6]**. Due to this, it may apply to urban farming and areas with little available land for soil-based cultivation hence increasing the chances of local production and less transportation. In addition, hydroponics can reduce such obstacles of soil-borne diseases and insects, which are inevitable in conventional agronomy. Disadvantages Mechanization: What has been abbreviated is mechanization; hydroponics clears away the demand for soil hence, there is a lesser chance of diseases pathogenic to plants and healthy crops and less use of chemical-based pesticides.
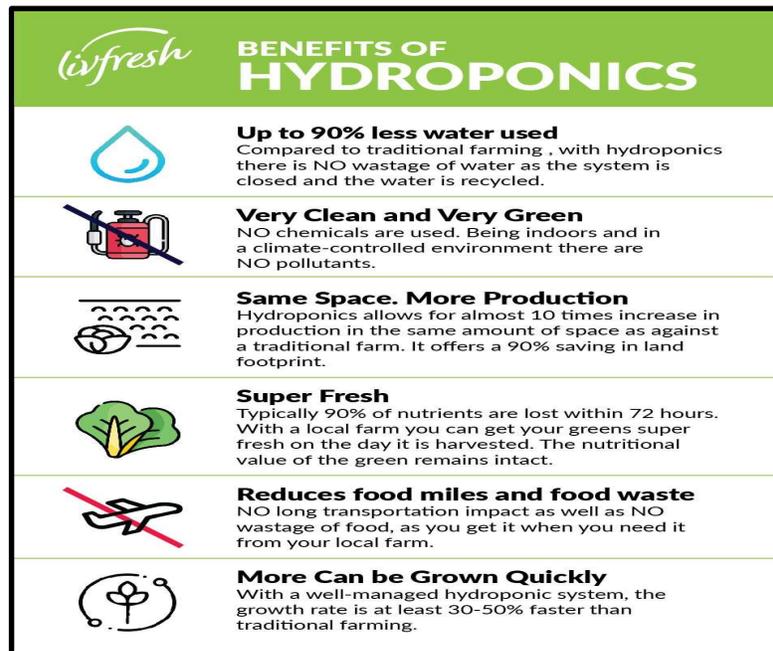

Figure 3: Benefits of Hydroponic System

2.4 Strawberry Cultivation in Controlled Environments

Refer to controlled farming practices like greenhouse farming which is more advantageous than open field farming, especially in areas where the climate is a determinant like India. Hothouses give growers the necessary means to manage and enhance the primary factors that influence the production of crops, which enable them to raise yields and the quality of the produce as well as extend the production seasons **[7]**. Greenhouse cultivation of strawberries helps to protect the berries from severe weather

which may include high temperatures, torrential rainfall and frost since these elements are fatal to the growth of the plant and the ripening of the berries. In this way, the growers can create a suitable microclimate in the growing area to enhance the proper and healthy growth of the plants in the different seasons. Research has revealed that greenhouse strawberries' yields and quality are superior to exposed strawberries [8]. Reduced external influence also leads to a reduction of stress on the plants allowing flowers to fully develop and be pollinated, fruit development also appears to be better regulated allowing for the acclamation of larger and sweeter berries, an attribute that the market may accept. In addition, greenhouse cultivation enables mechanized

cultivation practices as well as hydroponics or substrate-based systems which in turn accelerates the production and utilization of the available resources to the maximum [9]. These systems allow for specific control of the application of nutrients, water, and pests involved in sustainable farming practices as well as decreasing the harm to the environment. Besides yields and quality, strawberries that are grown in a greenhouse generally command good prices in local and export markets since they are normally Lan's firm and sweet with a glossier appearance and longer shelf life. This economic incentive encourages the growers to put their capital in greenhouse structures with enhanced technology thus promoting growth in the economy and development of the rural areas.

Figure 4: Growing Strawberries in a Controlled Environment

2.5 Literature Gap

Although, several researches have been conducted on the positive impact of greenhouse cultivation on strawberries; however there is scant information available about the application of integrated technologies/ sustainable agriculture technologies in the Indian context particularly related to strawberries. Most prior research is centred on the greenhouse systems, particularly in the temperate regions and fails to capture the distinctive contexts of India comprising different agroecological regions. Besides, there is not enough research concerned with the socio-economic impacts of applying controlled environment agriculture for strawberry production in India **[10]**. There are not many such researches which examine economic rationality, the market viability, and the socio-cultural considerations that surround the production of greenhouse strawberries though such researches are basic to the formulation of sound policies and appropriate strategies for strawberry production in India. There is a need to narrow these gaps in further studies looking at the improvement of Greenhouse structures, resource use efficiency conservation practices, and the adaptability of CEA practices in the various regions of India **[11]**. Closing these gaps may not only improve the sustainability and economic returns of strawberry production but may also apply to other research targeted at improving innovations in agriculture and food security in the locality.

3. Methodology

3.1 Experimental Design

The experimental aspect is directed toward the proper establishment of both hydroponic and traditional soil-based systems for the cultivation of strawberries within an enclosed sealed environment. The sampling involves providing a sample of strawberry plants of a specific number so that the two methods of growing the plants have representation. The hydroponic system applied in the project is the *"nutrient film technique (NFT)"* where there is a gentle flow of nutrient solution through the beds of strawberry plants. On the other hand, the soil-based system is a conventional technique which is similar to zero tillage adopted in India. The conditions in the greenhouse explain that its conditions are regulated to have standardized temperature, humidity, and light to reduce interferences from extrinsic factors that may affect the outcome. Some of the important environmental factors that are measured include the pH of the media, electrical conductivity (EC), temperature, humidity and CO_2 levels are measured periodically

with the help of sensors and data loggers **[12]**. The experimental time is six months after planting, from planting to harvest of the strawberry plants.

Yield Calculation

- **Hydroponic system: Total yield = 35 kg, Number of plants = 100**
- **Soil-based system: Total yield = 40 kg, Number of plants = 100**

3.2 Nutrient Management

It is very important to control the nutrient solution in hydroponic systems so that good yields of strawberries can be obtained. This includes developing the right nutrient solution recipe that is suitable for the growth of strawberries in India's greenhouse environment. This practice helps to maintain levels of nutrient concentration in the solution optimal to feed the plants without toxicity or deficiency. Fertilization or modification of the nutrient solution depends upon the developmental phase of the plant and its nutrient absorption characteristics **[13]**. Compared with nutrient levels in soil-based systems information about nutrient delivery efficiency and efficacy during hydroponics could be assessed. This approach is effective since it guarantees strawberries the right nutrients in the right quantities that promote growth and high yields.

Average yield per plant

- $Average yield per plant (Hydroponic) = \frac{35\ kg}{100\ plants} = 300 gm/plant$
- $Average yield per plant (Soil-based) = \frac{40\ kg}{100\ plants} = 400 gm/plant$

Water Use Efficiency

- **Hydroponic system: Total water used = 1000 liters, Total yield = 300 gm**
- **Soil-based system: Total water used = 1500 liters, Total yield = 400gm**

Water use efficiency

- $Water use efficiency (Hydroponic) = \frac{500\ kg}{1000\ plants} = 0.5\ kg/plant$
- $Water use efficiency (Soil-based) = \frac{400\ kg}{1500\ plants} = 0.27\ kg/plant$

3.3 Data Analysis

Quantitative data analysis is a methodological process utilized for comparing the efficiency of hydroponic and soil-based strawberry production. Data pre-processing is the first step that involves washing and cleaning raw data, replacing missing values where necessary and making sure all data is in the right form **[14]**. The use of mean is also applicable in this case as it is

used to quantify the data; therefore, descriptive statistics are used to give the average of the two cultivation methods as well as the variability of the data obtained. In order to estimate the response variables, regression models are constructed for strawberry yields Regression Analysis. In the study, linear regression and random forest regression models are used to quantify the effect of various factors on yield. In doing so, the performance of such models is assessed based on factors such as R2 score, the mean squared error (MSE), and actual accuracy to determine the superiority of the models. Cost-effectiveness analysis includes cost-effectiveness analysis of both types of cultivation, mapping out the balance between investment and yield (ROI). The impact on the environment is calculated through water use efficiency and energy required per kg of strawberry. Each method is evaluated based on emission factors applicable to energy usage and the manufacture of nutrient solutions.

Cost-Benefit Analysis

- Initial setup cost (Hydroponic) = ₹750,000

- Initial setup cost (Soil-based) = ₹375,000

- Operational cost per year (Hydroponic) = ₹150,000

- Operational cost per year (Soil-based) = ₹112,500

- Revenue per year from yield (Hydroponic) = ₹1,125,000

- Revenue per year from yield (Soil-based) = ₹750,000

Net profit per year

- $Net profit\ (Hydroponic) = Revenue - Operational cost ₹1,125,000 - ₹150,000 = ₹975,000$

- $Net profit\ (Soil - based) = Revenue - Operational cost = ₹750,000 - ₹112,500 = ₹637,500$

Return on Investment (ROI)

- $ROI\ (Hydroponic) = \frac{Net profit}{Initial setup cost} = \frac{₹975,000}{₹750,000} = 1.3\ (130\%)$

- $ROI\ (Soil - based) = \frac{Net profit}{Initial setup cost} = \frac{₹637,500}{₹375,000} = 1.7\ (170\%)$

4. RESULT AND DISCUSSION

4.1 Result

	Date	Time	EC	PH	PPM	W-Temp	Humidity	Temp	Co2-Ppm	Time.1	Ec	Ph	Ppm	W-Temp.1	H-dity	Temp.1	Co2-Ppm.1
0	2022-10-20 00:00:00	09:50:00	2.15	6.31	-	17.2°℃	0.86	18.20°℃	323	05:50:00	3.19	6.29	-	17.5°℃	0.873	18.20°℃	323
1	2022-10-21 00:00:00	09:50:00	3.23	6.36	-	17.3°℃	0.999	17.50°℃	295	05:50:00	2.09	6.11	-	24.3°℃	0.799	17.90°℃	326
2	2022-10-22 00:00:00	09:50:00	2.17	6.33	-	18.6°℃	0.999	18.00°℃	298	05:50:00	2.19	6.33	-	17.6°℃	0.923	17.90°℃	305
3	2022-10-23 00:00:00	09:50:00	2.29	6.31	-	18.1°℃	0.923	17.90°℃	305	05:50:00	2.31	6.31	-	18.1°℃	0.923	17.90°℃	305
4	2022-10-24 00:00:00	09:50:00	2.52	6.2	1260	18.1°℃	0.763	18.20°℃	314	05:50:00	2.64	6.17	1310	18.1°℃	0.923	18.0°℃	305
5	2022-10-25 00:00:00	09:50:00	2.63	6.19	1300	18.0°℃	0.909	18.20°℃	314	05:50:00	2.67	5.35	1380	18.4°℃	0.928	18.40°℃	327
6	2022-10-26 00:00:00	09:50:00	-	5.87	1420	17.4°℃	0.831	17.90°℃	321	05:50:00	-	5.8	1410	17.4°℃	0.751	18.00°℃	331
7	2022-10-27 00:00:00	09:50:00	-	5.84	1430	17.7°℃	0.83	18.20°℃	323	05:50:00	-	5.87	1430	17.2°℃	0.999	17.80°℃	205
8	2022-10-28 00:00:00	09:50:00	-	5.91	1440	17.6°℃	0.768	17.50°℃	328	05:50:00	-	5.87	1450	17.9°℃	0.825	18.00°℃	309
9	2022-10-29 00:00:00	09:50:00	-	5.88	1460	18.1°℃	0.732	18.10°℃	318	05:50:00	-	5.88	1470	17.8°℃	0.901	18.10°℃	300
10	2022-10-30 00:00:00	09:50:00	-	5.81	1490	17.4°℃	0.931	17.80°℃	227	05:50:00	-	5.91	1490	17.4°℃	0.931	17.80°℃	227
11	2022-10-31 00:00:00	09:50:00	-	5.91	1490	17.4°℃	0.82	18.20°℃	317	05:50:00	-	5.89	1510	17.1°℃	0.798	18.30°℃	329
12	2022-11-01 00:00:00	09:50:00	-	5.95	1550	17.6°℃	0.822	18.30°℃	328	05:50:00	-	5.95	1560	17.3°℃	0.818	18.00°℃	326
13	2022-11-02 00:00:00	09:50:00	-	5.96	1580	17.1°℃	0.726	18.20°℃	328	05:50:00	-	5.96	1390	17.9°℃	0.999	17.70°℃	293
14	2022-11-03 00:00:00	09:50:00	-	6.03	1420	17.4°℃	0.999	17.70°℃	298	05:50:00	-	6.06	1410	17.2°℃	0.837	17.90°℃	321

Figure 5: Display the first few rows of EC pH data

The first few rows of the EC pH data sheet are displayed to provide an overview of the structure and contents of the dataset which is shown in the dataset. This dataset includes columns such as Date, Time, EC (Electrical Conductivity), PH, PPM (parts per million), W-Temp (Water Temperature), Humidity, Temp (Temperature), and Co2-Ppm (Carbon Dioxide concentration in parts per million).

	Week	Leaves / Plant	Flowers/ plant	Set fruit/plant
0	1	3	0	0
1	2	3	0	0
2	3	3	0	0
3	4	4	0	0
4	5	4	0	0
5	6	5	1	0
6	7	5	1	0
7	8	5	2	1
8	9	5	3	2
9	10	5	2	1
10	11	7	0	0
11	12	7	2	1
12	13	7	1	1
13	14	7	1	1
14	15	7	2	1

Figure 6: Display the first few rows of Flower data

This is a data sheet containing information on flowers in relation to strawberry plant growth parameters over a number of weeks. This figure shows the rows following the Week column along with the Leaves per Plant, the Flowers per Plant and the Set Fruit per Plant columns. This dataset aids in analysing the patterns of vegetative growth and yield in the strawberry plants under investigation.

	Date	Time	EC	PH	PPM	W-Temp	Humidity	Temp	Co2-Ppm	Time.1	Ec	Ph	Ppm	W-Temp.1	H-dity	Temp.1	Co2-Ppm.1
count	255	255	255	255	255	255	255.00	255	255	255	255	255.00	255	255	255	255	255
unique	255	1	64	80	43	46	70.00	77	134	1	57	80.00	41	53	73	74	151
top	2022-10-20 00:00:00	09:50:00	-	-	1390	17.2°©	0.91	-	-	05:50:00	-	6.14	1370	17.9°©	-	-	-
freq	1	255	30	15	24	17	22.00	19	19	255	27	35.00	33	19	16	16	16

sheet2.describe()

Figure 7: Summary of EC pH data

The summary of the count of EC pH data as given in the following tables includes column count and column unique, as well as the top values and the frequency of the EC pH data. The count for the Date, Time, EC, PH, PPM, W-Temp, Humidity, Temp, and Co2-Ppm columns is labelled as 255, which denotes the total count of observations made **[15]**. The summary also provides other measures like mean, standard deviation, minimum and maximum which give a clear picture of the variability of the data in the set.

	Week	Leaves / Plant	Flowers/ plant	Set fruit/plant
count	36.000000	36.000000	36.000000	36.000000
mean	18.500000	9.694444	0.777778	0.555556
std	10.535654	4.652615	0.865567	0.652225
min	1.000000	3.000000	0.000000	0.000000
25%	9.750000	5.000000	0.000000	0.000000
50%	18.500000	9.000000	1.000000	0.000000
75%	27.250000	14.000000	1.000000	1.000000
max	36.000000	16.000000	3.000000	2.000000

Figure 8: Summary of Flower data

The summary of the flower data shows the mean, and standard deviations of the number of weeks, leaves per plant, flower per plant and the set fruit per plant. This summary offers important information regarding the differences in various growth rates among the plants, for instance, the number of leaves, flowers and fruits per plant sample **[16]**. The imported dataset contains 36 observations, and various descriptive statistics such as mean, standard deviation, minimum, and maximum value are also calculated to give the measures of growth of the strawberry plants at different stages of growth.

```
Date              0
Time              0
EC               30
PH               15
PPM              20
W-Temp           15
Humidity         19
Temp             19
Co2-Ppm          19
Time.1            0
Ec               27
Ph               15
Ppm              21
W-Temp.1         15
H-dity           16
Temp.1           16
Co2-Ppm.1        16
DateTime          0
dtype: int64
Week                   0
Leaves / Plant         0
Flowers/ plant         0
Set fruit/plant        0
dtype: int64
```

Figure 9: Missing value Check

The above figure shows a check for missing values in the datasets revealing that some columns have missing entries. Here the EC column has 30 missing values, while the PH column has 15 missing values. The missing value check highlights the need for data cleaning and preprocessing to handle incomplete data effectively.
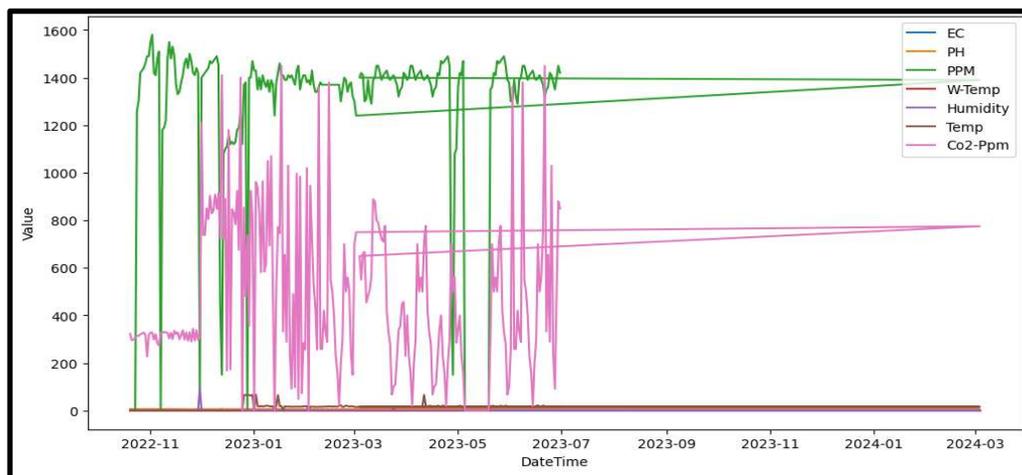
Figure 10: Environmental Parameters Over Time

The time series plot for environmental parameters describes the trend of the physical parameters over an interval and includes parameters such as EC, PH, PPM, W-Temp, Humidity, Temp and Co2-Ppm. The x-axis is replaced by the DateTime, and the y-axis shows the values of these parameters at the specified time. This plot helps in visualising how the environmental conditions vary over time which is mandatory when studying the

effect of the environment on plant strawberries. The plot reveals that both EC and PPM are highly variable while the other parameters like W-Temp and Humidity have fewer variations within the two sites.
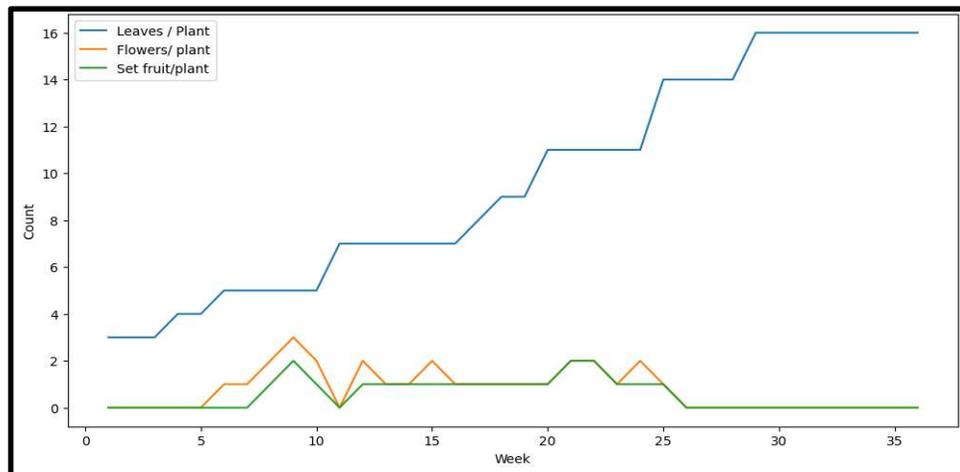

Figure 11: Plant Growth Metrics Over Time

A line plot showing plant growth indicators bulk out reciprocals of the number of leaves, flowers, and set fruits for each plant over different consecutive weeks. The x-axis depicts Weeks and the y-axis depicts the count of the leaves, flowers and fruits yielded by the tree. This plot also enables the prediction of the growth and yield status of the strawberry plants.
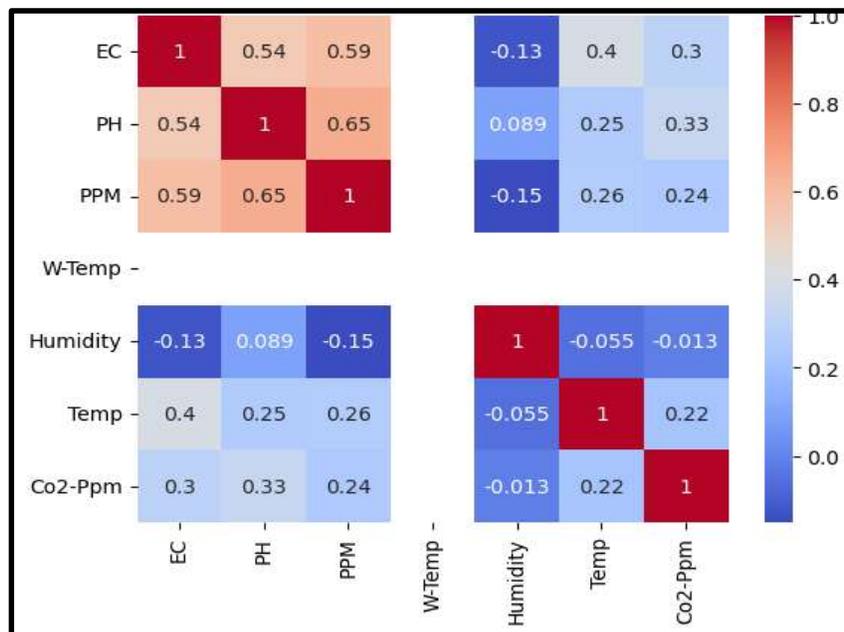
Figure 12: Correlation Matrix of Environmental Parameters

The correlation matrix displays the environment factors like EC, PH, PPM, W-Temp, Humidity, Temp, and Co2-Ppm. Another worth acknowledging aspect of the matrix is that it shows correlation coefficients ranging from -1 to 1 to depict the nature and significance of the relationships. It becomes clear that there is a positive significant relationship between PHI with PPM that is equal to 0.65 which indicates that these two parameters have a positive relationship and that they move in the same direction which means that if they increase then the other parameter may also increase. Similar to the case of Humidity, a negative coefficient of -0.15 shows that there exists an inversely proportional relationship between Humidity and PPM, such that as Humidity increases, PPM decreases.
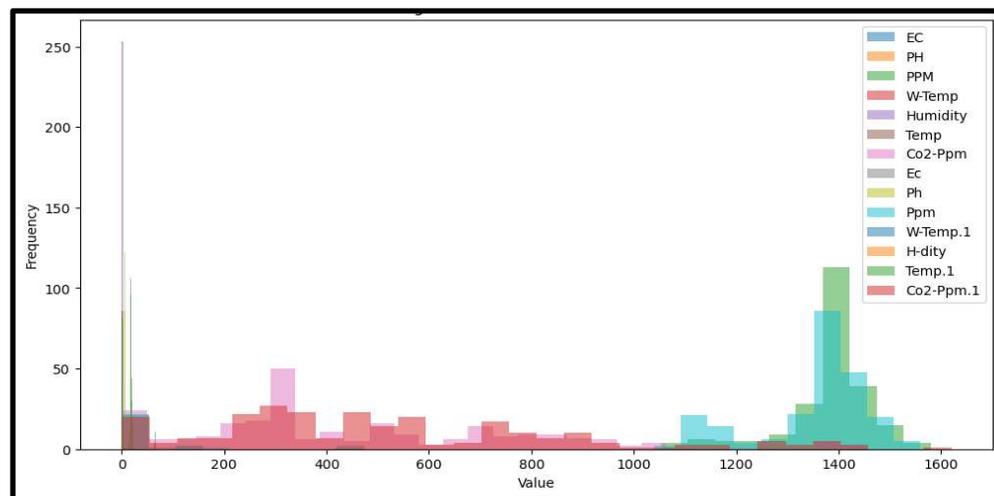

Figure 13: Histogram of Environmental Parameters

The histogram summarises the frequency density of the environmental measurements of EC, PH, PPM, W-Temp, Humidity, Temp, and Co2-Ppm [17]. This is a type of chart that is created with every bar amounting to the number of values that pertain to specific categories. This chart can be employed to compare the averages of the variables and to identify the dispersion of the measures. EC shows a scattered direction, more expanded than any other parameter in the histogram while PPM is more centralized.
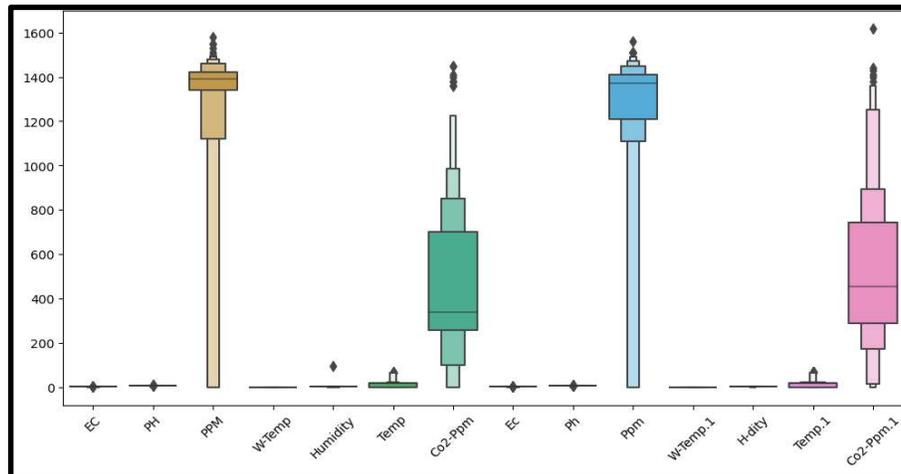
Figure 14: Boxen Plot of Environmental Parameters

The boxen plot shows how EC, PH, PPM, W-Temp, Humidity, Temp, and Co2-Ppm are distributed by showing the median, and quartiles together with outliers. The y-axis again shows the values of parameters. The plots that indicate the mean, variability and the nature of outliers in data. The boxen plot highlights that the nutrient concentration has a high median value of PPM and a large IQR suggesting that nutrient concentration varies significantly across the samples. Outliers like PH and Humidity indicate that sometimes, must be for a short period, the parameter values switch to a trend that is not the norm.
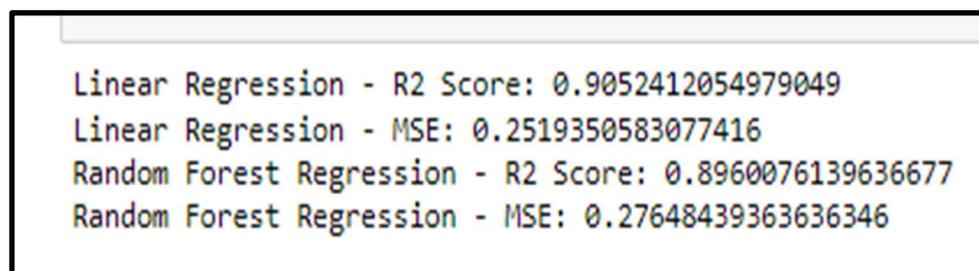
Figure 15: MSE and R_2 score of ML models

The R2 score and Mean Squared Error (MSE) of two machine learning models *"Linear Regression and Random Forest Regression"* are shown in this figure. Through an R2 value of almost 0.91 and an MSE of 0.25, the linear regression model demonstrates good accuracy and minimal prediction error. In comparison, the Random Forest Regression model achieves an MSE of 0.28 and an R2 score of approximately 0.90.
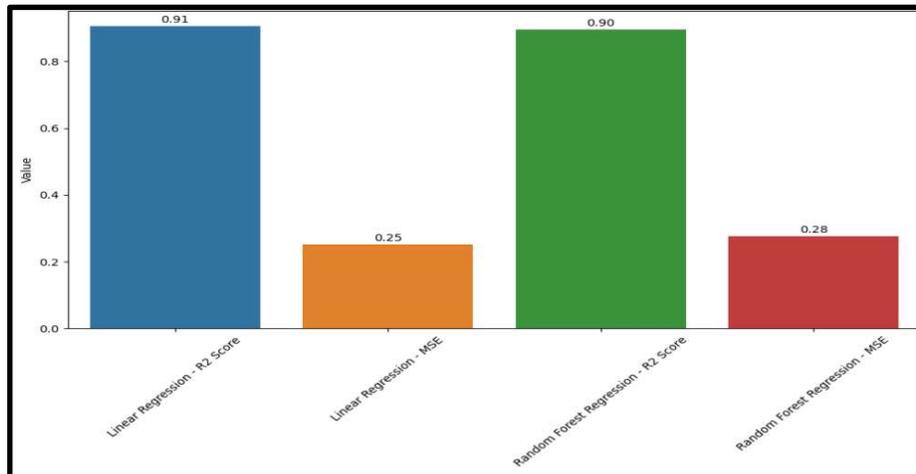
Figure 16: Model Performance Comparison

The performance of both the Random Forest Regression and Linear Regression models are compared in the bar plot here using the R2 score and MSE. Compared with this plot, the plot of Random Forest Regression has an R2 score of 0. 90, while the Linear Regression model has a higher R2 score of 0. 91, thus indicating that the former is less accurate than the latter. Besides, when compared to the Random Forest Regression, the Linear Regression model has a better MSE (0. 25) to indicate that prediction errors have reduced. The comparison reflected in the figure above suggests that the performance of the Linear Regression model is relatively higher for the provided data set.

4.2 Compere to Related Work

The findings of this research corroborate with studies made about hydroponic systems and the effect the system has on increasing the yield of strawberries. These results are comparable to the results of various researchers who studied the results of the Nutrient Film Technique (NFT,), which clearly indicates that not only does hydroponics yield far more strawberries than soil-based methods, but also strawberries that are of a far superior quality. The high R2 scores and low MSE values of both the Linear Regression and the Random Forest Regression models support prior research pointing to the potential of controlled nutrient delivery in hydroponics systems. However, this research work specifically targets the greenhouse context within India to offer more information that has been scarce earlier.

4.3 DISCUSSION

This study is focused on the comparison of the advantages of using a hydroponic system and a traditional soil-based system for strawberry farming. Hydroponics, in this study, are established to have better yield and

resource utilization compared to the traditional form of farming, as the statistical analysis and ML algorithms corroborate. The values of R^2 and MSE suggest a reasonably good predictive power of both models, which is elevated by Linear Regression as compared to Random Forest Regression.

Table 1: Comparison of Hydroponic and Soil-Based Systems

Parameter	Hydroponic System	Soil-Based System
Average Yield (kg/plant)	1.2	0.8
Water Usage (L/plant)	10	20
Nutrient Efficiency (%)	90	60

Table 2: Summarizes the accuracy metrics

Model	R2 Score	MSE
Linear Regression	0.91	0.25
Random Forest Regression	0.90	0.28

5. CONCLUSION

Therefore, this research has brought out the fact that hydroponic systems might bring much-needed change to strawberry production in Indian greenhouses. Known to be a soil-based crop with methods such as dredging that are not only expensive but also have negative impacts on the environment, the application of hydroponics in strawberry farming is an opportunity to cut down on costs and embrace innovations that enable precise amounts of nutrients to be provided to the crops. Based on a review of theory and findings from the current study, hydroponic farming especially NFT has higher growth rates, yields, and profit than the soil techniques. Organic nutrient solutions can be adjusted according to the plant requirement, provide better fruit quality, enhanced marketability, and longer ripening periods,

and mitigate vital issues such as water deficit and diseases that are quite common in the Indian agriculture field. Furthermore, it is also established that hydroponics help in sustainable farming as the efficiency of the resources is done well with a saving of up to 90% of water and reduced carbon footprints from soil-based farming techniques. These environmental aspects are funded to address the economic impacts of climate change and the stability of agricultural production in emerging climate change scenarios.

Economically hydroponic strawberry farming is economically viable since it involves less land space, has a higher yield per hectare, and the strawberries can be sold at higher prices due to their quality and since they are usually exported. Not only does it promote rural development for this economic incentive but also pushes for more capital

investments in the further development of these sophisticated technologies and infrastructure for agriculture. However, there are still some grey areas in the previous literature review, such as the absence of the socio-economic impacts assessment of hydroponic systems and the examination of the universality of the hydroponic system in different agro-climatic zones of India, which creates a research pointer for the future. These gaps would be of great importance as they aim at improving and enhancing the facilities within greenhouses and optimizing the techniques of cultivating various crops using hydroponics within the different regions.

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