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A Proposed Prediction System and Analysis of Nutrients Uptake for Better Crop Growth in Hydroponics System †

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Abstract: With the ascent of new techniques in farming, Hydroponics, an efficient and smart method of cultivating crops in water is becoming an increasingly popular choice for growing crops. It is likewise being utilized for augmenting crop yield. Water nutrient management thus becomes a vital technique for ensuring optimal requirements for crop growth. A balanced supply of these nutrients is the key to healthy plants. We studied the dynamics of the nutrients uptake for the tomato crop which aids in enhancing its absolute crop growth rate (CGR). This paper proposes a framework to predict the absolute CGR using machine learning technique for the tomato crop in hydroponics. Input variables like Electric conductivity (EC) limit, Nutrient solution (NS), ion concentration uptake, dry weight matter of the fruits are contributing factors for the feasible growth of hydroponic tomato crops. The study shows positive and negative correlations with the growth parameter dry weights of the fruits. The dynamics of uptake of nutrient ions Na, K, Mg, N and Ca during growth of tomato fruits was shown and its effect on the target variable absolute growth was studied. This correlation analysis helped us determine the important variables that affect the CGR and will give us more insights on the correct supply of nutrients for good growth and development of the crops. The proposed system design provides a smart and efficient way to predict and achieve good absolute CGR while estimating the optimum value of the essential parameters will help us in achieving good quality yields.

Keywords: hydroponics; absolute crop growth rate (CGR); nutrient solution (NS), dry weight matter; electric conductivity (EC) limit; correlations

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1. Introduction

Hydroponics is a soil-less method to cultivate crops in water. This zero soil cultivation method represents an excellent opportunity for the agriculture domain, especially in areas dealing with challenges like unmanageable soil degradation and restrained water sources [1]. Furthermore, this agricultural practice demonstrates excellent results towards an environment-friendly and user-friendly farming. It is also a reliable tool for the future of upcoming challenges in terms of food security [1]. Various parts of the globe that face challenges like unpredictable weather patterns, excessive heat, reduced space availability, are taking hydroponics as an alternate approach to farming and a potential solution for their problems. The world commercial hydroponics industry has multiplied 4 to 5-fold in the last decade and is currently approximated between 20,000 and 25,000 hectares with a farm gate value of US $6 to $8 billion. (Hydroponic Green Technologies India Pvt Ltd-HGTIPL, India). As a result, farming practices are rapidly shifting to more automated and precision farming practices for better crop yields and financial gains [2]. With the new era of big data, techniques such as machine learning and artificial intelligence available, data can be used to analyze, generate patterns and make predictions [2].

Hydroponics farming can be broadly divided into three types: Nutrient Film technique (NFT), Aquaponics, and Deep Flow technique. The Nutrient film technique (NFT) is one of the hydroponic methods wherein a shallow stream of water containing the required dissolved nutrients also called as Nutrient solution (NS) is used which is a good medium for plant growth. It is re-circulated through the roots of the plants in watertight pipes, also termed as channels. The rationale of the set up and working of the NFT is the recycling of the NS. In this system, NS is enriched with material like sand, vermiculite, or rock wool which is passed and re-circulated through a slope consisting of plants placed in a plastic trough. It provides the optimum amount of nutrients to the plant through its root system. It is ideal for short term crops like lettuce, tomatoes, strawberry, and raspberries. Hydroponics has been termed as a promising tool in the areas with limited land resources. It offers major advantages over the traditional soil farming and other cultivation methods. Low cost of installment, easy operation, management and effective utilization of nutrients, and recycling of water are some of the reasons which has made it a popular choice [3]. In general, closed hydroponic systems have lower water and nutrient requirements for plant growth [4] due to the recycling of water and nutrients. The field of hydroponics is relatively new and combining it with advancing technologies and computation can provide cost and time effective solutions. Some of the limitations in the area of hydroponics include the lack of:

(1) effective management of nutrients used in the water for hydroponic crops,
(2) detailed analysis and study of parameters that promote rapid growth with good quality yields, and,
(3) easy and smart approaches, wherein automation processes using machine learning can help us in predicting.

Different types of algorithms are used in-order to estimate and predict accurate values of the parameters involved during the growth process of the crops. This will enhance the efficiency and make hydroponics farming an easy and smart technique to maximize yields.

2. Related Work

Paper [5], discusses the application of Fuzzy algorithm Mamdani method to predict the growth and development of hydroponic watercress. The concept behind the work is to use the Fuzzy Inference System (FIS) which is basically a computing system that works on the principle of fuzzy reasoning and a similitude of human reasoning to predict crop growth. The process constructed the rule base system using the fuzzy algorithm Mamdani method, and it can form twenty-seven rules. The prediction system utilizes the independent variables having a high impact on the growth of the watercress. Authors in [6] proposed a system to monitor the growth of the plant using IoT and a fuzzy logic to maintain optimum water supply and nutrient levels. The design is effective when compared to the traditional methods used in hydroponics to monitor the nutrient and water requirements during the life-cycle of the plant. In paper [7] specifically, artificial neural networks were applied to a model that predicts the values of pH and EC of the system. These predictions are very important because they are required by other intelligent systems that ensure the proper and optimal operation of the hydroponic system. This work also connects artificial intelligence and machine learning with hydroponic systems that opens the way to further advancement and study of smart systems in the field of hydroponics that will lead to more precise cultivation. The authors in [8] utilized algorithms like neural networks to predict optimum values of temperature, pH, humidity data were obtained by sensors. The paper discusses the use of machine learning and IoT in hydroponics farming which can facilitate the farmers to do their work without continuous supervision thereby making it an efficient and easy method. In paper [9] machine learning techniques like k-nearest neighbor and lasso regression have been used for nutrient value predictions and thereby helping to maximize the crop yields.

The authors in [10] highlighted the importance of machine learning techniques in accurate crop prediction and analysis which has a positive impact on the resource management and environment.

3. Proposed System Design

The proposed system design shown in Figure 1, depicts the proposed framework for prediction of absolute CGR using machine learning. The steps followed are data gathering which includes water sample analysis, that undergoes the ion chromatography process, to determine ion concentrations. The EC limit, dry weight matter of the entire plant and fruits are the other input variables used in the database for analysis. The outputs from the data gathering and analytic steps will be fed to the machine learning algorithm to derive prediction results. The complete process is elaborated in three sections: design architecture, prediction system, flowchart of the system.

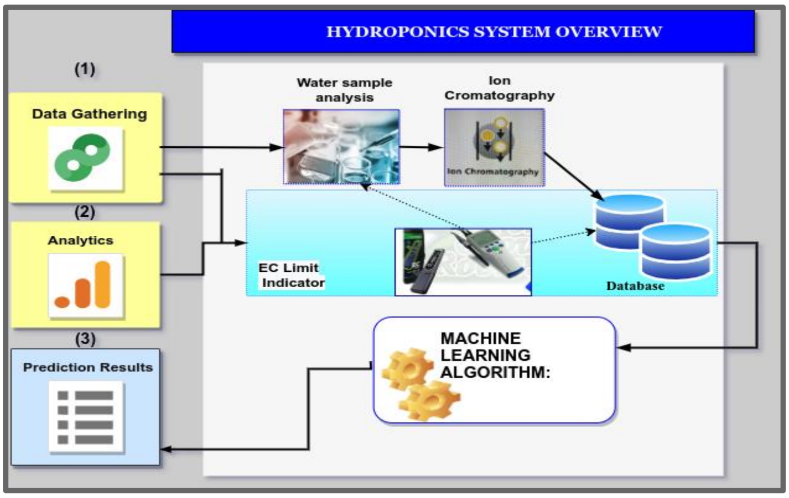

Figure 1. Hydroponics systems overview: Comprising of 3 stage: (i) Data gathering. (ii) Analytic, (iii) Prediction Results.

3.1. System Design Architecture

The complete setup is divided into three main parts: (i) data gathering (ii) analytics and (iii) prediction results. The system is flexible, easily adaptable, and can be used for crops suitable for NFT. The tomato crops were cultivated with a soil-less NFT, a re-circulated close system [11]. In our case, we consider tap water samples for analysis however we can also use rain water or treated or recycled water in NFT. The minimum value of temperature was maintained at 12 °C, and the ventilation temperature was set to 20 °C [11]. The NS solution can be bought premixed based on quantity requirements or can be prepared by self-based [12]. The formulation for the NS should be crop targeted and optimal. NS was added for hydroponic tomato crops and the volume of the NS was measured with the help of a flow meter [11]. Every 2 days, every tank was refilled with fresh NS up to the initial volume. The amount of nutrients, salts, or impurities, in the water, is referred to the Electric conductivity (EC) limit. For maintaining optimum levels of EC, authors from the study [11] set up the EC to levels (5, 7.5 and 10 $dS{\cdot}m^{-1}$, note that these values can vary for different crops). EC-based nutrient control for hydroponics crop cultivation may provide amounts of nutrients that are not in optimal amounts for the plants [13], hence cannot be used directly to determine the ions concentration [3]. An ion chromatography process Dionex model DX500; Dionex Corporation, Sunnyvale, CA, USA) process was used by [11], to indicate the total dissolved ion concentrations in the solution. The information provided the values for the ion concentration (cations) in the various parts of the tomato plant, which is subdivided into the leaf, stem, fruits, and roots. A minimum temperature of 12 °C was set and ventilation temperature was 20 °C with a relative humidity that was always higher than 50%, except for 2 days, in which it reached 45% [11]. Fortnightly, one plant from each experiment area was taken for study. The plant density was found to be 3.3 plants m^{-2}. A forced-draft oven was used to determine the dry matter weight and measured with two decimal places to weigh it [11]. The variables that were measured included dry matter weight of the entire plant (leaves, roots, stem, fruit), EC limit, NS consumption, absolute CGR total Nitrogen content of leaves and fruits, the ion concentrations for every organ was further divided according to their origin (i.e., fruits from before and after harvest). The data-set values are stored in an excel sheet that contains raw data with the following parameters of a soilless tomato crop for a period of 167 days which is approximately 5.5 months. We updated the data set with absolute CGR values and an average has been taken for the ions concentrations whose nine observations were taken per day. These details are used for the statistical data analysis and the highly correlated variables will be fed into the machine learning algorithm to predict an output for the target variable i.e., absolute CGR in our proposed system. Since the data is analyzed at each stage it will aid us in calculating the concentration of the elements into the NS and the mineral composition of the plants on a daily basis [11]. The growth and development parameters of the crops is highly dependent on dry weight matter of its yields and the entire growth of plant (Growth and development indices in crop production by Souvik Ganguly). Hence we have discussed these growth parameters in detail. The input data-set consists of observation during the growth of the hydroponic tomato crop in the Mediterranean region of Europe [11]. The data-set includes:

- The entire dry matter weight of the tomato plant (in grams) and dry weights of the different parts i.e., leaves, stems, fruits and roots,
- nutrient solution (NS) consumption. (All data is expressed in litres/plant). NS fresh/new Plant, fresh NS stands for the NS added after the NS was completely replaced. NS added plant,is the (NS added for the first time) and lastly the NS residual of the plant left during the cycle and at the end of it was measured,
- uptake of inorganic cations, namely Sodium (Na), Potassium(K), Calcium (Ca), Magnesium (Mg), split for the various parts (stem, leaves, fruits, and roots) and is expressed in gm $L^{-1}d^{-1}$ (grams per liter per day),
- Nitrogen content for the several parts of the plant (leaves, stems, roots and fruits), and
- Days after Transplant (DAT).

3.2. Prediction System

The prediction part of the system design is based on the premise of using machine learning techniques to predict the absolute CGR of the plants, 'x' days ahead in time. The model aims to predict the absolute CGR output based on parameters such as: dry weight matter of the entire plant (stem, leaves, roots, fruits), NS, ion uptakes of the fruit samples before and after harvest, EC limit, and total nitrogen content of the fruit. The absolute CGR of the crop can be calculated by the given formula [11]:

$$\text{Absolute CGR} = \frac{W_2 - W_1}{t_2 - t_1} \tag{1}$$

where, W1 and W2 are dry weights of the tomato plant in grams with respect to time in days t1 and t2. It indicates the rate of increase of the entire dry weight matter of the plant.

Unit of Absolute CGR: grams (dry matter weight/day).

3.3. System Flowchart

The following steps describe the approach in greater detail:

And are shown in Figure 2.

Step 1: Collection water samples for analysis (Tap water).

Step 2: Setup and adjustment system parameters according to (tomato) crop requirements EC limit range (5, 7.5, 10) led lights range 400–700 nm, and NS injection.

Step 3: Ion chromatography used to determine ion cation and anions i.e., ion concentration.

Step 4: Collection for nutrient data analysis by taking input variables like ion concentration, Nitrogen content, EC limit, NS, and dry weights of the entire plant (tomato crop).

Step 5: Calculation of the absolute crop growth ratio using Equation (1).

Step 6: Correlation between input variables and target variable absolute CGR.

Step 7: Application of machine learning algorithm on the data set of the given variables.

Step 8: Prediction results (Output: Absolute CGR).

END.

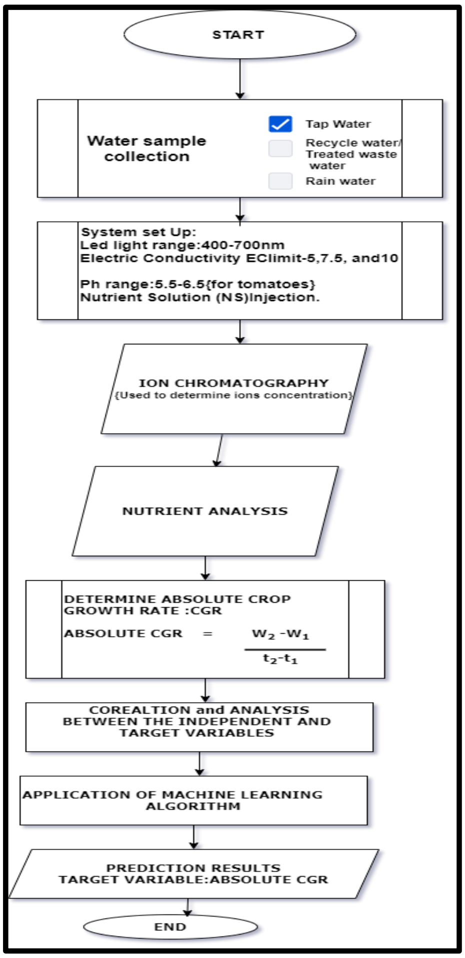

Figure 2. Flowchart of the system.

4. Data Analysis

4.1. Nutrient Analysis

A nutrient solution (NS) is a liquid fertilizer solution adjusted in fixed compositions to enhance the crop growth and protect it from nutrient deficiencies [12].The plant's need is fulfilled through the ionic form of nutrients supplied through the water and nutrient fertilizer added. The NS varies from crop to crop along with their growth duration and environmental conditions. NS are basically composed of macro and micro nutrients classified as Potassium (K), Nitrogen (N), Calcium (Ca), Magnesium (Mg), and micro nutrients classified as Sodium (Na) [4]. Macro nutrients are utilized in greater quantities when compared with micro nutrients. In hydroponic systems, plants and crops are generally nurtured and grown in water mixed with liquid nutrient solution (NS) in it [13]. The solution is monitored at regular intervals and circulated to ensure that the correct chemical composition is maintained. They have a definite composition and a relatively high concentration of nutrients adjusted according to its electric conductivity (EC) [13]. The EC is proportional to the total dissolved cations and anions present in the solution, making it a suitable measurement parameter of nutrient solution strength [13]. An optimum oxygen supply, potential of hydrogen (pH levels), EC limit and optimal temperature conditions are required. Environmental factors and NS are the two key factors for productivity in hydroponics [12]. Supply of nutrient elements has to be monitored continuously during the growth cycle and it depends upon the requirement of crops, and the frequency of usage [12]. In the setup, the authors [11] used NS and supplied it over the whole benches using pumps (one for every bench) submerged into tanks (one for every bench system). The EC limit was set up to (5, 7.5 and 10 $dS{\cdot}m^{-1}$), during the entire process, above which, the NS was completely replaced with a fresh NS and is labeled as NS new plant [6]. After every 2 days, every tank was replaced with fresh NS (NS new plant) up to the initial volume of the tank. In addition, the volume of NS residual during the end of the cycle was also measured [11]. The readings were taken for the period of 167 days i.e., 22 weeks approximately. The NS consumption was mainly due to transpiration, because in a Nutrient Film Technique (NFT) system the evaporation is negligible, referred to a single plant [11]. The author [11] divided the volume of NS added to each tank by the plant's number. Ion concentrations for Na, K, Ca, Mg, and N for various organs like stem, leaves, fruits and roots were measured by using ion chromatography.

4.2. Fruit Analysis

The destructive samples (before harvest) of tomato plant were taken every 2–3 weeks until 56 days after transplantation (DAT) to determine the ion uptake analysis of Na, K, Mg, Ca and Nitrogen (N) content for the fruits. A forced-draft oven was used to calculate the dry matter weight and a balance with two decimal places was used [11], all the observation values are taken in grams. The growth parameters included the dry weight matter of the tomato fruits and absolute CGR of the entire plant. The absolute CGR of the plant was observed (during destructive sampling of fruits, while fruits were not harvested). After a period of 116 (DAT) i.e., around 3 and a half months, tomato fruit samples were harvested and their ion uptake was analyzed every 6–8 days along with the tomato fruit dry matter weights.

5. Results and Discussions

5.1. Absolute Growth Rate of the Entire Plant and Phases of Tomato Growth

The fruits were first observed on the plant during the initial Stage I i.e., (Fruit set) after 56 (DAT), as shown in Figure 3 the absolute CGR of the tomato plant was 2.7 gms/day during this stage. After 77 days NS (new plant) solution was added multiple times to the tomato plant. At Stage II: (Fruit ripening) after 93 days an exponential growth rate of the plant was observed with a maximum absolute CGR of 4.27 gms/day. The NS new plant was added multiple times during this stage as well. At Stage III (Fruit maturity and harvest), 116 (DAT) the fruits were matured and harvested, however a decrease in the absolute CGR was observed at this stage with a value of 2.7 g/day. A continuous supply of NS was maintained till 167 days during the stage III, which indicated an increase in the demand of ions by the plants for the (Fruit set); a slight increase of 0.01 in the CGR was also observed during the late stages of harvest.

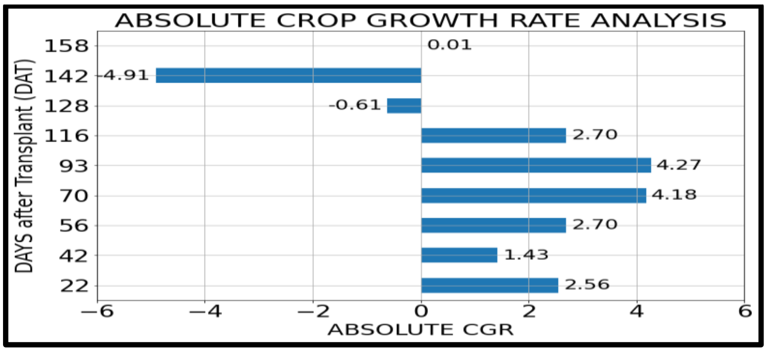

Figure 3. absolute CGR of the entire tomato plant over a period of 21 weeks (159 days) approximately in the NFT Hydroponics system.

5.2. Nutrient Ion Uptakes during Different Growth Stages of Tomato Fruit before and after Harvest and Its Impact on Absolute CGR

The macro and micro nutrient ion uptakes of the tomato fruits during the entire growth process of 167 days are shown in Figure 4, and Table I, Table II. The ion uptake rates were in the order K > N > Na > Mg > Ca during both the stages (before and after harvest). In the initial period of Stage I and Stage II (Fruit set and Fruit ripening) the concentration of the ion uptake was observed in the range (0–1.8) gm $L^{-1}d^{-1}$, however the K ion showed a significant difference in the uptake with highest values of uptake in range (21–33) gm L^{-1} d^{-1} The nutrient uptake rates increased significantly after the fruits started maturing and were ready to harvest until day 142. The variation trends in ion concentrations show that there was an increasing trend for all the ions after 93 (Fruit Ripe: Stage II) and highest absolute CGR (4.27 gm d^{-1}) was observed simultaneously. In the later period a decreasing trend was observed for the CGR and absorption levels of all the ions except K ions. respectively. The maximum uptake rates of K, N, Na, Mg and Ca was 31.47, 1.90, 1.67, 1.74 and 1.23 gm $L^{-1}d^{-1}$ respectively. Figure 5 shows the dynamics of nutrient uptakes from day 116, the harvest stages (Stage III) and its impact on the dry weight matter of the fruits. Nitrogen absorption was too low hence was not observed until day 139. Dry weight matters of the fruits showed an increase till 124 (DAT). A rapid decrease in weights was observed till day 146. The trends in variation for Na, Ca, Mg, N and K ions did not follow the trends in variation of the dry weight matter. The maximum concentrations values observed were 1.67, 1.008, 1.74, 1.90, 31.47 respectively. K ions continued to have the highest absorption rates while the uptake rate of Ca ions was observed to be the lowest during the entire growth cycle as compared to the other ions.

Table 1. Ion concentrations for tomato fruits after harvest.

DAT	Na	Mg	Ca	N	K	Dry Weight of Fruits
116	1.18	0.87	0.73	0	27.12	39.12
124	1.29	0.99	0.81	0	28.74	45.82
130	1.33	1.01	0.93	0	29.64	34.82
139	1.52	1.17	0.78	0	31.47	26.44
146	1.30	1.55	2.12	1.82	28.75	25.72
158	1.34	1.02	0.94	1.48	29.64	37.45
167	1.53	1.18	0.78	1.56	31.47	23.84

Table 2. Ion concentrations for tomato fruits before harvest.

Stages of Growth	DAT	Na	Ca	Mg	N	K	Absolute CGR
Stage I	56	1.00	0.70	1.08	0	21.57	2.7
Stage II	70	0.88	0.78	1.07	1.73	24.77	1.43
	93	0.72	0.89	1.25	1.76	22.95	4.27
	116	1.05	0.23	1.52	1.90	24.95	4.18
Stage III	128	1.32	1.003	1.55	1.77	25.64	−0.61
	142	1.67	1.008	1.74	1.79	24.47	−4.91
	158	1.47	0.80	1.17	1.76	31.47	0.01

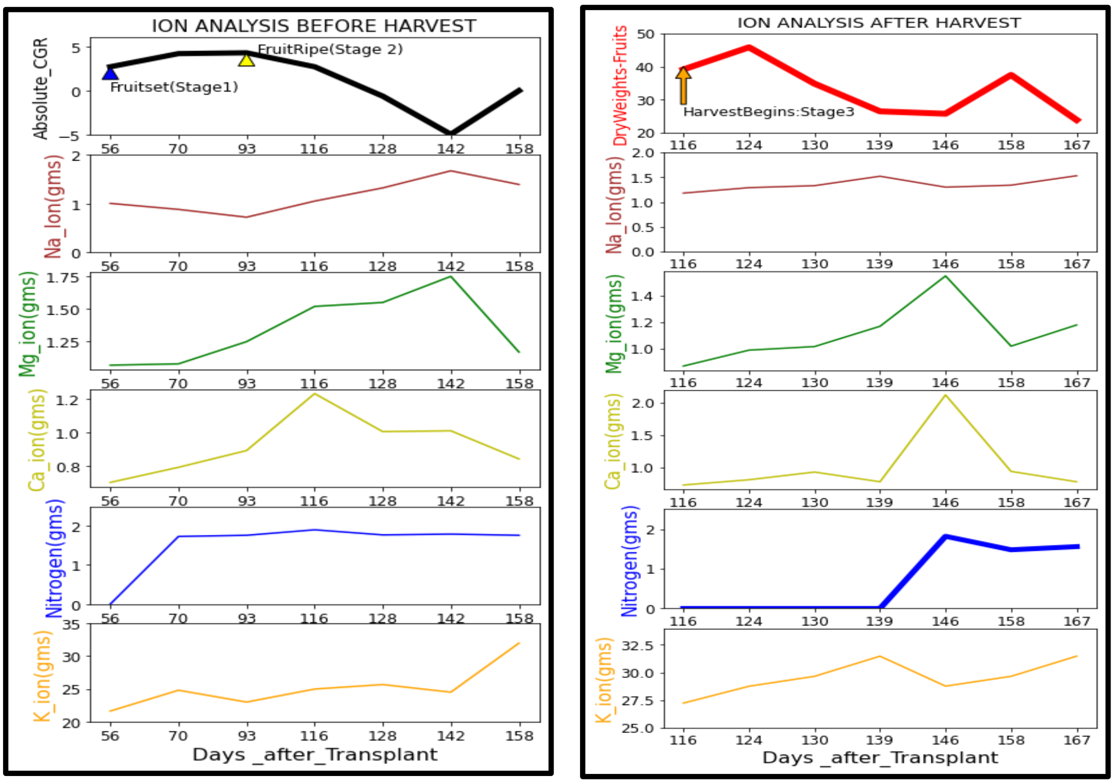

Figure 4. (ION ANALYSIS BEFORE and AFTER HARVEST) Dynamics of nutrient ion uptake of the tomato fruits and related variation trends with absolute CGR before harvest, and variation trends of dry weight matter of the fruits after harvest in a closed NFT hydroponics system.

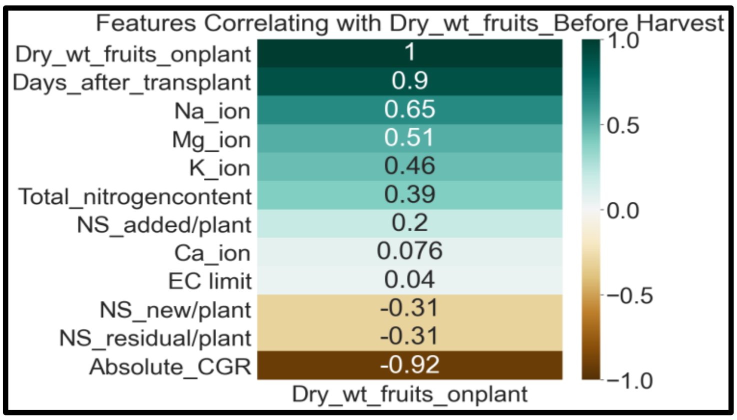

Figure 5. Heat map depicts correlation analysis between dry weight matter of the fruits on the plant before harvest with different input variables during the growth process.

5.3. Relationships between Growth Parameters, Absolute CGR, Dry Weight Matter of Tomato Fruits with Other Input Variables

The Figure 5, shows a strong positive correlation was observed between the dry weights and DAT which indicates a good productive yield with time. Negative correlations were observed with the CGR of the plant during this stage. NS (NS added) played an important role during the growth process and had a positive correlation with the increase in dry weights. Other variables like EC limit had a weak correlation indicating greater absorption of dissolved ions during this stage Na ions observed the highest correlations of 0.65 explaining its possible good precipitation. It was observed that Ca ion had a very weak correlation of 0.076 during the growth process before harvest. The dry weights of fruit samples after harvest shown in Figure 6, observed a high positive correlation of 0.5 with EC limit (increased values of EC) suggested that the fruits possibly absorbed more water instead of dissolved ions [13], during the Stage 3: (Fruit maturity and harvest). NS (new plant) continued to play a critical role during the harvest stages as well with a positive correlation of 0.2. No positive correlations were observed with (DAT) and N, Na, K, Mg ions.

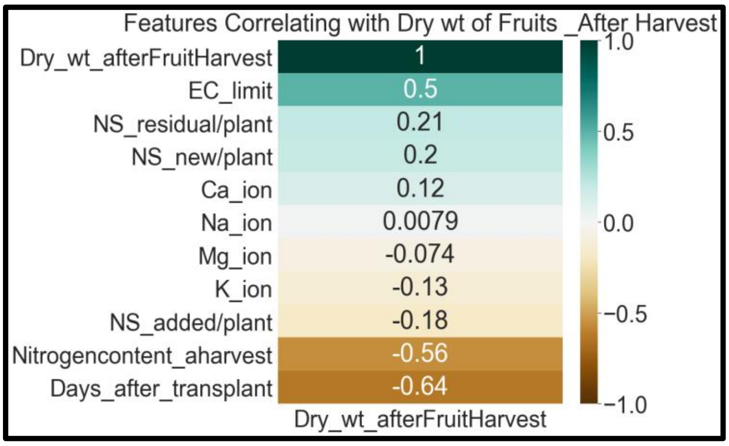

Figure 6. Heat map depicts correlation analysis of dry weight matter of fruits after harvest with the different input variables during the entire growth process.

We proposed and designed a flexible framework for hydroponics that can be used in the prediction of the absolute CGR. The three stages in our system are interdependent with each other and aim to predict the CGR in an easy manner utilizing input variables important during the growth process. The environmental conditions set in the NFT closed hydroponic system were good to support the optimal cultivation of the tomato plants. A detailed study analysis shows the nutrient concentrations and dynamics of ions uptakes of Na Ca, Mg, K and N at different stages of growth for the tomato fruit. The absolute CGR of the plant was calculated and observed for all the different stages of the tomato plant. No significant changes were observed between the absolute CGR and the different stages of fruit growth. The correlation analysis further suggested the input variables which had a strong impact on the growth parameters like dry weight of the entire fruits. It was observed that nutrient ion Na had the highest correlation, these ions enhance the growth and development of the tomato plants and also contribute in improving the flavors of the edible parts [13]. Ca had a lowest rate of uptake and the weakest correlation with the dry weight matter of the fruits, indicating that the amount in the nutrient solution absorbed was not optimal for tomato growth. The supply of Ca ions is more essential for rapid increase in fruit size [13]. Hence higher amounts of Ca should be added during the growth process in order to prevent their deficiency during the growth process and promote good yields of tomato. The K and Mg ions had positive correlations and variation trends during the growth process. Elevated levels of K ions may improve the fruits [14]. Higher EC values indicate more ions in the solution [13]. The EC limit remained constant

(5,7.5,10) during the growth of tomatoes indicating that a similar amount of ions were absorbed at this interval. However, an exponential growth in the tomato plants and increased EC correlation values indicate that the water absorption was more as compared to the dissolved ions in the solution. These results indicate that specific ion monitoring and adjustments are required (preferred over EC based control methods) for better uptakes which can result in good growth and development of the plants in hydroponics.

6. Future Work

Our system approach is smart and easy however can be specific by using efficient algorithms like Random forest, Deep neural networks. Currently comparative study is done on various machine learning algorithms performances for soil cultivation, however it could be useful if more comparative study is done with hydroponics data-sets, including more variables. In our current approach we only focus on predicting the absolute CGR however other parameters like dry weight matter, relative growth rate can also be utilized which help us in determining faster growth rate. Other areas of study like better analysis of nutrient uptake of different water samples like recycled water or rain water which is beyond the scope of this paper, can also be very useful.

7. Conclusions

This paper proposed a smart and easy framework that can be used to predict absolute CGR based on the machine learning paradigm in hydroponics. We aim to automate our process and reduce the complexities involved in order to achieve optimum growth rates for the crops. The analysis shown here will assist in the identification of parameters important for an increased growth rate. The results show that the NS and NS (new plant) used played a critical role during the entire growth period and aided the increase in absolute CGR of the entire plant and tomato yields (dry weights). The Na and K ions showed a significant increase in the uptake as compared to other ions, however Ca ions observed lowest rates of absorption during the entire growth process indicating better adjustments to be done in the NS. A regular monitoring of ions instead of EC based controls is a better way to prevent the nutrient deficiencies observed and promote good growth. These analyses facilitate us with better insights for good tomato yields and the proposed technique presented can be used to predict absolute crop growth rate in an effective manner for tomatoes. The overall aim of our work is to propose: a machine learning approach to provide useful insights into the field of hydroponics and minimize the complexities during the process. The controlled environment with precision techniques used in the framework is the future of our farming and can be utilized in any hydroponic crop in general thereby helping in maximizing crop yields.

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