IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 17 January 2024, accepted 29 February 2024, date of publication 5 March 2024, date of current version 15 March 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3373787

RESEARCH ARTICLE

Comparative Growth Analysis of Onion in Deep Water Culture and Soil Based Systems: Enhancing Medicinal Plant Cultivation in Urbanized Environments

MONICA DUTTA [1], **DEEPALI GUPTA** [1], **SAPNA JUNEJA** [2], **ALI NAUMAN** [3], **AND GHULAM MUHAMMAD** [4], **(Senior Member, IEEE)**

[1]Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab 140401, India
[2]KIET Group of Institutions, Ghaziabad 201206, India
[3]Department of Information and Communication Engineering, Yeungnam University, Gyeongsan-si 38541, Republic of Korea
[4]Department of Computer Engineering, College of Computer and Information Sciences, King Saud University, Riyadh 11543, Saudi Arabia

Corresponding author: Ghulam Muhammad (ghulam@ksu.edu.sa)

This work was supported by the Researchers Supporting Project number (RSP2024R34), King Saud University, Riyadh, Saudi Arabia.

ABSTRACT Medicinal plants play a vital role in treating human and livestock ailments. A majority of the population living across the world relies on medicinal plants as a primary source of healthcare. The rural as well as the urban habitats depend on medicinal plants. Medicinal plants may be of root type or shoot type. Onion is one of the root types of medicinal plants that has abundant health benefits as well as economic value. Due to increasing urbanization, the availability of agricultural land is decreasing rapidly which is causing an increase in the demand for medicinal plants in a reduced cultivation area. This has led to the cultivation of soilless smart precision farming methods. Sensors are used to monitor and control the environmental factors affecting the growth and yield of agricultural produce. Among all the vertical farming methods, hydroponics is found to be the best way for cultivating herbaceous plants. This article deals with the comparison of growth responses of hydroponically grown onion (Allium cepa) in a Deep-Water Culture setup, as compared to that cultivated in soil. A systematic literature survey of onion grown in a hydroponic cultivation system is carried out. Finally, the growth responses of hydroponic and soil-grown onions are checked and compared with the results obtained from the 'AquaCrop' simulator. Results of the actual and simulator are verified and validated, and it is found that the actual and the simulation results are similar.

INDEX TERMS Hydroponics, medicinal plants, onion (Allium cepa), smart precision farming methods, urbanization.

I. INTRODUCTION

Agriculture has been identified as the backbone of the economy of India, which contributes to almost 18% of the Gross Domestic Product (GDP) and 43% of the geographical area [1]. The world population and urbanization are on an exponential hike, and the population is expected to exceed 9.8 billion by 2050 [2]. Urbanization is another unavoidable change that our society is going through. Various innovations and opportunities are brought about in modern society as a result of urbanization. This is resulting in the relocation of a huge mass of population towards the urban habitations, which in turn is causing increased traffic, pollution, industrialization, deforestation, increased pollution, soil erosion, etc. All these factors have caused a compromised lifestyle in urban habitats and an imbalance in the demand-supply ratio of agricultural produce [3].

The combined issue of decreasing cultivatable land and increasing demand for medicinal herbs is a major challenge being faced in the last few decades. This issue is effectively addressed by using alternate cultivation mediums in different vertical farming setups. Three types of soilless vertical

The associate editor coordinating the review of this manuscript and approving it for publication was Liandong Zhu.

farming setups are practiced to facilitate cultivation without soil: aeroponics, hydroponics, and aquaponics [4]. These farming methods resolve the issue of decreasing availability of cultivatable land, by eliminating the dependency on soil as the cultivation medium. The cultivation medium for aeroponics is air and that for hydroponics and aquaponics is water. All the nutrient requirements of the plant are sufficient by infusing the air or water with the nutrient solution. The possibility of damage due to pests and rodents is eliminated in the case of soilless cultivation methods. Diseases like fungal infection in plants also impose a huge loss in the agricultural sector which is still a possibility in soilless cultivation but the intensity of such losses is mitigated to less than 50% as compared to soil cultivation methods. This further enhances the productivity of the crops in soilless vertical farming methods [5]. Fig. 1 depicts the three major types of soilless cultivation methods.

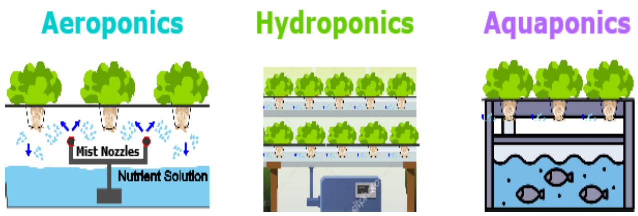


FIGURE 1. Types of soilless cultivation methods.

These setups consist of vertically stacked rows where cultivation is carried out, thus justifying the name 'vertical farming'. Therefore, in a considerably small area, cultivated yield is increased multiple times because the cultivation is carried out in vertically stacked layers [6]. Though the issues of less land for cultivation, and an increase in demand for medicinal plants can be addressed, another major issue comes up when it comes to dedicating time to the farming process. Urban people follow hectic work schedules and vertical farming methods need continuous monitoring for the better yield and efficient working of the process. This issue was then resolved by making the vertical farming setups smart [6]. Sensors, microcontrollers, clouds, LED, buzzers, pumps, actuators, etc. are attached to the vertical system which helps in continuous monitoring of the system, making it smarter and more efficient. All the parameters are monitored by using specific sensors, which communicate with the cloud for analysis and further actions are taken according to the analysis of the real-time data generated from the sensors. This method is termed smart precision farming. Providing all the necessary growing conditions to plants externally, in smart precision farming is termed as Controlled environment agriculture (CEA). CEA along with vertical farming methods ensures all the optimal required conditions for the medicinal plant to produce the maximum yield in a comparatively shorter vegetation period and minimal loss due to damage. Thus, sustainable, year-round, qualitative produce is ensured along with multiplied quantity [7].

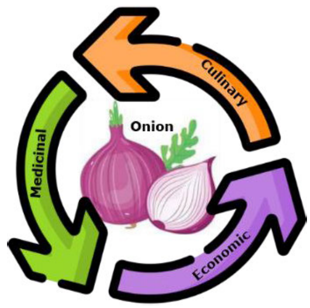


FIGURE 2. Major utilities of onion.

Apart from the increasing demand for various agricultural produce, the demand for cultivation of medicinal plants is also increasing at an exponential pace. The potential of the cultivation of medicinal plants like onion, has to be maximized to meet the continuous qualitative and quantitative demands of rural and urban habitats. Rural habitats have a very high dependency on the cultivation and production of medicinal plants due to several reasons like lack of modern health facilities, cultural priorities and beliefs, cost of modern drugs, etc. Medicinal plants have a very high impact on the lives of the urban habitats too due to their healing properties. Some vertical farming method enhances shoot growth whereas other enhances root growth [8]. The cultivation of herbaceous medicinal plants has to be ensured in such a way of precision vertical farming, that the part of the plant used for medicinal use, has a better growth response than that in the substrate cultivation methods. Therefore, the growth responses of various herbaceous medicinal plants need to be checked for different precision farming methods to identify the best-suited method that gives a year-round and better qualitative and quantitative yield [9]. The year-round production of herbaceous medicinal plants will not only enhance the economic benefit but also ensure the year-round availability of medicinal herbs for living beings. The reasons like compromised, unhealthy lifestyles caused by hectic work schedules, and increased pollution in the lifestyles of the urban population are causing a lot of health issues and other ailments. Commercially available medicines and modern treatments also cause severe side effects. Medicinal plants are thus, the most trusted source of medications that cure illnesses without having adverse effects on the health of the individual.

One such important medicinal plant is Allium cepa, commonly known as onion. Apart from being a widely used condiment plant around the world, it also has many medicinal benefits [10], [11]. Dried onions come in the form of powder and can be used as spices. Onions are overloaded with Vitamin B, vitamin C, calcium, phosphorous, etc., and can also be used to extract oil [10]. Many of its constituents like thiosulphates, phenolic acids, and quercetin contribute to its therapeutic effects [12]. Many disorders, such as asthma, inflammation, scars, pain, wounds, etc. are effectively treated by onion. It is also found to possess important pharmacological properties like anti-cancer, anti-hypertensive, anti-spasmodic, anti-diarrheal, and anti-diabetics along with being effective for bones, nervous systems, cardiovascular systems, respiratory disorders, etc. The three basic utility areas of onions are shown in Fig. 2.

Onion cultivation also plays a pivotal role in boosting the economy of many nations like China, Egypt, Nepal, Turkey, Afghanistan, and various regions of India [11], [12]. It is cultivated in huge amounts in many Indian states, making India one of the leading producers of onions [10], [13], [14], [15]. India is recorded to produce around 21% of the total onion production of the world, which is led by China with around 26% of the global onion production. To reach the zenith of economic growth from agricultural production, cultivation of economically potent crops like onion. The qualitative yield of onions can be enhanced by monitoring the environmental conditions, which can be easily achieved by using Internet of Things (IoT) sensors. Onion is the major medicinal food crop that is exported among vegetables in India. revenues as large as Rs. 222,70.3 million had been generated from exporting onions in 2015 which has increased to Rs. 523.8 million in 2022 [14]. India is the second leading exporter of onion after China. Cultivation and export of high-quality onion can form the basis for improving the Indian economy. Traditional cultivation methods have unlimited limitations, like risks, demand-supply mismatch, poor soil quality, and lesser arable land, that cause a hindrance towards onion cultivation thus leading to an adverse effect on the Indian economy [10], [12], [15]. Concerning the significant boost in the Indian economy from onion export and the continuously decreasing farming land and natural resources, there is a dire need to enhance the cultivation of onions. This can be achieved by prioritizing precision farming techniques using hydroponics to cultivate onions.

IoT is a vast network of smart devices that connects things to people anytime, and anywhere [16], [17]. These systems are capable of making decisions with minimal human interference and thus, make systems faster, smarter, and more efficient [18]. The number of connected smart devices encompassing IoTs has increased drastically and is further predicted to surpass 43 billion by 2023, making them a part of almost every application [19]. One of the major areas of application of IoT is agriculture. It forms the backbone of smart precision farming. Hydroponics is a method of smart precision farming which practices soilless cultivation, by using nutrient-rich water as the cultivation medium for plants [20]. Out of all the vertical farming methods, hydroponics outperforms the rest in terms of increased yield, lesser cost, easier maintenance, feasibility in various scenarios, water consumption, environmental sustainability, and wider adaptability. The hydroponic cultivation method is much more scalable than the other vertical farming methods because it can be modified and scaled according to the adaptability of the herbs to be cultivated. It comprises different setups to adapt to various types of plants. Some of the most popular types are nutrient film technique (NFT), ebb and flow, deep water culture (DWC), drip system, and wick system [21], [22], [23], [24], [25], [26]. Thus, smart precision farming in hydroponics is the key solution to all the issues of urban farming, including increased year-round qualitative and quantitative food demand. Fig. 3 represents the various types of hydroponic setups.

The selection of hydroponic technique out of all the five types listed above is dependent upon many factors, such as plant height, structure, irrigation needs, root anatomy, vegetation cycle, etc. DWC is considered to be the best-suited setup for the hydroponic cultivation of onions due to the compatibility with various growing requirements of onions as well as the cost and feasibility of establishing and maintaining the setup.

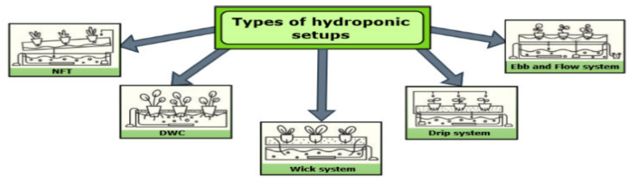


FIGURE 3. Various types of hydroponic setups.

In [27], the author carried out two experiments of centrosema, stylosanthes, trifolium, and lotus cultivation in soil medium, and the effect of vesicular-arbuscular mycorrhiza on the cultivation was studied in various compositions of soil nutrients. The results showed the total fresh weight, root/shoot ratio, and the percentage of mycorrhizal infection. In [28], the authors have carried out the growth response analysis of cucumber and the effect on its growth using the T-203 strain of the biocontrol agent Trichoderma harzianum in soil and axenic hydroponic conditions. In [29], soybean cultivation was carried out in controlled soilless conditions using four different nutrient concentrations, i.e. 0%, 50%, 100%, and 150%. The results showed significant variations in growth and all the measured parameters under these different conditions. The root thrived the most in 50% nutrient concentration, whereas the shoot growth was maximum in 150% concentration of nutrients. Three growth mediums i.e. cork thin waste with rice hulls, peat, and coir fiber were compared in three soilless cultivation methods, and the microbial influence, pH, and EC were analyzed in [30]. In [31], two varieties of lettuce were cultivated to analyze their growth on different types of media in a wick system of hydroponics using three mediums: cocopeat, Rockwool, and charcoal, whereby it was found that charcoal husk showed the best cultivation results. Rice was cultivated in a hydroponic setup and the effect of sodium and potassium chloride was analyzed in [32]. The rice seedling shoot was sensitive to KCL. In [35], different nitrogen sources were supplied to lettuce from two sources, one source with 200 ppm NO 3–N, and the other with 150 ppm NO 3–N and 50 ppm NH 4+-N. The highest growth was recorded using 200 ppm NO 3–N. The authors of [36] have cultivated legumes called Serra Della in aluminum-toxic soil to conclude that AI tolerance varies among various cultivars. In [24], a certain variety of lily is cultivated in an ebb-and-flow system of hydroponic cultivation where statistical analyses showed no correlation between the weights of the initial and the final bulblets. Elongation of roots and growth and survival of bulblets were dependent upon the hydroponic setup, the substrate type, and the composition of the nutrients in the solution medium. 'Rubinela' lettuce was cultivated in soil-filled pots and hydroponic systems by the authors of [38] where the research aimed to analyze its physiology through a comparative analysis of dry and fresh mass, production, leaf count, chlorophyll, and carotenoid contents. It was found that the hydroponic plants showed prominent variations in chlorophyll content, with more biomass than those grown in soil. In [39], the authors built an innovative hydroponic fuel cell to reduce methane emissions from rice plants. Rice was cultivated in a hydroponic setup where the results show that the methane emission was significantly reduced with the use of these cells. The effect of actinomycetes on hydroponic lettuce was studied in [40], where it was found that mitigation of detrimental effects in various growth parameters was found using Streptomyces thermocarboxydus S3 type of actinomycete. In [25], the authors have grown basil in soil and hydroponics, where the hydroponic basils had more browning than hydroponic ones at the end of storage and shelf-life periods. An IoT-based smart NFT setup was created in [26] where various environmental parameters were collected in a Raspberry Pi database. A Proteus simulator was also used for analyzing the results, where a "very good" rating was given to the implemented device. The authors of [41] propose a method to combine the theoretical and practical of aquaponic and hydroponic farms by modeling and simulating the systems. Petri nets were used for modeling and the GPenSIM tool was used for the simulation and monitoring. Support vector regression (SVR) was also used to predict the temperatures of air water and humidity. The research in [42], investigates the economic and technical feasibility of greenhouses in arid regions on a larger scale, where the results demonstrate that these systems have a massive potential to show considerable climate resilience which helps to enable vegetation in arid and infertile regions.

The following research gaps have been identified from the background study regarding growth response analysis of medicinal plants:

- Growth responses of various herbaceous plants have been compared in previous studies, but very little research is focused particularly on the cultivation and yield enhancement of medicinal herbs [27], [28], [29], [30], [31], [32], [35], [36]. Medicinal herbs add to the essential nutrient contents in edible products of humans and livestock. Herbal medicines are also preferred over the chemical medicines available commercially because they are devoid of harmful side effects. Medicinal herbs eliminate food security issues and ensure healthy lifestyles in rural and urban habitats. Thus, the need of the hour is to enhance the cultivation and yield of medicinal plants.
- In the existing research works, either the root [24], [35], [36], [37] or the shoot growth responses are monitored [25], [28], [38], [39], [40] not both.
- The comparative growth responses of any plant are carried out only in any one medium, growth responses in multiple mediums are not analyzed for a single plant [24], [28], [30], [31], [32], [33], [34], [35], [36].
- Either the growth responses of a plant are analyzed in actual cultivation [27], [28], [29], [30], [31], [32], [35], [36], [42] or the analysis is done using the simulator, the incorporation of both methods in a single experiment is not found [26], [41], [42]. This research focuses on the analysis based on actual experimentation as well as results obtained from the 'AquaCrop' simulator.

The present investigation was guided by the formulation of the following research questions:

RQ. 1: Which hydroponic setup is most suitable for growing herbaceous medicinal bulbs?

RQ. 2: What is the comparative growth analysis for the growth of onions in traditional and hydroponic methods?

RQ. 3: How relatable are the actual results as compared to the simulator results?

RQ. 4: Which method is more beneficial, in terms of environmental footprint, expenses, and yield of the medicinal plant under consideration?

RQ. 5: Which method is more effective in terms of energy consumption?

The novelty of this research lies in the fact that a real-time comparative analysis of root as well as shoot growth responses of onion, a medicinal plant, is carried out in this experiment. The experimental results are then verified and validated using a simulator. Very few works have focused on the better qualitative and quantitative yield of the root as well as the shoot of any medicinal plant [27], [28], [29], [30], [31], [32], [35], [36]. Some of the research works focus on only the root [24], [35], [36], [37] or only the shoot of any plant [25], [28], [38], [39], [40]. This work demonstrates the root and shoot growth responses of a medicinal plant (onion) having abundant medicinal properties in its shoot as well as its root. Also in previous works, the growth responses have been analyzed on any one method of cultivation [24], [28], [30], [31], [32], [33], [34], [35], [36], whereas the authors have considered the analysis of root and shoot growth response comparison in soil cultivation as well as in hydroponics. No previous work includes the verification and validation of the actual results with the simulator results, either the actual cultivation is carried out [27], [28], [29], [30], [31], [32], [35], [36], [42] or the simulation is carried out [26], [41], [42] not both. All these aspects are incorporated in this research work where the actual cultivation results in soil as well as hydroponics are verified and validated with the results of the 'AquaCrop' simulator. The main objective of the research is to enhance productivity and obtain a better qualitative and quantitative yield of onion in a shorter span, all round the year. Thus, the results of this research will be helpful for the agricultural, medical, as well as economic benefit of any nation.

The major contributions of this research article are mentioned as follows:

- The necessity and importance of soilless cultivation methods in modern urban localities are discussed in terms of various parameters. The authors have highlighted the advantages of soilless cultivation over soil cultivation methods in terms of better, faster, and year-round yield. Parameters like space optimization, resource conservation, increased year-round yield, and shorter vegetation period are considered for a comparative analysis of hydroponic and soil cultivation methods in this research.
- The emerging need to cultivate medicinal plants via vertical farming methods is explained in context to the nutritional components and medicinal properties of onion shoots and roots. The effect of onion cultivation on the economy of India is also discussed, which adds to its importance as one of the majorly exported medicinal food crops.
- In this research, various types of hydroponic setups are discussed. The workings and components of a smart hydroponic setup are also explained. Out of the five most popular classifications of hydroponic setups, DWC is identified as the most suitable setup for the cultivation of onion.
- Classification of various types of medicinal plants is done based on their medicinal properties in their roots and shoots. The trend of using medicinal plants in India is also shown along with the trend of IoT and sensor-enabled hydroponics in the last year.
- Onion bulbs are cultivated in the soil as well as in DWC hydroponics. The growth responses of onion shoots, roots, and bulbs are monitored, analyzed, and compared in qualitative and quantitative terms. The obtained results are also verified and validated using the 'AquaCrop' simulator in both mediums.

The rest of the paper is organized as: section II covers the extensive background study regarding smart hydroponic farming, medicinal plants, and onion as a medicinal plant. Section III encompasses the materials and methods employed in the process of this experiment, and the results and discussions are projected in Section IV. Finally, the article is concluded in Section V.

II. BACKGROUND STUDY

This section deals with the extensive literature studied concerning smart hydroponic farming methods associated with the cultivation of onions. Three subsections are created to present a detailed overview of each aspect. The first subsection deals with the study of the hydroponic method of smart precision farming, and the second subsection gives a detailed overview of various types and classifications of medicinal plants. The third and final subsection of this topic deals specifically with the importance of onion as a medicinal plant, its growing period, and its cultivation in smart hydroponic setups.

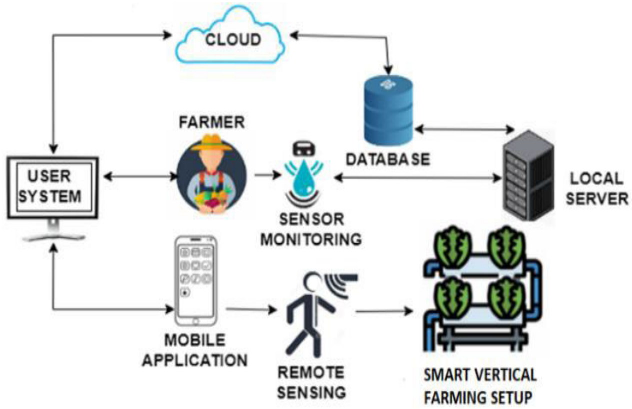


FIGURE 4. Working with a smart precision hydroponic setup.

A. HYDROPONIC TYPE OF SMART PRECISION FARMING

Hydroponic type of precision agriculture is the agricultural process that uses water as the cultivation medium and inputs the precise values of the agricultural conditions to the system to obtain the best possible yield with the use of IoTs [43]. The IoT usage makes the system more intelligent and self-sustaining, thus consuming less time and effort for the farmer along with enhancing the cultivated produce [3]. Fig. 4 explains the working of a smart precision hydroponic setup. The smart hydroponic farm is integrated with the cloud to analyze sensor data and the farmer can monitor and control the farm remotely. This will help serve the multiple purposes of having a healthier living, a cleaner surrounding environment, easy and handy cultivation methods, domestic as well as economic benefits to the cultivators, etc.

A fully automatized greenhouse integrated with the hydroponic type of vertical farming ensuring provisions for security and surveillance is proposed which makes it an advanced and diverse form of all the existing models. It is observed to provide an improved product with a cent percent success rate, maintaining the ranges of the parameters [44]. An automatic aeroponic system of cultivation for lettuce while keeping the humidity, time taken for irrigation, temperature, etc. in control and spraying the nutrient mist to the plant root, is proposed as a cost-effective Arduino-based system using IoT [45]. IoT tools connected to a web server help in monitoring the variables remotely. As compared to the traditional processes of cultivation, lettuce leaves as well as roots grew more than 40% with around 400% better performance, had been recorded [46]. The system designed in this study is capable of keeping healthy growing parametric conditions for the crops automatically, irrespective of the prevailing climatic conditions, and with minimum user interference. It shows the temporal variations, light intensity variations, temperature, humidity, electrical conductivity, pH, and CO_2.

To show better vigilance in a hydroponic setup, the system even monitors the level of water in the storage. Smart cooling is ensured of lettuce roots in the smart aeroponic setup for lettuce cultivation. The temperature and humidity data are also retrieved in [47]. Cost-effectiveness is maintained using a fan that is connected to the Arduino board to ensure continuous data recording. An application for mobile phones is employed to get the data. An Excel sheet is updated and kept and updated every week by the farm owner. This increased the lettuce growth and also the inorganic nutrients absorbed by the plant [48]. Role of IoT to control the growth and communication of alerts to the user using web applications. The controlled plants are found to show better growth responses than those cultivated in an uncontrolled environment and also there are fewer unwanted values in the case of controlled growth of plants. The growth responses of plants are shown as a figure on the website app and the values violating the preset ranges can be identified conveniently and efficiently. Subsequently, the farm owners are notified, and thereby minimum losses are incurred by activating the alternative control measures present in the system [49]. To improve the efficiency of hydroponic cultivation, Electrical conductivity (EC), fluid level, total dissolved solids (TDS), and the potential of Hydrogen (pH) values are controlled automatically. Facilitation data collected continuously, from a large number of sensors, in urban farms, a system is developed for adjusting the pH value automatically, and in the cultivation of lettuce using a neural network is developed to facilitate continuous data collection from multiple sensors in urban farm conditions [50]. A study based on image processing is put forth to check the percentage of deficit of macronutrients in a hydroponic environment [51]. Determination of a lack of macronutrients can be done in multiple phases such as acquisition and pre-processing of images, feature extraction, image segmentation, task identification, and estimation. IoT is used to process image data acquisition automatically. The plant under consideration in [52] is chili. The main feature of this research work is to improve the output of the precision agricultural methods, three of the features were combined in the form of the texture, color, and shape of the leaf. This study is also focused on estimating various plant condition types like a deficit of nutrients like Sulphur, calcium, potassium, magnesium, etc., or a healthy plant condition. A model is aimed to be built that is capable of performing identification as well as estimation. Along with analyzing multiple nutrients.

B. TYPES OF MEDICINAL PLANTS WITH MEDICINAL VALUES IN VARIOUS PARTS

Medicinal plants have always held major importance in the lives of all living beings [53]. Various parts of the medicinal plants are put to use in various ways. In plants like ginger, turmeric, burdock, and ginseng, roots have medicinal properties of antioxidants, anti-tumor, enhanced immune system, etc. [52], [55], [59], whereas in plants like basil and thyme, the leaves have medicinal properties of liver detoxifier, disinfectant, reliever of the wound, kidney stones, muscle aches, etc. [25], and in plants like lavender and saffron, the flowers contain medicinal values of stress, pain and anxiety reliever, helpful in Alzheimer disease and depression [57], [58]. The vertical precision farming methods are best suited for herbs and thus, the herbaceous medicinal plants must be analyzed in terms of the smart precision vertical farming method that suits them the best [53]. A generalized answer to this question cannot be found because each medicinal plant has a different part that is put to use for its medicinal value. Thus, the plants whose roots are used for medicinal purposes would need a different precision vertical farming method whereas the plants whose leaves or flowers or any other part of the shoot would need a different method of precision vertical farming method for it to thrive to the fullest. Fig. 5 is a representation of examples of herbaceous medicinal plants with various parts having medicinal properties.

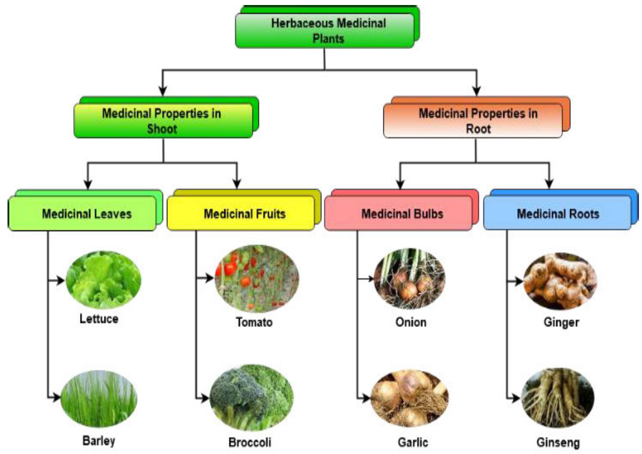


FIGURE 5. Examples of herbaceous plants with medicinal values.

Every medicinal plant has medicinal properties in different parts of the plant. Some plants have medicinal properties in the shoot part (stem, leaves, fruits, or flowers), and some may have medicinal properties in the root part. Lettuce and barley are examples of medicinal leaves, whereas tomato and broccoli are medicinal fruits. Garlic and onions are seen to have medicinal values in their bulb roots, and ginger and ginseng are examples of roots that contain medicinal properties. Thus, to employ the vertical farming method for herbaceous medicinal plants, the part of the plant containing the medicinal properties needs to be identified [54]. Thereafter, a suitable cultivation method can be used to cultivate the identified plant and a smart precision farming method can be used to cultivate it.

The authors of [55] tested the growth of medicinal plants in aeroponics and hydroponics whereby no significant variation is seen in the shoot growth characteristics of the plants. The ginseng roots contain healing properties which makes it very important to maintain its root quality. Rotting of roots is a major disease-causing deterioration of ginseng root quality. The authors in [56] proposed a way to detect the disease-causing rotting of roots by checking the colored images of the plant through image processing and deep learning. The authors in [57] checked three categories of medicinal herbs in multiple hydroponic setups and one aeroponic setup. Post that results comparisons are done with plants grown in substrate medium, with exactly similar environmental conditions. An innovative frame of aeroponic setup was formed in [58] to enhance the produced quality of Burdock root (Arctium lappa L.) cultivated in an aeroponic method in a controlled soilless greenhouse environment. The production of biomass from the aerial parts of the plant was found to be considerably high in an aeroponic setup as compared to the controlled cases. Whereas the biomass yields of the root of the plant did not exhibit any significant variations between treatments. The authors in [52] and [59] found that hydroponic techniques are optimal in reproducibly and efficiently generating the medicinal herb Withania somnifera (L.).

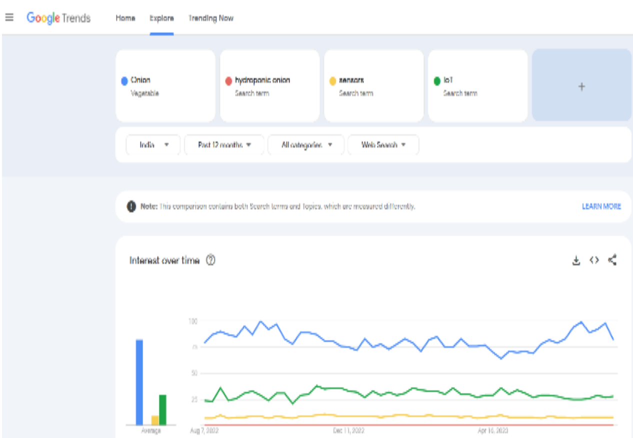


FIGURE 6. Plot obtained from Google trends showing the trend of medicinal plants, IoTs, sensors, and hydroponics in India for the past year.

Fig. 6 shows the Google trend plots showing interest and trends in smart hydroponic farming of onion over the past 12 months, specifically in India. The trends of Onion and IoT are increasing at a very fast pace.

C. ONION (ALLIUM CEPA)

Onion is a category of medicinal plant that has medicinal properties in its shoot as well as in its bulb. Onion can be cultivated in three seasons, namely, Rabi, Kharif, and Late Kharif. Table 1 is a tabular representation of the various growing seasons of onion. The production cycle of onion, if shortened, can be advantageous to mankind in multifold ways [12], [13], [15].

Apart from being loaded with vitamins, minerals, and other beneficial medicinal, pharmacological, and therapeutic properties, onions are also loaded with several nutritional components. It has the capability of curing various ailments and health disorders. The authors of [10], [13], and [15] have come up with the amount of nutritional components per 100 grams of the edible portion of onion. Energy, carbohydrates, sugars, fibre, fat, protein, various vitamins, calcium, iron, manganese, phospsorous, and potassium are the major component found in onion.

Table 2 is a generalized representation of the nutritional contents contained in the edible portion of onion.

TABLE 1. Production cycle of onion.

Growing season	Plantation time	Harvesting season
Rabi	December – January	March-May
Kharif	July – August	October – December
Late Kharif	October – November	January – March

TABLE 2. Nutritional components per 100 grams, in the edible portion of onion.

Components	Amount (per 100 grams of the edible portion of onion)
Energy	72 kcal
Carbohydrates	16.8 grams
Sugars	7.87 grams
Fibre	3.2 grams
Fat	0.1 grams
Protein	2.5 grams
Vitamin B1	0.06 mg
Vitamin B2	0.02 mg
Vitamin B3	0.2 mg
Vitamin B9	34 mg
Vitamin C	8 mg
Calcium	37 mg
Iron	1.2mg
Manganese	0.29 mg
Phosphorous	60 mg
Potassium	180 mg

III. MATERIALS AND METHODS

This section deals with the materials used in the cultivation of onion bulbs in soil as well as in water mediums. Onion is the medicinal plant selected as the experimental subject in this experiment because it contains medicinal value in its shoot as well as in its bulb. Onion thrives well in water as well as soil mediums. This experiment comprises the cultivation of onion bulbs in in substrate medium and DWC hydroponic system, a comparative analysis of their growth responses, and validation of the obtained results with the results obtained from the 'AquaCrop' simulator.

The soil was prepared for onion cultivation by adding sand and compost and making it moist. Onion bulbs were slit from the top and planted in soil in a way that ample space is maintained between the onion bulbs to ensure proper root and shoot growth. The water used for onion cultivation was infused with essential nutrients as mentioned in Table 2. The growth responses of onion were monitored and compared in soil and hydroponic methods. Onion growth was found to be much faster and more qualitative in water as compared to its growth in soil. Fig. 7 represents the flowchart of the overall framework of the experimental work done in the experiment.

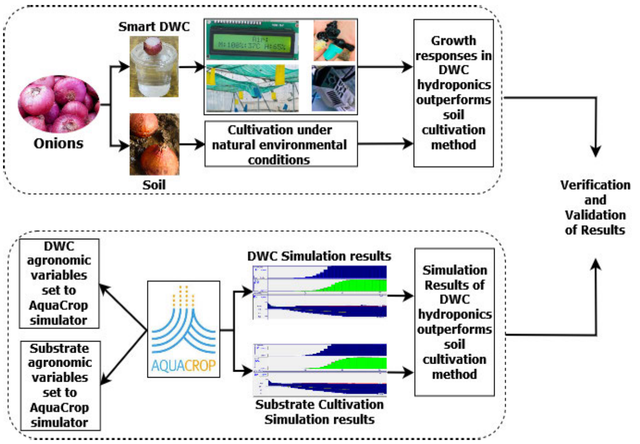


FIGURE 7. Flowchart of the proposed experiment.

(a) (b)

FIGURE 8. (a) Fungus-inflicted onion bulb. (b) Root growth of n inflicted onion bulb in hydroponics.

The input parameters of soil and DWC cultivation were set in the 'AquaCrop' simulator separately and the experimental results were then verified and validated through the results obtained from the simulator. The comparative analysis of onion growth was thus carried out in an actual experimental setup as well as in the 'AquaCrop' simulator.

The substrate cultivation has to be carried out when the weather conditions are favorable for its growth, whereas, in the smart DWC hydroponic cultivation, the cultivation can be done at any time of the year because all the environmental conditions and the nutrient requirements can be monitored in real-time and controlled as per the requirements of the plant. This ensures year-round qualitative and quantitative produce. The DWC hydroponic method uses a specific setup where the roots of the plants are submerged in nutrient-rich water. The pH, EC, and nutrient content of the growing medium are monitored continuously for any alteration, and the nutrient-infused water is also changed periodically to ensure proper nutrient intake by the plants. A smart DWC setup carries out the additional task of maintaining a CEA in the cultivation system whereby the pH, temperature, TDS, and other essential parameters are controlled externally.

Onion plants have medicinal properties in their shoot as well as in their bulbs. The onion shoots grow much faster and can be harvested sometimes before the onion bulbs are developed and harvested. Till the time the shoots are thick and green at the base, they can be harvested repeatedly. Once the shoot dries up and wilts from the base, the bulbs are ready to be harvested. Onion bulbs were planted simultaneously in a DWC hydroponic setup and soil medium. The growth responses of onion root and shoot were compared in both the mediums and it was verified and validated with the results obtained from the 'AquaCrop' simulator.

A. CONTROLLED PARAMETERS FOR OPTIMAL ONION GROWTH

Many researches have proved that the cultivation of onions under controlled environmental conditions has produced enhanced and uniform shoot growth and bulb formation of onion plants. Onions were cultivated simultaneously in a smart DWC setup and soil. Soil cultivation is dependent on the natural resources and climatic conditions, thus it has to be carried out in the season which suits its requirements, whereas the cultivation in a smart DWC setup can be carried out at any time of the year. A low relative humidity and high-temperature help in enhancing the shoot and bulb growth of onions, whereas a high relative humidity causes fungal and bacterial growth on the onion bulbs. Fig. 8 (a) is a picture of fungus fungus-inflicted onion bulb, and Fig. 8 (b) shows the root growth of the fungus-infected onion bulb in the DWC hydroponic setup.

The life cycle of onion is also affected by temperature fluctuations. Higher temperatures cause early bulb development in onions, therefore ensuring precise temperature while studying various growth phases of onion cultivation is important. The light source used in the experiment was natural sunlight for optimum daylight.

B. PESTS AND DISEASE CONTROL

Onion bulbs are prone to fly infestation and fungal infections. Cultivation of onions under controlled environmental conditions ensures minimized damage due to pest and disease infestations. These pests and diseases must be managed efficiently with continuous monitoring of the system, especially in greenhouses. A few precautions to be taken while cultivating in any controlled environment can be mentioned:

- Maintaining cleanliness in and around the growing area.
- The substrate mix must be kept tightly sealed before and after use to avoid drying up or infestation.
- Use preferable new potting units or sterilized, washed with the bleach solution, and rinsed thoroughly.
- Using insect repellants or sticky insect traps for real-time control of fly and pest infestations.
- Dead, wilted, or damaged plants must be removed from the setup regularly to ensure the safety of the other plants in the setup. Diseased and weak plants are more prone to infections.

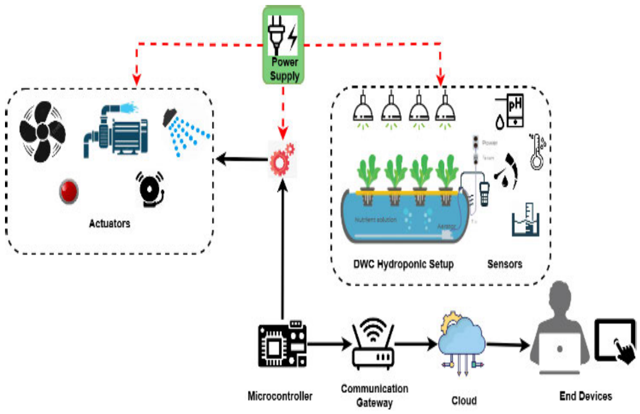


FIGURE 9. Components of an IoT-enabled smart precision agriculture setup.

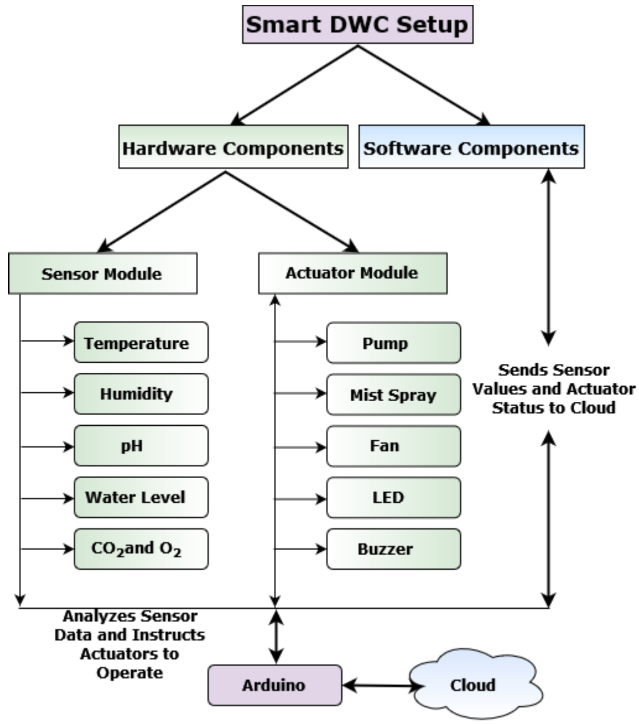


FIGURE 10. Various components of the smart DWC setup are used.

C. SMART DWC HYDROPONICS SETUP

A representation of the commonly used components of an IoT-enabled smart precision agriculture setup is depicted in Fig. 9. The smart precision agriculture setup is equipped with a sensor module and an actuator module. A microcontroller acts as an interface between the entire hardware system and the cloud or the communication gateway. The sensor module collects data on various parameters. All the sensors are preset with a particular range. The data collected in real-time is then sent to the cloud for analysis [60]. If any value is found to drop below the lower limit of the set range or exceed the upper value of the range, the user or the farm owner will be notified of the situation.

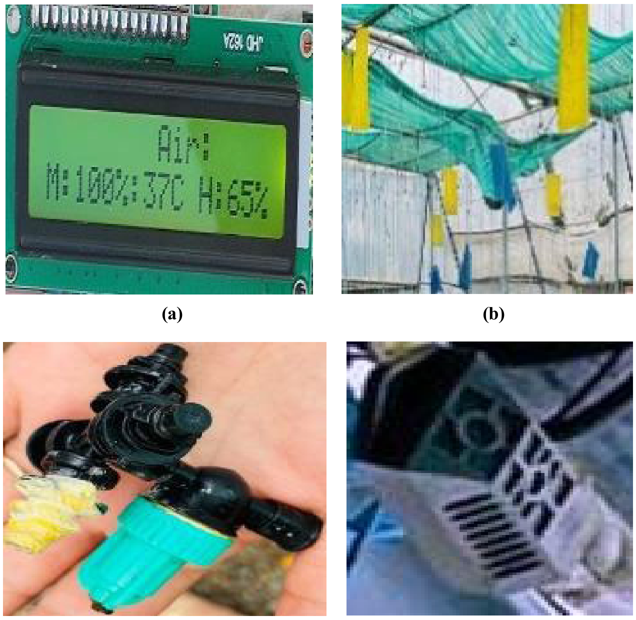
If the setup is well equipped with actuators, corresponding alternative arrangements could also be activated to get the data value of the sensors in range to regain the smooth functioning of the smart precision farming setup. The fact that the cultivation is done in a CEA setup, ensures high-quality, year-round produce which eliminates the dependency on climatic conditions and thus reduces wastage or damage in agricultural produce to a large extent [61], [62], [63].

Fig. 10 is a pictorial representation of the components of a smart DWC setup. The components of the setup can be broadly classified into two categories: hardware components and software components. The hardware components can be further classified into two subcategories: sensor module and actuator module.

The sensor module is responsible for collecting real-time data on the parameters that are controlled in the setup. Sensors to monitor temperature, pH, water level, and humidity are deployed in the system to collect real-time data on the respective parameters. Every sensor is provided with the permissible parametric range, and the values collected by the sensors are then sent to the cloud for analysis. If the values are found to violate the specified range, the actuators are instructed to facilitate the situation. Actuators are hardware components like fans, water pumps, nutrient pumps, buzzers, etc. that are used to keep the parametric values within the range. This is very helpful to the urban habitats that perform vertical farming, where they can have a remote check on the farm and the system takes care of the farm.

Fig. 11 shows the various hardware components used in the smart DWC setup. The hardware components used in the setup can be described as:

- Temperature sensor: According to the requirement of onion, the temperature sensor was set with a range of 29°C – 32°C. The Arduino microcontroller board receives the real-time temperature values collected by the temperature sensor and analyses the values concerning the specified range. If the recorded temperature is beyond 32°C, the fans are activated and the temperature is lowered. When the temperature comes within the range, the fan is switched off. The experiment was carried out in August – September when the temperature did not fall too low. Thus, the lower level of temperature was maintained.
- pH sensor: The pH value is set to 6.0 – 6.4. If at any moment, the pH value drops below 6.0, sodium carbonate (Na_2CO_3) is added to the mater medium, alternatively if the pH rises above 6.4, nitric acid (HNO_3) is added to the growing medium to balance the pH of water.
- Humidity sensor: A minimum of 66 % and a maximum of 70 % humidity is suitable for growth of onion. More than 70% humidity causes fungal infestations on the bulbs of onion which hampers the proper growth of onion shoots. The humidity sensor monitors the humid-



(a) (b)

(c) (d)

FIGURE 11. Various hardware components are used in the smart DWC setup. (a) LED; (b) Insect Trap; (c) Mist Spray; (d) Temperature Sensor.

ity and sends the collected value to the microcontroller. If the humidity rises above 70 %, the fans are used to circulate dry air, and if the humidity falls below 60%, the mist spray is activated to increase the humidity and bring it within the range.

- Water level sensor: The DWC setup has a stagnant nutrient solution in which the roots of the plant are submerged. The water level of the cultivation units has to be maintained to a level where there is a little gap between the water level and the lid of the box to ensure space for vapor.
- CO_2 and O_2 sensors: Both CO_2 and O_2 are required in the nutrient solution for the optimal growth and development of the hydroponic plant. These sensors notify the users if the CO_2 level exceeds 900 ppm or the O_2 level drops below 18%. The nutrient solution of the DWC setup is then replaced with a fresh one.
- Buzzer and LED display: These hardware components in the smart DWC hydroponic system help in facilitating continuous monitoring of the system and send alerts in case of any unwanted situation.

A smart DWC hydroponic setup implementing CEA is used for cultivating onions for this experiment. Table 3 shows the optimal parametric ranges required by onions in a DWC hydroponic system and their corresponding values or ranges [10], [12], [15].

A static nitrogen-rich nutrient solution is provided as the cultivation medium for the onions. The culture unit used in this experiment consists of plastic boxes. Each of the boxes has a capacity of 1 L of the nutrient solution. Holes of 1 – 1.5 cm diameter were drilled in the center of the lids of each of the boxes, and 4 other holes of 0.5 cm diameter were drilled around it as shown in Fig. 12.

The bigger hole was for the onion to immerse its roots in the nutrient solution inside the box, and the four smaller holes were drilled to ensure proper ventilation and release of heat from the inside of the box. Onions can be harvested as immature spring onions or full-grown bulbs. To ensure proper growing space for each of the onion bulbs, all the onions were planted in separate boxes. The onion bulbs were planted at the end of July. The nutrient solution was changed

TABLE 3. Parameters and their permissible ranges for growth of onion in a DWC hydroponic system.

Parameters		Values / Ranges
Temperature		29°C – 32°C
Humidity		66 %– 70 %
pH		6.0 – 6.4
EC		1 – 2.2 mS/cm
Cultivation medium		Nutrient infused water
Vegetation period	Bulb to shoot sprouts	3 – 4 days
	Bulb to bulbs	28 – 32 days
Cultivation month		Throughout the year
Water consumption		Approximately 24 liters/Kg
Setup		DWC hydroponics
TDS		600 – 750 mg/l
CO_2		< 900ppm
O_2		> 19%
Essential nutrients: N, P, K ratio	Initial week	10:20:10
	Subsequent weeks	20:05:05
Additional nutrients		Sulphur, Boron, Magnesium

FIGURE 12. Onion bulbs are planted in boxes filled with nutrient-mixed solution.

FIGURE 13. Algae formation at the bottom of the container.

(a) (b)

FIGURE 14. Cultivation of onion bulbs in soil. (a) Onion bulbs planted in soil; (b) LED depicting NPK contents in soil.

every week to ensure proper nutrition to the plants and avoid algae formation inside the boxes. Fig. 13 depicts a case where algae formation was found at the bottom of the hydroponic container. A pH level of 5.8 to 6.9 and an EC level of 1.4 to 1.8 was maintained throughout the cultivation process.

D. SUBSTRATE CULTIVATION

The onion needs a substrate that has a good aeration and water retention capacity. Sandy or heavy soil types are the most suitable soil types for onion cultivation. garden soil, sand, and compost are mixed to make the growing medium ready for onion cultivation. The moisture retention capacity determines the frequency of watering. The moist substrate is one of the important requirements for the healthy growth of onions. The stage of plant development along with the relative humidity and temperature maintained in the growth chamber determines the frequency of watering the plants. Growing stages require more frequent watering as compared to the maturity stage. The onion bulbs were cultivated at the end of July when an average temperature of 22 – 38 °C temperature was prevailing in the Punjab region. An average relative humidity of 60 – 70 % prevailed in the region during the mentioned period. A tabular representation of the necessary parameters for cultivating onions in soil is shown in Table 4 [10], [12], [15].

Fig. 14 (a) shows plastic trays of dimensions (20 × 15) cm filled with soil and 4 onion bulbs uniformly planted in it. Optimum distribution of air and water was ensured to maximize the growth of the plants. Regular watering is done in the soil using distilled water to prevent algae growth on the soil surface. Colorless plastic trays were used to ensure proper passing of light to the onion roots. Also, dark-colored pots absorb much heat and cause damage to the plants.

Fig. 14 (b) is a picture of an instance where the LED displays the N, P, and K percentages in the soil.

E. RESULTS AND DISCUSSIONS

The utility of onion in culinary, medicinal, and economic aspects, is discussed in the introduction section of the manuscript, which highlights its importance and the necessity for its better and enhanced yield. Apart from having a wide range of medicinal, therapeutic, and pharmacological

TABLE 4. Parameters and their permissible ranges for growth of onion in soil medium.

Parameters		Values / Ranges
Temperature		28°C – 34°C
Humidity		64 % – 72 %
pH		5.9 – 6.3
EC		3 – 4.5 dS/m
Average rainfall		600 – 900 mm
Cultivation medium		Potting mix made up of garden soil, sand, and compost
Cultivation month		July – August
Essential nutrients: N, P, K ratio		2:1:1
Vegetation period	Bulb to shoot sprouts	15 days
	Bulb to bulbs	65 – 75 days
Additional nutrients		Sulfur, Magnesium

properties, onion also contains various nutrients in its bulbs and shoots as mentioned in table 2 of the background study. It also plays a significant role in boosting the economy of India by being one of the majorly exported medicinal plants. Keeping in view all these aspects, the onion is selected for this research, and its root, shoot, and bulb growth in soil and DWC hydroponics are monitored, analyzed, and compared. Furthermore, the actual cultivation results are verified and validated with the results of the 'AquaCrop' simulator.

The analysis of resulting growth responses of onion cultivated in soil and a smart DWC hydroponics is done in this section. The growth responses of onion shoot, root as well and bulb are analyzed based on the experiment conducted, and qualitative as well as quantitative yield analysis of the obtained yield is carried out. The obtained results were finally compared and validated with the results obtained from the simulator. The growth responses of shoot, root, and bulb in DWC hydroponics are found to outperform those in the soil cultivation method.

F. GROWTH COMPARISON OF ONION SHOOTS AND ROOTS IN SOIL AND DWC HYDROPONICS

Onion bulbs were cultivated in the soil as well as in a DWC hydroponic setup. The plant with the best shoot growth is considered for the comparative analysis. In all the cases, the hydroponic roots and shoots showed the best growth responses as compared to soil cultivation. It is observed that the maximum length of onion shoot in hydroponics was found to reach 21.5 cm, whereas the maximum onion shoot length attained in soil medium was 16 cm. As a result, the hydroponics proved to give almost 74.4 % better shoot yield as compared to soil.

The root length obtained in the DWC hydroponic method was also found to be 21.43 % better and much faster as compared to that in soil.

The graph in Fig. 15 is a comparative plot of the maximum shoot and root length of onion bulbs in water and soil mediums.

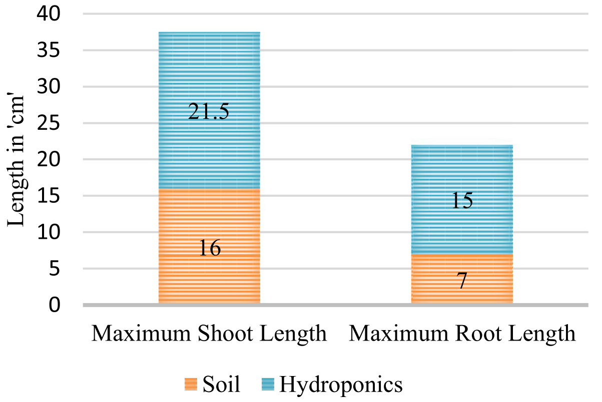
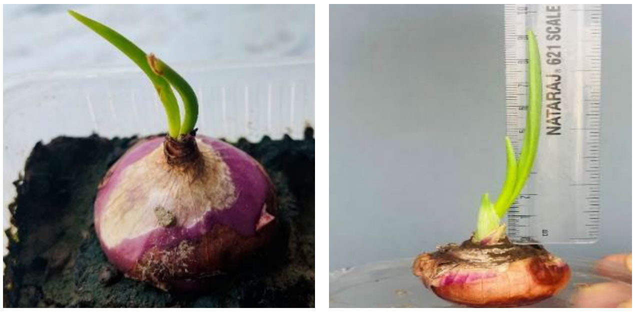


FIGURE 15. Growth analysis of onion shoot and root growth cultivated in substrate and hydroponics.



(a) (b)

FIGURE 16. Shoot growth from onion bulbs on day 15 after planting. (a) Onion shoot growth in soil; (b) Onion shoot growth in water.

G. DAY-WISE GROWTH COMPARISON OF ONION SHOOTS IN SOIL AND DWC HYDROPONICS

Fig. 16 (a) and (b) show the onion shoot measurement on day 15 of cultivation in soil and DWC hydroponics respectively. The growth of the onion shoot was found to be better in hydroponics than in soil.

The plot in Fig. 17 demonstrates the growth trend of onion shoots in soil and water mediums. The lengths of the best sample of both the cases are considered and the day-wise graph is plotted. This graph proves that the DWC method of cultivation produces approximately 1.3 times better yield in less than half the number of days as compared to the results obtained when cultivated in a soil medium.

Therefore, in response to RQ. 1, it can be answered that the DWC hydroponics method is the best for the cultivation of herbaceous medicinal bulbs.

H. DAY-WISE GROWTH COMPARISON OF ONION ROOTS IN SOIL AND DWC HYDROPONIC

Fig. 18 shows the picture of roots developed in both methods of cultivation on the fourth day after cultivation. it is visible that the root growth in the soil medium is considerably lesser than that in the water medium.

The maximum root length recorded in soil medium was 9 cm whereas that recorded in water was 13 cm. The concept

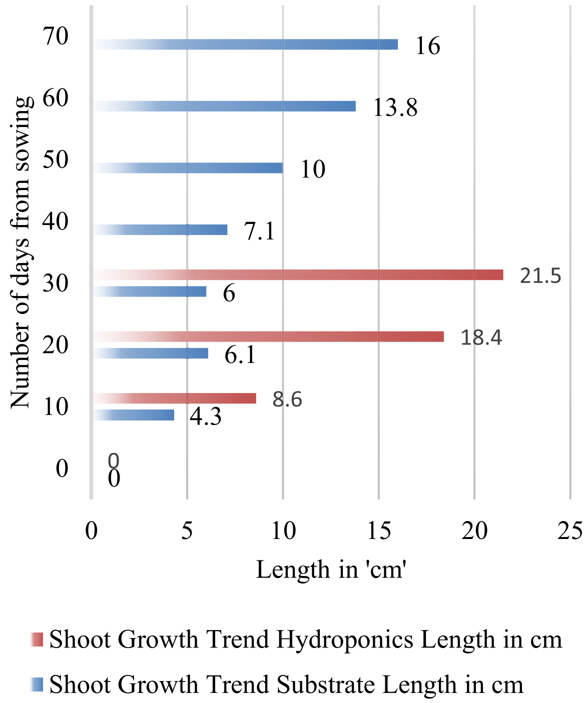


FIGURE 17. The day-wise plot of onion shoot lengths in soil and hydroponic methods respectively.

(a) (b)

FIGURE 18. Root growth of onion bulbs on day 4 after planting. (a) Onion root growth in soil; (b) Onion root growth in water.

of analyzing the qualitative and quantitative comparison of the shoot, root as well as bulb growth characteristics of a medicinal plant with high economic value (onion), cultivated in water as well as in substrate mediums, which are further, verified and validated using simulator results in the same experiment, contribute to the novelty of this research.

I. ONION BULB FORMATION FROM BULBS CULTIVATED IN SOIL AND DWC HYDROPONICS

Fig. 19 depicts the bulb formation of onions in soil and hydroponics systems respectively. The quality of bulbs is found to be much better than that formed in soil and also the time required by the onion bulb to produce newer bulbs in soil medium is almost more than double the time taken by the hydroponic onion.

(a) (b)

FIGURE 19. **Onion bulb formation. (a) Onion bulb formation in soil; (b) Onion bulb formation in water.**

Thus, as a response to RQ. 2, it can be concluded that in all three cases, i.e., shoot growth, root growth, and bulb formation, hydroponics is found to outperform the soil cultivation method in terms of better quality, quantity, and lesser vegetation period.

RQ. 4 can be answered as hydroponics outperforms soil cultivation method not only in qualitative and quantitative terms, but also has an advantage of being more certain in terms of yield, and less expensive. However, the negative environmental footprint is much higher in terms of energy usage in hydroponics as compared to the soil cultivation method. The entire setup and the external controlling of environmental conditions is carried out with the help of energy. To sum up, the answer to RQ. 5, the soil cultivation method is more efficient in terms of energy efficiency.

J. EVALUATION OF GROWTH RESPONSES OF ONION USING 'AQUACROP' SIMULATOR IN SOIL AND DWC HYDROPONIC SYSTEMS

The actual results of growth responses obtained from the experiment are then verified with the results obtained from the 'AquaCrop' simulator. All the parametric requirements for optimal growth of hydroponic and soil onion shoots and bulbs as mentioned in Tables 3 and 4 are provided as input to the simulator. The growing conditions of DWC hydroponics and soil are input to the simulator separately. The results obtained from the simulator produced similar outputs as those obtained from the actual cultivation methods. Therefore, in response to RQ. 3 it can be stated that the actual and simulator results are similar and completely relatable. Fig. 20 is the screenshot of the simulator output screen showing the growth responses of the onion bulb in a DWC hydroponic setup.

It can be observed from Fig. 20 that the transpiration, canopy cover, and root growth are maximum when the growing conditions as per Table 3 are input to the simulator. there is no gap between maximum and actual growth. Fig. 21 is the screenshot of the simulator output screen showing the growth responses of the onion bulb in a substrate medium.

Transpiration in the soil, as well as DWC hydroponics, is maximum in the soil as well as in hydroponics.

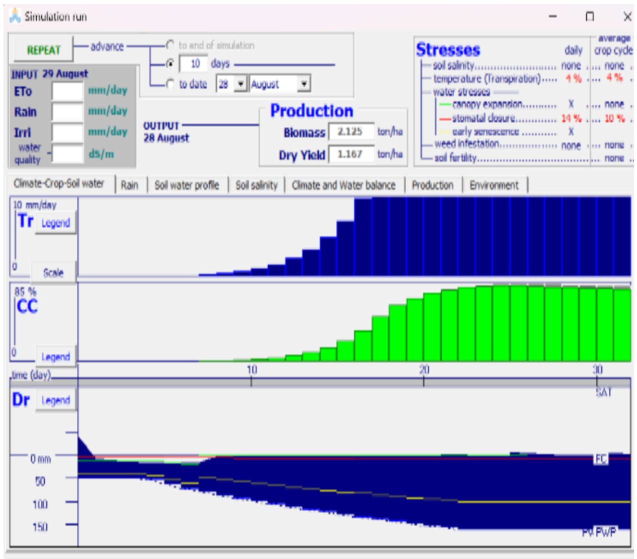


FIGURE 20. **'AquaCrop' simulation results for cultivation of onion in a DWC hydroponic setup.**

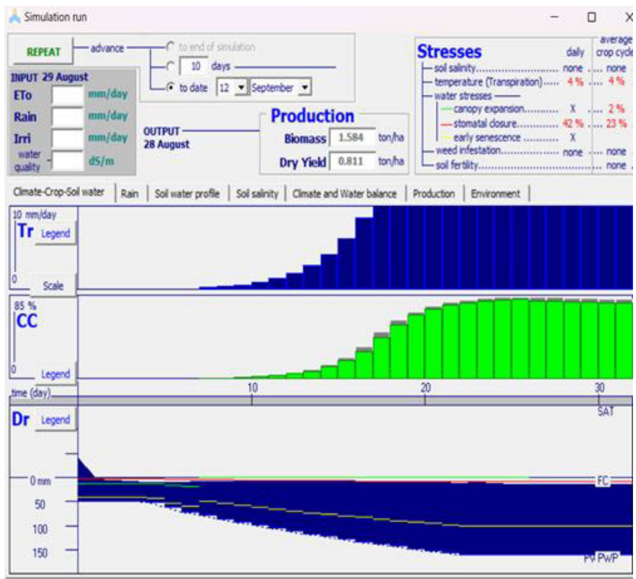


FIGURE 21. **'AquaCrop' simulation results for cultivation of onion in substrate cultivation.**

The simulator outputs of canopy cover (CC) in case of substrate cultivation results are shown in two colors: grey and green. The grey portion depicts the gap between the optimal and actual growth of the onion shoot. It can be seen that there is a considerable gap between the actual and optimal results of canopy cover in the case of the cultivation of onion bulbs in a substrate medium. All the necessary agronomic conditions including the most appropriate soil type are input to the simulator, still, the substrate cultivation methods do not always produce optimal results in terms of growth due to the presence of weeds and pests in the soil. Also, soil cultivation is dependent on natural resources and climatic uncertainties,

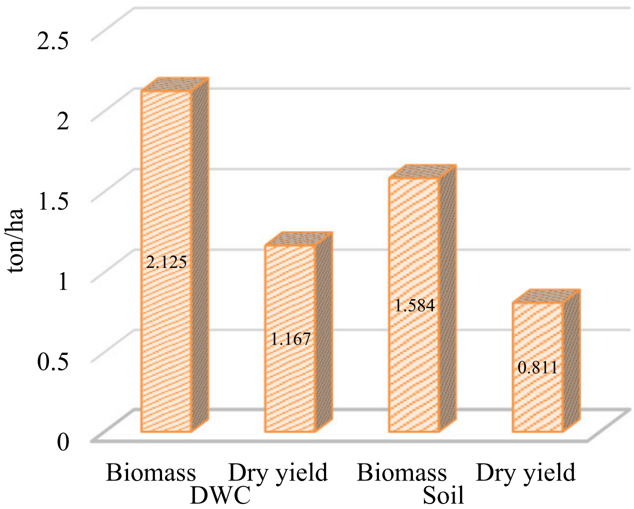


FIGURE 22. Comparative plot of the biomass and dry yield of onion when cultivated in DWC and soil separately.

TABLE 5. Quantitative growth analysis of onion: DWC vs. substrate mediums.

Cultivation Techniques	Quantitative Parameters	Obtained values (ton/ha)
DWC setup of hydroponics	Biomass	2.125
	Dry yield	1.167
Substrate cultivation	Biomass	1.584
	Dry yield	0.811

which in turn causes depleted growth responses of agricultural produce. Table 5 shows a tabular representation of the quantitative growth analysis of onion in DWC hydroponics and substrate mediums.

The comparative analysis of the growth responses obtained in soil vs hydroponic cultivation as obtained from the simulator can be further demonstrated graphically in Fig. 22.

From Fig. 22, it can be inferred that the quantitative yield of onion is approximately 1.4 times more in DWC hydroponics, as compared to soil cultivation. This analysis is obtained from the 'AquaCrop' simulator which shows that the biomass of onion obtained in DWC is approximately 1.34 times as much as that obtained in the soil cultivation method. Simultaneously, the dry yield of onion is approximately 1.44 times more in DWC than in soil. Thus, the comparative plot shows a better quantitative yield of onion in DWC hydroponics as compared to cultivation in soil, along with quantitative yield as inferred from the previous subsections of the result section.

Therefore, technically summarizing the comparison of growth responses of onion in DWC hydroponic cultivation, it is found that with an optimum average temperature of 30 $\pm$ 2 °C, the humidity of 68 $\pm$ 2 %, pH of 6.2 $\pm$ 0.2, and EC of 1.7 $\pm$ 0.5 mS/cm in a nutrient-infused water medium with N:P:K ratio of 10:20:10 and 20:05:05 in initial and subsequent weeks respectively, produces onion shoots in 3 – 4 days from sowing and onion bulbs within 30 $\pm$ 2 days, irrespective of any month of the year. The maximum shoot and root lengths attained were 21.5 cm and 15 cm respectively. The TDS in the nutrient-infused water medium must also be maintained within 600 – 750 mg/l and the CO_2 and O_2 concentrations must be $<$ 900 ppm and $>$ 18 % respectively to attain the said yield. The biomass and dry yield as obtained from the 'AquaCrop' simulator results in DWC hydroponic conditions were found to be 2.125 and 1.167 respectively.

Whereas in soil cultivation, it is found that with approximately similar temperature, humidity, and pH as in hydroponics, an EC of 3.7 $\pm$ 0.7, and a rainfall of 750 $\pm$ 150 mm, with NPK ration of 2:1:1, in July to August, onions were seen to sprout in around 15 days of sowing and the bulbs were seen to form in 70 $\pm$ 5 days with a maximum shoot length of 16 cm and a maximum root length of 7 cm. The biomass and dry yield as obtained from the 'AquaCrop' simulator results in soil cultivation systems were found to be 2.125 and 1.167 respectively.

In a nutshell, it can be said that the DWC hydroponic method of cultivation outperforms the soil cultivation method of onion cultivation in various qualitative and quantitative parameters, without using soil or depending upon natural resources for its yield. The simulation results also complied with the actual cultivation results, thus, verifying and validating the actual and experimental results. It is evident from the research done, that the hydroponic cultivation method ensures year-round enhanced and sustainable agricultural yield, irrespective and independent of natural resources and climatic uncertainties. The hydroponic cultivation method eliminates other causes of damage in substrate cultivation, i.e., weeds, pests, and rodents. Thus, the production of shoot and bulb of the medicinal plant, onion, can be enhanced with the use of the DWC hydroponics method.

The scope of this experiment is limited to the comparison of root and shoot growth responses of only one species of onion. Other varieties of onion could be considered for their growth response analyses, and more distinct results could have been obtained for various species of onions.

IV. CONCLUSION

The DWC hydroponics is proven to be the best choice for the cultivation of onion in terms of qualitative, quantitative, and year–round yield. The total vegetation period of onion in a soil medium takes almost 2 $\pm$ 2 times more time to produce new bulbs than it takes in a water medium. The smart DWC cultivation implements CEA and produces almost 2 times more yield, irrespective of the growing season and the prevalent environmental conditions. Onion root as well as soot shows significant enhancement in growth responses in DWC setup of hydroponics as compared to cultivation in soil medium. This result was obtained by practically cultivating onion bulbs in the soil as well as in a smart DWC hydroponics setup and then verifying and validating the results with the results obtained from the 'AquaCrop' simulator. The previous works done in this regard have focused on the prediction of onion bulbs in hydroponics [64]. The authors of this research work have considered the onion as a medicinal plant whose shoot as well as the bulb contains medicinal properties, thus the growth responses of the shoot as well as the bulb of the onion were monitored and enhanced with the use of DWC hydroponics, which makes the work novel. The previous works also have focused on either the actual growth results or only simulation outputs, but the authors of this research work have carried out actual cultivation and then verified and validated the results with the results obtained from the simulator [65], [66]. All these features add to the novelty of this research work.

A comparative analysis of this research is done with the research of other authors under various domains. A major lack in the existing research is the lack of cultivation and enhancement of medicinal plants [27], [28], [29], [30], [31], [32], [35], [36]. The authors have focused on onion as the subject plant where its shoots, as well as roots, have abundant medicinal properties. Some of the existing research works like in [24], [35], [36], and [37] have focused on the root growth of plants, others like [25], [28], [38], [39], and [40] have demonstrated and analyzed the shoot growth responses of various plants, but the focus of this research is to analyze and enhance both the shoot and root in qualitative and quantitative aspects.

Also, in many researches like [24], [28], [30], [31], [32], [33], [34], [35], and [36], the cultivation is carried out in either soil or soilless medium. The growth analysis of medicinal plants in both mediums was an aspect lacking for research which is carried out in this experiment. Another dimension of the novelty of this research work can be mentioned by the fact that actual experimental results are verified and validated using simulator results. In previous works like in [27], [28], [30], [31], [32], [35], [36], and [42], the growth responses of plants are analyzed only in actual cultivation methods, and in experiments in [26], [41], and [42], the analysis was done using a simulator.

Therefore, after comparisons with the previous works done by many researchers, it can be said that this experiment is a novel work done by comparing the shoot and root growth responses of the medicinal plant, onion, under various qualitative and quantitative aspects. The two cultivation mediums used for the analysis are soil and water, particularly in DWC hydroponics. The results of which were verified and validated by comparing the actual results with the simulator results.

V. FUTURE OUTLOOK

The scope of this research can be further expanded by comparing the growth responses and the resource utilization while comparing with the other forms of vertical farming methods, i.e., aeroponics and aquaponics. Various other species of onions may also be considered to carry out their growth response analyses to obtain more specific results dedicated to each type of onion. Though the water consumption in DWC hydroponics is much less than that needed in soil cultivation, the nutrient solution needs to be drained and replaced at regular intervals. Lack of cultivatable land and water conservation are the major concerns in the urbanized localities. Thus, wastewater treatment plants can act as a further measure of water conservation by making wastewater reusable.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGMENT

(Monica Dutta and Ali Nauman contributed equally to this work.)

REFERENCES

[1] M. Dolli and K. S. Divya, "A study on present Indian agriculture: Status, importance, and role in Indian economy," *ZENITH Int. J. Multidisciplinary Res.*, vol. 10, no. 3, pp. 30–34, 2020.

[2] N. Alexandratos and J. Bruinsma. (2030). *World Agriculture Towards 2030/2050: The 2012 Revision*. Accessed: Jul. 29, 2023. [Online]. Available: https://www.fao.org/global-perspectives

[3] M. Dutta and D. Gupta, "Towards green IoTs–enabling sustainable environment, bibliometric analysis and beyond," in *Proc. 10th Int. Conf. Rel., INFOCOM Technol. Optim.*, Oct. 2022, pp. 1–6.

[4] S. Sharma, N. Dhanda, and R. Verma, "Urban vertical farming: A review," in *Proc. 13th Int. Conf. Cloud Comput., Data Sci. Eng. (Confluence)*, Jan. 2023, pp. 432–437.

[5] M. Dutta, D. Gupta, S. Sahu, S. Limkar, P. Singh, A. Mishra, M. Kumar, and R. Mutlu, "Evaluation of growth responses of lettuce and energy efficiency of the substrate and smart hydroponics cropping system," *Sensors*, vol. 23, no. 4, p. 1875, Feb. 2023.

[6] M. S. Mir, N. B. Naikoo, R. H. Kanth, F. A. Bahar, M. A. Bhat, A. Nazir, S. S. Mahdi, Z. Amin, L. Singh, W. Raja, A. A. Saad, T. A. Bhat, T. Palmo, and T. A. Ahngar, "Vertical farming: The future of agriculture: A review," *Pharma Innovat. J.*, vol. 11, no. 2, pp. 1175–1195, 2022.

[7] P. K. Maurya, R. Y. Karde, A. S. Bayskar, and N. Charitha, "Innovative technologics such as vertical farming and hydroponics to grow crops in controlled environments," in *Advanced Farming Technology*, S. Rai et al., Eds. New Delhi, India: Scripown Publications, 2023, ch. 6, p. 87.

[8] M. Dutta, D. Gupta, Y. Javed, K. Mohiuddin, S. Juneja, Z. I. Khan, and A. Nauman, "Monitoring root and shoot characteristics for the sustainable growth of barley using an IoT-enabled hydroponic system and AquaCrop simulator," *Sustainability*, vol. 15, no. 5, p. 4396, Mar. 2023.

[9] P. J. Vazhacharickal, T. Chandrasekhar, and D. Chandrasekharam, "Perils of irrigated agriculture in urban environment: Case study from the Mumbai metropolitan region (MMR), India," Indian Inst. Technol. Bombay, Mumbai, India, Tech. Rep., 2023, doi: 10.21203/rs.3.rs-2604543/v1.

[10] S. Usha, P. K. Nimbrayan, and V. P. Luhach, "Economic analysis, marketing and storage of onion cultivation in district Bhiwani, Haryana," *Ann. Agri-Bio Res.*, vol. 28, no. 1, pp. 152–158, 2023.

[11] M. Ahmed, "Economic and productive efficiency of using modern irrigation systems in Egypt (A case study of fayoum Governorate)," *Assiut J. Agricult. Sci.*, vol. 54, no. 1, pp. 270–283, Jan. 2023.

[12] A. Kumar, D. Roy, G. Tripathi, and P. K. Joshi, "Determinants and impacts of contract farming: Evidence from cultivation of onion, Okra and pomegranate in Maharashtra, India," *J. Agribusiness Developing Emerg. Economies*, vol. 11, no. 3, pp. 280–300, Jun. 2023.

[13] S. R. Sinhasane and S. R. Hange, "Origin, history and diversity of onion," Plant Genet. Resour. Res. Inst., Bunso, Ghana, Tech. Rep., 2023, doi: 10.3390/plants12183294.

[14] D. Samanta, "Estimating impact of technological adoption in farming in bihar: A propensity score matching approach," *Int. J. Social Econ.*, vol. 50, no. 7, pp. 1007–1016, Jul. 2023.

[15] T. Gu, B. Aj, and L. Tn, "Economics of onion cultivation and it's marketing pattern in Satara district of Maharashtra," *Int. J. Agricult. Sci.*, vol. 3, no. 3, pp. 110–117, Dec. 2011.

[16] C. Bulut and P. F. Wu, "More than two decades of research on IoT in agriculture: A systematic literature review," *Internet Res.*, vol. 25, no. 6, pp. 145–170, May 2023.

[17] M. McCaig, D. Rezania, and R. Dara, "Framing the response to IoT in agriculture: A discourse analysis," *Agricult. Syst.*, vol. 204, Jan. 2023, Art. no. 103557.

[18] P. Sambo, C. Nicoletto, A. Giro, Y. Pii, F. Valentinuzzi, T. Mimmo, P. Lugli, G. Orzes, F. Mazzetto, S. Astolfi, R. Terzano, and S. Cesco, "Hydroponic solutions for soilless production systems: Issues and opportunities in a smart agriculture perspective," *Frontiers Plant Sci.*, vol. 10, p. 923, Jul. 2019.

[19] H. Rahmani, D. Shetty, M. Wagih, Y. Ghasempour, V. Palazzi, N. B. Carvalho, R. Correia, A. Costanzo, D. Vital, F. Alimenti, J. Kettle, D. Masotti, P. Mezzanotte, L. Roselli, and J. Grosinger, "Next-generation IoT devices: Sustainable eco-friendly manufacturing, energy harvesting, and wireless connectivity," *IEEE J. Microw.*, vol. 3, no. 1, pp. 237–255, Jan. 2023.

[20] D. I. Pomoni, M. K. Koukou, M. G. Vrachopoulos, and L. Vasiliadis, "A review of hydroponics and conventional agriculture based on energy and water consumption, environmental impact, and land use," *Energies*, vol. 16, no. 4, p. 1690, Feb. 2023.

[21] N. Dubey and V. Nain, "Hydroponic—The future of farming," *Int. J. Environ., Agricult. Biotechnol.*, vol. 5, no. 4, pp. 857–864, 2020.

[22] F. Modu, A. Adam, F. Aliyu, A. Mabu, and M. Musa, "A survey of smart hydroponic systems," *Adv. Sci. Technol. Eng. Syst. J.*, vol. 5, no. 1, pp. 233–248, 2020.

[23] D. J. Gaikwad and S. Maitra, "Hydroponics cultivation of crops," in *Protected Cultivation and Smart Agriculture*, S. Maitra, D. J. Gaikwad, and T. Shankar, Eds. New Delhi, India: New Delhi Publishers, 2020, pp. 279–287.

[24] B. Traykova, E. Molle, and M. Stanilova, "In vivo and in vitro bulb multiplication of lilium rhodopaeum Delip. And growth acceleration using hydroponic technologies," *Vitro Cellular Develop. Biol.-Plant*, vol. 58, no. 2, pp. 200–212, Apr. 2022.

[25] D. Maurer, A. Sadeh, D. Chalupowicz, S. Barel, J. A. Shimshoni, and D. Kenigsbuch, "Hydroponic versus soil-based cultivation of sweet basil: Impact on plants' susceptibility to downy mildew and heat stress, storability and total antioxidant capacity," *J. Sci. Food Agricult.*, vol. 103, no. 15, pp. 7809–7815, Dec. 2023.

[26] A. S. Morite, R. R. Bacarro, G. Z. Gamboa Jr., V. J. V. D. Angob, and E. J. M. Manzo, "Water circulation and control of hydroponics using the Internet of Things," *Sci. Int.*, vol. 35, no. 3, pp. 299–305, 2023.

[27] J. R. Crush, "PLant growth responses to vesicular-arbuscular mycorrhiza VII. Growth and modulation of some herbage legumes," *New Phytologist*, vol. 73, no. 4, pp. 743–749, Jul. 1974.

[28] I. Yedidia, A. K. Srivastva, Y. Kapulnik, and I. Chet, "Effect of *Trichoderma harzianum* on microelement concentrations and increased growth of cucumber plants," *Plant soil*, vol. 235, pp. 235–242, 2001.

[29] R. A. Ghani, S. Omar, M. Jolánkai, Á. Tarnawa, N. Khalid, M. K. Kassai, and Z. Kende, "Response of shoot and root growth, yield, and chemical composition to nutrient concentrations in soybean varieties grown under soilless and controlled environment conditions," *Agriculture*, vol. 13, no. 10, p. 1925, Sep. 2023.

[30] F. Martínez, S. Castillo, C. Borrero, S. Pérez, P. Palencia, and M. Avilés, "Effect of different soilless growing systems on the biological properties of growth media in strawberry," *Scientia Horticulturae*, vol. 150, pp. 59–64, Feb. 2013.

[31] J. H. Purba, I. P. Parmila, and W. Dadi, "Effect of soilless media (hydroponic) on growth and yield of two varieties of lettuce," *Agricult. Sci.*, vol. 4, no. 2, pp. 154–165, 2021.

[32] M. Shaibur, A. Shamim, and S. Kawai, "Growth response of hydroponic rice seedlings at elevated concentrations of potassium chloride," *J. Agricult. Rural Develop.*, vol. 6, no. 1, pp. 55–61, Jan. 1970.

[33] M. Zailani, R. A. Kuswardani, and E. L. Panggabean, "Growth response and crop production (Brassica juncea L.) against watering time interval at various hydroponics media," *Budapest Int. Res. Exact Sci. (BirEx) J.*, vol. 1, no. 1, pp. 9–22, Jan. 2019.

[34] S. Dehnavard, M. K. Souri, and S. Mardanlu, "Tomato growth responses to foliar application of ammonium sulfate in hydroponic culture," *J. Plant Nutrition*, vol. 40, no. 3, pp. 315–323, Feb. 2017.

[35] M. A. El-Nemr, A. M. R. Abdel-Mawgoud, M. M. H. A. El-Baky, E. S. Mettawee, and S. R. Salman, "Responses of yield and leaf nitrate content of two lettuce cultivars to different sources of nitrogen in NFT system," *J. Appl. Sci. Res.*, vol. 13, pp. 2050–2056, Apr. 2012.

[36] G. B. Monshausen and S. Gilroy, "The exploring root—Root growth responses to local environmental conditions," *Current Opinion Plant Biol.*, vol. 12, no. 6, pp. 766–772, Dec. 2009.

[37] D. R. Kidd, M. H. Ryan, T. D. Colmer, and R. J. Simpson, "Root growth response of serradella species to aluminium in solution culture and soil," *Grass Forage Sci.*, vol. 76, no. 1, pp. 57–71, Mar. 2021.

[38] J. Zappelini, R. Pescador, G. M. Girardello, P. P. F. D. Souza, M. Borghezan, and J. L. B. Oliveira, "Physiological alterations in 'Rubinela' lettuce (*Lactuca sativa* L.) cultivated in conventional and hydroponic systems," *Acta Scientiarum. Agronomy*, vol. 46, no. 1, Oct. 2023, Art. no. e62502.

[39] S. Wang, Y. Gariepy, A. Adekunle, and V. Raghavan, "The role of hydroponic microbial fuel cell in the reduction of methane emission from Rice plants," *Electrochimica Acta*, vol. 450, May 2023, Art. no. 142229.

[40] B. Kitwetch, P. Rangseekaew, Y. Chromkaew, W. Pathom-Aree, and S. Srinuanpan, "Employing a plant probiotic actinomycete for growth promotion of lettuce (*Lactuca sativa* L. Var. longifolia) cultivated in a hydroponic system under nutrient limitation," *Plants*, vol. 12, no. 22, p. 3793, Nov. 2023.

[41] T. Sandbakk, M. Usama, and R. Davidrajuh, "Simulating a monitoring system for an aquaponics farm," *Int. J. Simul., Syst., Sci. Technol.*, vol. 23, no. 1, pp. 1–8, May 2022.

[42] S. Goddek, O. Körner, K. J. Keesman, M. A. Tester, R. Lefers, L. Fleskens, A. Joyce, E. van Os, A. Gross, and R. Leemans, "How greenhouse horticulture in arid regions can contribute to climate-resilient and sustainable food security," *Global Food Secur.*, vol. 38, Sep. 2023, Art. no. 100701.

[43] G. Kaur, P. Upadhyaya, and P. Chawla, "Comparative analysis of IoT-based controlled environment and uncontrolled environment plant growth monitoring system for hydroponic indoor vertical farm," *Environ. Res.*, vol. 222, Apr. 2023, Art. no. 115313.

[44] B. Ahmad, R. Ahmed, S. Masroor, B. Mahmood, S. Z. U. Hasan, M. Jamil, M. T. Khan, M. T. Younas, A. Wahab, B. Haydar, M. Subhani, M. A. Khan, and S. Tariq, "Evaluation of smart greenhouse monitoring system using raspberry-Pi microcontroller for the production of tomato crop," *J. Appl. Res. Plant Sci.*, vol. 4, no. 1, pp. 452–458, Jan. 2023.

[45] L. Lucero, D. Lucero, E. Ormeno-Mejia, and G. Collaguazo, "Automated aeroponics vegetable growing system. Case study lettuce," in *Proc. IEEE ANDESCON*, Quito, Pichincha, Oct. 2020, pp. 1–6.

[46] S. C. Kerns and J. L. Lee, "Automated aeroponics system using IoT for smart farming," in *Proc. 8th Int. Sci. Forum (ISF)*, Sep. 2017, pp. 7–8.

[47] T. Mahrous Korany Mohamed, J. Gao, and M. Tunio, "Development and experiment of the intelligent control system for rhizosphere temperature of aeroponic lettuce via the Internet of Things," *Int. J. Agricult. Biol. Eng.*, vol. 15, no. 3, pp. 225–233, 2022.

[48] F. Francis, P. L. Vishnu, M. Jha, and B. Rajaram, "IoT-based automated aeroponics system," in *Intelligent Embedded Systems*. Singapore: Springer, 2018, pp. 337–345.

[49] F. Bafort, S. Kohnen, E. Maron, A. Bouhadada, N. Ancion, N. Crutzen, and M. H. Jijakli, "The agro-economic feasibility of growing the medicinal plant euphorbia peplus in a modified vertical hydroponic shipping container," *Horticulturae*, vol. 8, no. 3, p. 256, Mar. 2022.

[50] S. Pawar, S. Tembe, and S. Khan, "Design of an affordable pH module for IoT based pH level control in hydroponics applications," in *Proc. Int. Conf. Converg. Digit. World-Quo Vadis (ICCDW)*, Mumbai, India, Feb. 2020, pp. 1–4.

[51] K. T. Mya, M. M. Sein, T. T. S. Nyunt, Y. W. Chong, and R. N. Zainal, "Automatic data-driven agriculture system for hydroponic farming," in *Proc. 3rd Asia–Pacific Inf. Technol. Conf.*, Bangkok, Thailand, Jan. 2021, pp. 6–11.

[52] D. Rahadiyan, S. Hartati, and A. P. Nugroho, "Design of an intelligent hydroponics system to identify macronutrient deficiencies in chili," *Int. J. Adv. Comput. Sci. Appl.*, vol. 13, no. 1, pp. 1–9, 2022.

[53] M. Dutta, D. Gupta, S. Juneja, A. Shah, A. Shaikh, V. Shukla, and M. Kumar, "Boosting of fruit choices using machine learning-based pomological recommendation system," *Social Netw. Appl. Sci.*, vol. 5, no. 9, p. 241, Sep. 2023.

[54] M. Dutta and D. Gupta, "Bibliometric analysis on herbaceous plants using smart precision farming," in *Proc. IEEE Renew. Energy Sustain. E-Mobility Conf. (RESEM)*, May 2023, pp. 1–6.

[55] P. von Bieberstein, Y.-M. Xu, A. A. L. Gunatilaka, and R. Gruener, "Biomass production and withaferin a synthesis by withania somnifera grown in aeroponics and hydroponics," *HortScience*, vol. 49, no. 12, pp. 1506–1509, Dec. 2014.

[56] P. K. Jayapal, E. Park, M. A. Faqeerzada, Y.-S. Kim, H. Kim, I. Baek, M. S. Kim, D. Sandanam, and B.-K. Cho, "Analysis of RGB plant images to identify root rot disease in Korean ginseng plants using deep learning," *Appl. Sci.*, vol. 12, no. 5, p. 2489, Feb. 2022.

[57] R. M. Giurgiu, G. Morar, A. Dumitraş, G. Vlăsceanu, A. Dune, and F.-G. Schroeder, "A study of the cultivation of medicinal plants in hydroponic and aeroponic technologies in a protected environment," in *Proc. Int. Symp. New Technol. Manage. Greenhouses*, vol. 1170, 2015, pp. 671–678.

[58] A. L. Hayden, T. N. Yokelsen, G. A. Giacomelli, and J. J. Hoffmann, "AEROPONICS: An alternative production system for high-value root crops," *Acta Horticulturae*, vol. 629, pp. 207–213, Jan. 2004.

[59] M. Mittal, V. Kadyan, D. Kumar, and V. Kukreja, "Detection of DoS attacks using machine learning techniques," *Int. J. Vehicle Auto. Syst.*, vol. 15, no. 3/4, p. 256, 2020.
[60] A. Beniwal, D. Poolsingh, and S. S. Shastry, "Trends and price behaviour analysis of onion in India," *Indian J. Agricult. Economics*, vol. 77, no. 4, pp. 632–642, 2022.
[61] N. K. Trivedi, V. Gautam, A. Anand, H. M. Aljahdali, S. G. Villar, D. Anand, N. Goyal, and S. Kadry, "Early detection and classification of tomato leaf disease using high-performance deep neural network," *Sensors*, vol. 21, no. 23, p. 7987, Nov. 2021.
[62] P. Chiaranunt and J. F. White, "Plant beneficial bacteria and their potential applications in vertical farming systems," *Plants*, vol. 12, no. 2, p. 400, Jan. 2023.
[63] P. Dhiman, V. Kukreja, P. Manoharan, A. Kaur, M. M. Kamruzzaman, I. B. Dhaou, and C. Iwendi, "A novel deep learning model for detection of severity level of the disease in citrus fruits," *Electronics*, vol. 11, no. 3, p. 495, Feb. 2022.
[64] G. Idoje, C. Mouroutoglou, T. Dagiuklas, A. Kotsiras, I. Muddesar, and P. Alefragkis, "Comparative analysis of data using machine learning algorithms: A hydroponics system use case," *Smart Agricult. Technol.*, vol. 4, Aug. 2023, Art. no. 100207.
[65] H. Salari, R. S. Antil, and Y. S. Saharawat, "Responses of onion growth and yield to different planting dates and land management practices," *Agronomy Res.*, vol. 19, no. 4, pp. 1914–1928, 2021.
[66] S. Lee, "Development and performance test of a simulation-based tractor-attachable wind-blast-type onion stem cutting machine," *Machines*, vol. 11, no. 5, p. 508, Apr. 2023.

MONICA DUTTA is currently a Research Scholar with Chitkara University Research and Innovation Network (CURIN), Chitkara University, Punjab, India. She is also working in the field of IoT and machine learning. Along with the research papers she is working on, she has published various articles in SCI journals apart from various international conferences. She has nearly four years of work experience as an Assistant Professor in various engineering colleges and state and private universities in India. She is also an active member of the Computer Science Teachers Association (CSTA) and International Association of Engineers (IAENG) Professional Bodies.

DEEPALI GUPTA is currently a Research Professor with Chitkara University Research and Innovation Network (CURIN) and the Associate Dean (Ph.D. Programs) with Chitkara University, Punjab, India. She specializes in software engineering, machine learning, cloud computing, the IoT, and genetic algorithms. She has published more than 180 research papers in national and international journals and conferences. Based on these areas, she has guided many Ph.D. and M.E. scholars. She has worked at various administrative positions and is an active member of various professional bodies like IEI (India), IETE, and ISTE. Apart from being the Editor-in-Chief of MMU journal, she is an editorial board member and a reviewer of various journals.

SAPNA JUNEJA is currently a Professor with the KIET Group of Institutions, Ghaziabad, India. She has more than 19 years of teaching experience. Her research interests include software reliability of embedded systems, software engineering, computer networks, operating systems, database management systems, and artificial intelligence. She has guided several research thesis of UG and PG students in computer science and engineering.

ALI NAUMAN received the M.Sc. degree in wireless communications from the Institute of Space Technology, Islamabad, Pakistan, in 2016, and the Ph.D. degree in information and communication engineering from Yeungnam University, Republic of Korea, in 2022. Currently, he is an Assistant Professor with the Department of Information and Communication (ICE), Yeungnam University. He has contributed to five patents and authored/coauthored three book chapters and more than 35 technical articles in leading journals and peer-reviewed conferences.

GHULAM MUHAMMAD (Senior Member, IEEE) received the B.S. degree in computer science and engineering from Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, in 1997, and the M.S. degree in knowledge-based information engineering and the Ph.D. degree in electrical and computer engineering from Toyohashi University and Technology, Toyohashi, Japan, in 2003 and 2006, respectively. He is currently a Professor with the Department of Computer Engineering, College of Computer and Information Sciences, King Saud University, Riyadh, Saudi Arabia. He holds three U.S. patents. He has authored or coauthored more than 300 publications, including IEEE/ACM/Springer/Elsevier journals and flagship conference papers. His research interests include AI, machine learning, image and speech processing, and smart healthcare. He was a recipient of the Japan Society for Promotion and Science Fellowship from the Ministry of Education, Culture, Sports, Science and Technology, Japan.