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Machine learning based crop growth management in greenhouse environment using hydroponics farming techniques

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ABSTRACT

Today more than one billion out of 6.5 billion people in the world are affected by hunger. The significant growth in human population inevitably places considerable pressure on food supplies. In traditional farming, farmers require good quality soil, natural minerals and also the production relatively consumes more time. The hydroponics smart greenhouse method has been adopted as a result of technological advancements. Hydroponics is a technique of growing plants that does not require the use of soil, and the plants in hydroponics grows in a shorter duration and have higher yields. In normal hydroponics system, a portion of the greenhouse is used for harvesting and the parameters like temperature, and humidity can have an impact on plant growth, and the plants are not properly nourished. In this proposed system, in hydroponics for germination organic coconut coir medium is used rather than rock wool, because rock wool is not bio-degradable and composed of volcanic materials. In the proposed research of hydroponics, the system is automated on a wide scale covering the entire green house with different crops produced in different climatic conditions. The implementation is done on, stable greenhouse environment and plants are grown covering the entire greenhouse, under constant optimal conditions which is favorable to have maximum yield. The prediction of absolute crop growth rate of leafy vegetables is predicted using KNN algorithm under various conditions. The several forms of hydroponics for commercial crop growth has been compared and it has been concluded that NFT along with coconut coir medium is best suitable for hydroponics and it produces an accuracy of 93%. Macro average, a performance metric for F1 score produces 33% and weighted average, which represents the number of instances connected to different class labels, produces an accuracy of 93%.

1. Introduction

Agriculture is the backbone of India's economy, which is still in its early stages. Agriculture faces a number of challenges, including small and fragmented land holdings, manures, pesticides, agricultural chemicals, and so on. Consumers are also increasingly demanding a nutritious diet that is free of chemicals and pesticides. Agricultural lands are now being converted to commercial complexes which will have the impact on the economy. So the production capacity is declined due to the reduction of agricultural lands, climate change, water scarcity, soil pollution, and other factors [1].

Urban agriculture or farming is one of the main methods that consumes less space due to the lack of agricultural fields. Urban and indoor faming have made way for smart procedures and intelligent models because of technological improvement [2].

The above said difficulties and demands can be overruled using IoT and hydroponics methods and since it is done in a controlled environment, it may be carried out anywhere, such as balcony, room, terrace, and so on, and a large number of plants can be planted in a small space. If monitored and controlled properly, this type of agriculture could produce a high yield. A method is proposed for controlling the necessary conditions for hydroponically growing plants, as well as cultivators' ability to remotely control agriculture via the Internet of Things [3].

The Hanging Gardens of Babylon (Iraq) and the Floating Gardens of China are two ancient examples of hydroponics. These tactics have been employed by people for thousands of years. Although the fundamental principles of hydroponics have not changed, contemporary technology has enabled us to produce plants that are more quickly, more

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powerfully, and more healthily. William Frederick Gerick created hydroponics, a kind of agriculture that employs water as an inert medium to deliver nutrients to plants. The University of California, Berkeley later popularized it as an agricultural method. Initially calling the method aquaculture, he eventually realized that the term refers to the culture of aquatic organisms. Gerick grew tomato vines that were 25 feet tall using fertilizer mineral solutions rather than soil. It is safer to consume, since it doesn't use any pesticide [4,5].

Machine learning-based aeroponics techniques are used in conjunction with multiple input parameters to ensure accurate plant growth with minimal water usage and nutrient requirements. Smart farming is used to reduce complexity and energy inputs while increasing productivity for higher quality crops with limited resources [5,6]. According to the recent research, plants cultivated in the hydroponic method are less affected by global warming, allowing more plants to be harvested under ideal condition. Plants grown using this technique is unique as plants are grown without using soil. The amount of water used is very less that of what is used in the conventional method [7,8].

The proposed research focuses, emphasizes of hydroponics plants grown without using sunlight and soil, and plants in hydroponic system are grown in water where the roots are exposed to rich nutrients like nitrogen, phosphate, and potassium. The plant growth and yield shall be thoroughly examined and monitored on a regular basis considering the various parameters. The essential nutrition contents of the plants can be monitored continuously which in turn helps to predict the growth of the crops.

The novelty of the research states that

In a typical hydroponics system, a portion of the greenhouse is used for harvesting; however, the temperature and humidity can affect plant growth and result in inadequate nutrient intake by the plants. In order to achieve the highest yield, the implementation is carried out in a stable greenhouse environment where plants are grown by considering the entire structure.

2. Literature survey

Khan, Saad et al. [1] discussed a hydroponics technique that promises to produce wholesome, high-quality, locally-grown vegetables and fruits that are fresh and residue-free while overcoming the multiple manifestations of climate change, fresh water scarcity, and the urgent need of the expanding food demand. The merits and drawbacks of hydroponics are explored in this review paper. The emphasis is placed on the information needed for hydroponic farming, as well as the current trend in it and an overview of the key companies dealing with the same.

Muhammad Ikhsan Sani et al. [2] proposed the design of wireless sensor and actuator network. The control system manages the actuators such as mist maker and the fan that delivers water moisture. Data packets are sent from the microcontroller to the server to transmit data from sensors to the internet via GSM/GPRS module. Every 1 min, data is transmitted and can be accessed via the website. By installing cameras, future research can be directed toward visual monitoring systems.

Aris Munandar, Hanif Fakhrurroja et al. [3] presented smart hydroponic system design, development, and implementation using IoT concept, and also the connection to the cloud platform. The important challenge is quantity of data that are collected by the sensors. Using Agile method, working prototype was developed to minimize the planning process and the data is displayed on the web using front end.

Joshitha C et al. [4] used an IoT system to continuously monitors and manages the support of UBI dots cloud database. Farmers can have an eye on their cultivation even from a remote location. Controlling of pest is the major drawback in traditional farming.

Swapnil Verma et al. [5] depicts the prediction of absolute crop growth rate using machine learning techniques such as Random Forest and Deep Neural networks. Complexities are reduced considerably in order to achieve optimum growth rate or maximizing crop yield. Various input variables like electric conductivity, nutrient solution, ion concentration uptake, dry weight of the fruits are considered as more important for the feasible growth of hydroponic tomato crop.

Mahesh S Gour et al. [6] developed a system of Aeroponics with IoT, and also interfaced with machine learning. Various artificial intelligence techniques are used to detect faults. Machine learning-based aeroponics techniques are used in conjunction with multiple input parameters to ensure accurate plant growth with minimal water usage and nutrient requirements. A mobile application was developed that enables the farmers to remotely control and monitor the entire system.

Srivani P, Yamuna Devi C et al. [7] proposed an automated system by integrating the prediction models using, IoT, Machine Learning, Artificial Intelligence, different cloud, data analytics methods, wireless sensor network and many more. The study focuses on the issues that includes pest control, recycling and energy conservation, water conservation and recycling, and power optimization. Smart farming uses it to increase productivity for higher-quality crops while using less resources and reducing energy inputs. Different environmental factors were taken into consideration when analysing the plant growth.

R B Hari Krishna et al. [8] proposed an automated system using IoT and which has an inbuilt Wi-Fi Module and connected to cloud which uses a microcontroller ESP32. Data from the sensors are transmitted to the UBIDOTS cloud and viewed via mobile/web applications. Sensors are used to provide an artificial luminance, allowing for efficient photosynthesis even in low light/at night. According to the research, the amount of water used is only 10% of that used in the conventional method.

Manav Mehra et al. [9] proposed a system that uses neural networks and Bayesian networks, and two separate machine learning techniques, to manage the growth of hydroponic plants. IoT enables machine-to-machine communication, negating the need for human involvement. The method makes use of a number of input variables to predict plant development with excellent accuracy. The plant's growth will be least affected by global warming. A Arduino, Raspberry Pi 3, and Tensor Flow were used to generate a case study on the development of tomato plants.

A system that integrates controlled environment agriculture, Internet of Things, Computer vision, and machine learning techniques was proposed by Srinidhi H K et al. [10]. This approach uses continuous testing, development, and integration throughout the whole software development lifecycle of the project. It enters the consumer market by lowering the cost of small grow boxes, enabling anyone to grow their own premium vegetables.

Herman et al. [11] proposed a system that monitors and controls the hydroponic system based on IoT and Fuzzy Logic. IoT monitors the plants nutrition and water needs, fuzzy logic controls the supply of nutrition and water. Hydroponics plant grows better when compared to the plants that are grown using traditional method. Visual look of plant, leaf length and width of lettuce and bokchoy plants are increased better when compared with the plants that are grown using traditional manual method.

R.Vidhya et al. [12] suggests about Nutrient Film Technique (NFT) method, which provides the requirement for the healthy growth of the plants. IoT and different machine learning algorithms are used in this NFT technique, which resulted in higher yield compared to traditional framing. Waste water is recycled and irrigated to plants again. Consumption of water is less but the initial setup cost is higher.

Georgios Georgiadis et al. [13] developed a system where sensors are used to measure the parameters and the required information are sent to IoT platform, which uses data API's for communication and exchange of data. Machine learning can be used which will provide recommendations to facilitate the workload of professional agronomists. Repositioning the nodes in new places and reconfiguration of the sensor network, due to corrosion, leads to abnormal moisture values.

Bakhtar Nikita et al. [14] proposed several types of hydroponic methods like drip irrigation, deep water cultivation etc. Hydroponics can also be used to grow plants and vegetables in spaces like congested or crowded areas. Soil less methods and vertical hydroponics were used in places where gardening is not possible. Pesticide and insecticides usage will be reduced.

Anurag Shrivastava et al. [15] proposed a novel concept of hydroponics that increases crop, vegetable, and fruit production without the need for soil. Rock wool is utilized in farming procedures with water pollutants at regular intervals to provide enormous yields in shorten cultivation times. The proposed system is deployed with IoT sensors for predicting crop health and condition monitoring. Design and implementation of automated vertical hydro farming methods with IoT platforms are done using big data analytics. In comparison to traditional agricultural techniques, vertical hydro farming produces greater outcomes.

Velazquez-Gonzalez, Roberto S., et al. [16] proposed a system where precision agriculture is promoted on a small scale by paradigms like the Internet of Things and Industry 4.0, which enable the control of variables like pH, electrical conductivity, and temperature, among others, leading to higher production and resource savings.

Tatas, Konstantinos et al. [17] developed a web based system that remotely monitors the greenhouse by making use of sensors. The length of plant irrigation is determined by a cutting-edge fuzzy inference engine. To enable off-grid operation, the system is designed to consume little power and also the system can tolerate different transient faults without needing assistance.

Hariono, Tholib, and Mukhamad Cahyono Putra et al. [18] used ESP8266 microcontroller based system that is used to carry out data acquisition on an IOT-based hydroponic plant automation system. Data collection is used to track temperature data from the sensor, periodic plant growth monitoring based on an image from the ESP32 Cam, and as a backup source of energy for hydroponic plants using sonar panels. Each sensor's collected data is sent to the Firebase real-time database, and every time the data changes the database is updated. The dashboard page displays the data acquisition results in real-time so that they can be easily read by.

The Research gaps identified for this method are:

1. Seedling Problems
2. System clogging
3. Nutrition Deficiency
4. Sustainability problem
5. Assessment of crop growth characteristics

2.1. Proposed RESEARCH

Machine learning algorithm makes it an easy and smart approach for predicting maximum yields [9,10]. Based on the problems in traditional farming, a solution is provided by combining hydroponic farming methods, and IoT technology which in turn creates a smart controlling system that automatically controls plant nutrition and water needs [11, 17]. Each sensor device can communicate or send data to a cloud server that needs to be processed and monitored in real time by utilizing internet of things (IOT) technology [12].

Greenhouses are enclosed, secure structures with materials such as glass, fiber, polythene, that keep harvests from being directly influenced by weather conditions. The sensors are used to detect whether the climatic conditions are suitable for harvesting or not which in turn sends the signals to the microcontroller, and the actuators to act as needed [13, 18]. The below Fig. 1 represents the schematic representation of different types of hydroponics system.

1. Wick System:

The plants are placed directly within perlite or vermiculite, which is an absorbent substance. Nylon wicks are wrapped around the plants before they are dropped into the nutrient solution. It is the most basic technique when compared to others.

2. Deep Water Culture (DWC):

Roots of the plants are suspended into the nutrient solution directly, which means, the nutrients oxygen, water and nutrient supply is provided by suspending the roots into the solution where the plants can easily absorb it.

3. Ebb and Flow (flood and drain):

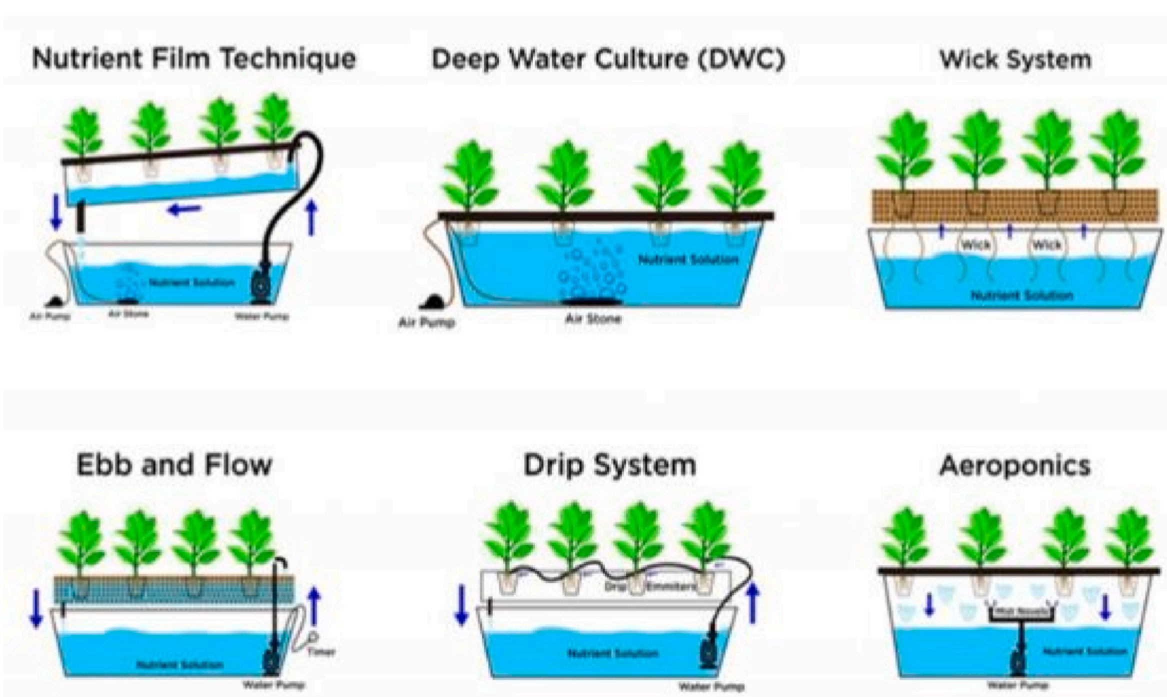


Fig. 1. Different types of hydroponics system.

Plants that are positioned in a sizable grow bed that is denselyfilled with a nutrient-rich material like perlite or rockwool. In order to keep the nutrient-rich solution from overflowing, it will be flooded onto the grow bed until the water is a few inches below the surface of the growth medium.

4. Drip System:

In a drip system, nutrients are poured into a tube that reaches the plant's roots directly and keeps them moist.

5. N.F.T (Nutrient Film Technology):

Pumping the nutrition solution into sloped tubes enables the extra nutrients to drain back into the reservoir. When nutrients are added to the channel, they flow over each plant's roots as they descend the slope, ensuring that the right quantity of nutrients is provided.

6. Aeroponics:

The necessary plants will be suspended in the air to be grown. A few mist nozzles are located below the plants. These nozzles will spray the nutrient solution onto the roots of each plant, which has shown to be a very effective hydroponic technique. This technique is comparable to the Nutrient film technique.

2.2. Proposed model

The crop yield is limited by crop varieties, planting areas, growing climate, and environmental conditions. Crop yield decreases as humidity and temperature rises, and can have an effect on plant growth, causing the plants to be under-nourished. For example, if crops are only grown in one lane inside the greenhouse, crop yield decreases because there are no other lanes carrying the same or different crops; Since the planting areas are restricted, there is an increase in temperature and humidity and this have an effect on plant growth, causing the plants to be undernourished.

In this proposed research, the entire greenhouse is considered for crop plantation. Environmental factors such as water, temperature, air, total dissolved solid (TDS), pH, humidity, and light conditions inside the greenhouse will have a direct impact on the growth of plants. If only a portion of the green house is used, the plants will not grow properly even if adequate nutrition is provided. This is due to the variations in external factors such as temperature and humidity gradients, this will vary depending on where the plants are grown and how much empty space there is in the green house. Because of the unplanted area, temperature and humidity will have an impact on plant growth and in order to overcome that the plants are planted covering the entire region of the greenhouse.

Figs 2(a) and (b) shows the schematic view of plants that are grown on only one side of the greenhouse. This clearly shows the production of low yield, and it is clear that the plants are not properly nourished.

It has been shown that the plants that has been grown inside this kind of environment are healthy and producing more yield. In hydroponics, plants are more densely packed together in comparison to the amount of land required to grow the same number of plants.

In the proposed research work, for the process of germination coconut coir is used as the medium, since it is an organic medium capable of retaining water and oxygen well and promotes healthy root structure and plant yields. It can quickly access the nutrients it requires, which simulates plant growth. The pH of coco coir is naturally 5.7–6.5. It is always suggested to make changes to the pH of your nutrient solution to 5.8–6.2 before watering when growing in Cocogro. It is biodegradable and leaves no trace after its useful.

The below Fig. 3 shows the view of fully nourished plants covering the entire green house.

Fig. 2a. Portion of Green House partially Planted. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 2b. Another partial lane of Green House Plantation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 3. Healthy and Fully nourished plants that covers the entire region of Green House. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

The below Fig. 4 shows the seeds that are sown in grow trays for germination, and it's the beautiful stage of a plant's life; it is the moment a seed is born and begins to sprout, gradually unfolding into its full potential. Use the proper growing medium, close attention is paid to

Fig. 4. Seeds sown for germination.

seed coating, keep the growing area humid, and keep it clean, transferred the sprouts to net pots and growing NFT channels later are taken into account.

The growth substrates used in order to grow the plants are discussed in the comparison Table 1. It gives the details of growth substrates for plant growth, and lists the advantages and disadvantages. It has been clearly shown that coconut coir is a good medium to grow plants and is 100% organic and safe for human health also.

A plant's basic needs are support, nutrients, protection from pests and insects, proper atmospheric conditions, oxygen, and moisture. A hydroponic system, which uses inert growing medium such as coconut coir, rock wool, and so on, can provide all of these conditions [15]. Each hydroponics method has its own set of advantages and disadvantages.

Wick, Nutrient Film Technique (NFT), Ebb and Flow, Drip Systems, Deep Water Culture (DWC), and Aeroponics, are the six major categories of hydroponic systems used for growing plants. The most commonly used method for growing leafy green plants is Nutrient Film Technique (NFT). Herbs suitable for growing in NFT include cilantro, parsley, basil etc. Nutrient film systems save water, are low in cost, and require little maintenance. It is simple to examine the roots for signs of disease which can reduce fungal risk because of the constant flow.

The proposed model diagram is shown in the below Fig. 5.

3. Experimental results and discussion

1. Data Collection:

Data set is collected from University of Agriculture Science GKVK, Bangalore [20].

https://uasbangalore.edu.in/index.php/kannada-uas.

Table 1
Growth substrate for plant growth and its advantages and disadvantages in hydroponics system.

Substrates	Advantages	Disadvantage s
Coconut Coir	100% organic, High water holding capacity, Acceptable PH and EC	Too salty
Vermiculit e and Perlite	Lightweight 610 lbs/ft3	Vermiculite: Waterlogging is rapid Perlite: Retained water is poor quality
Gravel	Inexpensive, Easy to clean, waterlogging is low	Heavy, Dries quickly
Rockwool (Volcanic Materials)	Lightweight	Expensive
Saw Dust	High water retention, Light weight	Tend to clot

Table 2
Confusion matrix.

Actual Values			
Predicted values		Positive (1)	Negative (0)
	Positive (1)	True Positive (TP)	False Positive (FP)
	Negative (0)	False Negative (FN)	True Negative (TN)

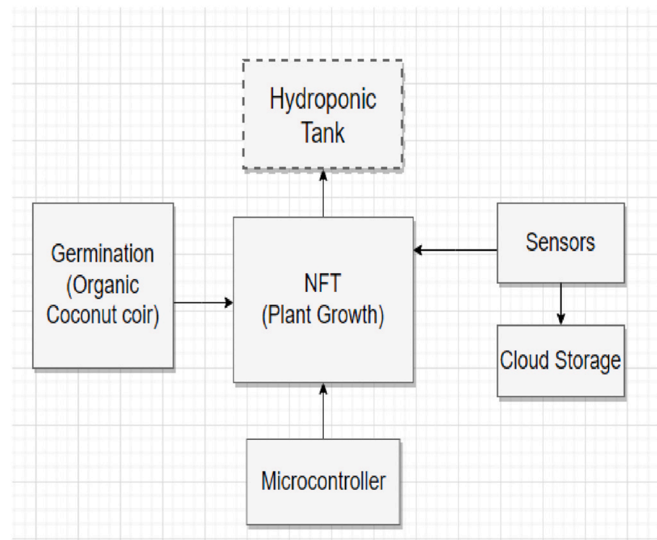


Fig. 5. Proposed model diagram of hydroponics System.

The process of data analysis is performed by gathering data from various sensors that detect the surroundings, ambient temperature, pH level, water temperature, electrical conductivity and air temperature/humidity sensor in a solution [[14]][[16,19]]. Because pH is not constant and varies from crop to crop, the pH sensor is used to detect changes in nutrition and detects water solvent acidity level. A temperature sensor is used to determine the moisture level. Water temperature sensors are used to determine the amount of nutrients in the water. Electrical conductivity measurements can be used to monitor and control nutrient solution concentration.

The data values that are collected from different growth substrate shows different accuracies when it is implemented using K-Nearest Neighbor (KNN) algorithm. It has been shown that Coconut fiber along with NFT techniques outperforms the best when compared to all other techniques. The two substrates (Coconut fiber and Rockwool) are considered for predicting the accuracy which is shown in Table 3.

2. Performance Analysis

Metrics like Accuracy, Precision, Recall, and F1 Score, can be used to gauge how accurate machine learning algorithms are. A table with a certain layout that enables the visualization of an algorithm's performance in the field of machine learning, specifically the statistical

Table 3
Growth media and their Accuracies.

Media	Techniques					
	Wick system (%)	DWC (%)	NFT (%)	EBB and Flow (%)	Drip System (%)	Aero ponics (%)
Coconut Fiber	60	92.3	93.3	65	52	45
Rock wool	60	72.3	79.3	85	82	85

classification issue, is known as an error matrix or confusion matrix. A table called a confusion matrix is used to describe how well a classification system performs and the effectiveness of a classification algorithm is represented and condensed in a confusion matrix. The structure of a confusion matrix is given in the below Table 2.

- The true positive rate of a classifier is computed by dividing the total number of positives by the proportion of positives that were correctly categorized.
- By dividing the total number of improperly categorized negatives by the total number of negatives, one can get a classifier's false positive rate.
- By accurately calculating the number of positive classes, the recall formula is successful.
- The number of estimated classes is calculated using the accuracy formula, and the answer is manifestly positive.
  Accuracy:

The total number of positives and negatives accurately classified by the total number of samples yields an approximation of a classifier's overall accuracy.

$$\text{Accuracy} = \frac{TP + TN}{(TP + TN + FP + FN)}$$

Recall:

The number of accurate positive predictions made out of all potential positive predictions is measured by recall. The model's recall gauges how well it can identify positive samples. The recall increases as more positive samples are found.

$$Recall = \frac{TP}{(TP + FN)}$$

F1 score:

An accurate performance evaluation score is provided by the F1 score, which is an accuracy and recall harmonic mean.

$$f1\ score = 2 * \frac{Precision * Recall}{Precision + Recall} = \frac{2TP}{2TP + FP + FN}$$

3. Experimental Results

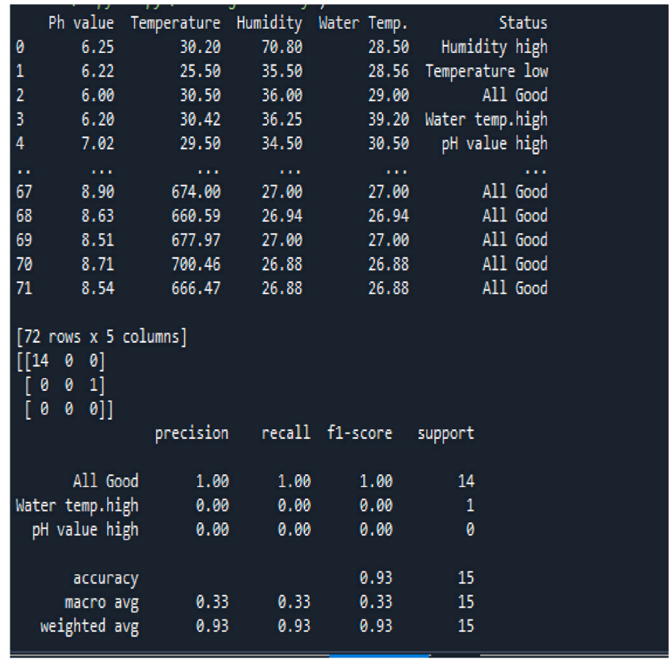
The experimental findings for categorizing the training and testing datasets using the proposed strategy is provided in this section. In order to conduct the experiment, 70% of the data samples are utilized for training and the remaining 30% are used for testing.

For high yield production, environmental factors like pH and EC values can be used to analyze the plant development rate. As a result, it is necessary to use well developed statistical and supervised machine learning models to research the connection between these characteristics and plant development and health. To predict plant development and health dynamics, these models are created and tested.

The data values are collected for both the growth substrate and it shows different accuracy when it is implemented using K-nearest neighboring algorithm. It has been shown that Coconut fibre along with NFT techniques outperforms the best when compared to all other techniques.

The Fig. 6 shows that hydroponically grown crops produce higher yields than conventional agriculture. Crops grown using entire greenhouse produces leafy green crop, plants mature faster and are less susceptible to pests and diseases. The entire process is maintained under optimal environmental conditions for maximum performance.

The procedure uses a task-specific KNN rule in an end-to-end procedure that employs a graph neural network that predicts the label using the instance's KNN graph. The neural network of the graph contains implicitly embedded weighting and distance functions. Through the usage of a KNN search step from the training data to form a KNN graph and passing it through the graph neural network, the prediction for a query is obtained. The below Fig. 7 represents the exponential graph for the dataset.



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   Ph value  Temperature  Humidity  Water Temp.           Status
0      6.25        30.20     70.80        28.50    Humidity high
1      6.22        25.50     35.50        28.56  Temperature low
2      6.00        30.50     36.00        29.00         All Good
3      6.20        30.42     36.25        39.20  Water temp.high
4      7.02        29.50     34.50        30.50    pH value high
..      ...          ...       ...          ...              ...
67     8.90       674.00     27.00        27.00         All Good
68     8.63       660.59     26.94        26.94         All Good
69     8.51       677.97     27.00        27.00         All Good
70     8.71       700.46     26.88        26.88         All Good
71     8.54       666.47     26.88        26.88         All Good

[72 rows x 5 columns]
[[14  0  0]
 [ 0  0  1]
 [ 0  0  0]]
                 precision    recall  f1-score   support

       All Good       1.00      1.00      1.00        14
Water temp.high       0.00      0.00      0.00         1
  pH value high       0.00      0.00      0.00         0

       accuracy                           0.93        15
      macro avg       0.33      0.33      0.33        15
   weighted avg       0.93      0.93      0.93        15
```

Fig. 6. Output using KNN.

4. Conclusion

A hydroponic system of farming with technological integration allows growers to cultivate crops in a precise environment. The system's automation and intelligence have provided a number of advantages for this sort of farming in terms of increasing crop production while utilizing minimal resources. It includes information on how to use a hydroponics system to increase yield while using less water. Organic coconut coir is a

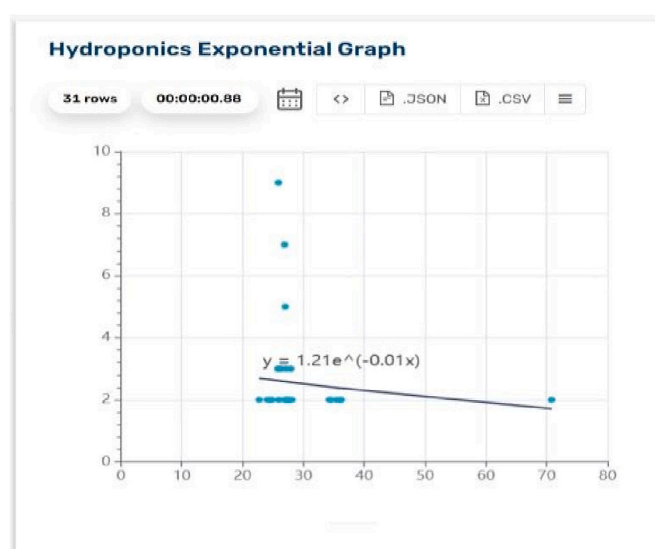

Fig. 7. Exponential graph.

natural medium that provides excellent water and oxygen retention while also promoting plant yields and a healthy root structure. The NFT technique is the best commercial hydroponics system for growing plants and it has been concluded that growth rate is comparatively higher in NFT technique. The growth of plant is directly affected by the environment conditions, and if the crops are grown in a portion of a greenhouse it decreases the crop yield as the other portion is left empty and does not carrying the same or different crops. The production decreases mainly due to the increase in humidity and temperature and also of fluctuating precipitation. The use of KNN algorithm along with NFT technique produces an accuracy of 93% in the prediction of crop growth. In this proposed system of research, the experiments are carried out only on leafy vegetables; and in future it can be done for fruits which are hydroponically grown. The major drawback is setting up a hydroponics system costs more when compared to conventional method. It needs constant monitoring and maintenance because it is more susceptible to power outages. Waterborne diseases have a quicker impact on plants.

CRediT authorship contribution statement

V. Mamatha: Writing – original draft, Methodology, Writing – review & editing, Software, Validation. **J.C. Kavitha:** Conceptualization, Supervision, Review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The dataset and the images are taken from the University of Agricultural Sciences (GKVK), Bengaluru.

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