Technological Influences on Monitoring and Automation of the Hydroponics System

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***Abstract*— Scarcity of fertile land, irrigable water and pure air are concerns that challenge the food chain. This is further degraded by the use of artificial fertilizers, pesticides and chemical compounds which yield appreciable short-term benefits but causes degradation in the long run. Soil less farming using alternate mediums under isolated conditions and controlled by technological advances has provided an altogether different dimension towards the solution to this problem. This is further supported by various technological advances in the domains of sensors, interfacing, microcontrollers, data storage devices, smart apps, IoT interfaces, WSN connections and web-based access. Vital parameters – pH, EC, Nutrition, Water, CO_2, Light, Temperature, Humidity, external atmospheric parameters and the crop growth are monitored-either in an open loop manner or in a closed loop setup to ensure maximum yield with minimum resources. With water as the nutrient carrier, this becomes a typical Smart Hydroponics system. The most fundamental feature associated with Hydroponics is the utility of the vertical space in a highly effective manner. This provides an opportunity to grow diverse crops even if the climatic condition is not the correct match for the crop. And Automation is the lead front that facilitates such kind of advancement by detecting anomalous responses and rectifying the same for better yields.**

***Keywords* — Hydroponics, Monitoring, IoT, AI/ML/Robotics.**

I. Introduction

As per the statistics provided by Grandviewresearch [1], the hydroponics market at the global level is valued at USD 2.1 billion in 2020, USD 2.6 billion in 2021 and projects a Compound Annual Growth Rate (CAGR) of 20.7% by 2028. The Asia Pacific zone is the major contributor at 36.9% in 2020, led by China, Australia and South Korea. Government incentives and higher yields are the key reasons that drive such drastic growth. A study of the Indian sector reveals a CAGR of 13.53% over the same period with floriculture reaching a near 50% shareholding stake as compared to fruits and vegetables combined together, based on the reports by Datamintelligence [2].

What we know today as Hydroponics blooming around the busy Israeli urban zones- Tel Aviv and Jerusalem, had its first roots floating through the hanging gardens of Babylon (present day Iraq) an estimated twelve hundred km away, way back in 500 BC. Other countries who lead the global market in hydroponics today are driven either by the natural atmospheric factors or the dearth of it. UK, India, Australia, Japan, South Africa, Moon and Space are each motivated by one or more of the following factors- windchills, heat waves, overpopulation, scanty rainfalls, infected soil micro-organisms, water crisis or transportation cost. And that could be the reason the world researchers/agriculturists/farmers/cultivators/florist started working towards alternate sources of farming using soilless mediums.

Thus, developing a controlled micro climate zone under the roof of a chaotic world using Climate-Land-Energy-Water (CLEW) mapping techniques is the most viable alternative. It also targets to support the Sustainable Development Goals (SDGs) proposed by UN in 2015. The Food and Agriculture Organization (FAO) and UN Environment Programme (UNEP) are leading the objectives of UN decade of Ecosystem Restoration which co aligns with the decade of action for SDGs (2021-2030) [3]. Increased analytical modeling and computational capacity further supported by bilateral linkages across borders have led to better socioeconomic outcomes. In this context, analysis of historic data reveals that technology has interwoven with agriculture to a highly remarkable extent – so deep that these two standalone entities have now become one.

Hydroponics is broadly classified into two categories- an open system in which depending upon the desired harvest, various input parameters – pH, Electro Conductivity (EC), Nutrition, Water, Light, Temperature, Humidity and CO_2 can be altered. In the last century, due to limited technological developments, and Hydroponics being an upcoming sector, the open systems were popular. These open systems are still pursued by hobbyists or small-scale growers for short term, short cycle crops; mostly in a non-commercial manner. The other kind is the closed system where most of the real-world agriculturists are heading. A closed loop system is more dynamic and can be challenging as the targets and the scale of implementation both are equally high. Based on available databases, automated control of various systems can be achieved. A typical closed loop system is shown in Fig. 1.

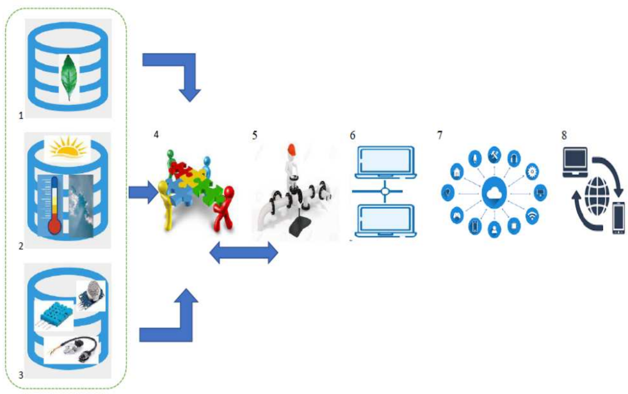

Fig. 1. A typical hydroponics closed loop structure

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It essentially consists of three databases- plant database, Atmospheric database and sensor database (derived from current sensing). The integrating or decision-making unit plays the key role of selecting the correct quantity of various parameters and sets/resets/adjusts the performance of all the valves related to nutrient distribution, temperature, humidity, pH level, solution EC, CO_2 content control and aeration for the system. Data obtained from various crops and seasons can be stored for future reference. Also, with increasing technological growth, all such data can be made available to remote locations via wired or wireless mediums. Table I lists all the vital blocks that are involved in a typical closed loop Hydroponics system along with its basic functions.

TABLE I. THE FUNCTIONS OF THE VARIOUS BLOCKS OF A TYPICAL CLOSED LOOP HYDROPONIC SYSTEM

Block	Functions
1. Plant database	Plant specific requirements
2. Atmospheric/ Surrounding database	Details of the prevailing atmosphere and seasons.
3. Sensor database	Details collected by installed sensors.
4. Integration/ Decision making Unit	The Processor unit takes decision based on previous databases and present readings.
5. Automated Control of valves, flow of water and nutrients.	As nutrients travel via the aqueous medium, this unit senses the extent of specific micro/macro nutrients in the water and controls the same.
6. Data storage	Vital information is stored in a selective/nonselective manner.
7. IoT interface	The network of connected sensors is used to connect and communicate.
8. Remote Access	Access to vital information using various communication protocols to ensure 24X7 connectivity from far away locations

Various other sub-blocks can be interfaced to the existing system to improve its performance and to overcome the challenges associated with uncertain weather, power failure and/or sudden system disturbances.

The paper is proposed in the following format. Section I is about the Introduction, Section II deals with the Literature Review about the global market happenings in Hydroponics. Section III is about the study of hydroponics. Section IV is about the different types of hydroponics systems and their specific applications. Section V is about crops supported by the Hydroponics system. Section VI is about the monitoring and automation of the hydroponics system. Section VII reflects the influence of Artificial Intelligence/Machine Learning Techniques/Robotics interface to generate more profits from various Hydroponic setups. Section VIII is the conclusion.

II. LITERATURE REVIEW

The concept of hydroponics has been a very successful one as it has been replicated across various climatic zones round the world. Various statistical analysis has indicated that as compared to the traditional soil-based methods, hydroponics can flourish at 75-90% less water and equally less land resources. Apart from the various initiatives taken, the FAO's Global Framework on Water Scarcity in Agriculture (WASAG) shoulders the Herculean task of converting water scarcity into favorable opportunities for sustainable agriculture, food security and nutrition during 2021-2024 [4].

Life seems to find its ways in highly irrelevant nonliving spaces. When the barbaric clans of World War II were dropping the shells and waging the war, a 180 steps descent old, suffocating, deserted tunnel was constructed with the intention to shelter thousands of people during the war. The same place drastically inspired a documentary film maker, Ballard (of the Ballard-Dring led Growing Underground fame [5]) to target vertical farming using LEDs in 2014. From 33 meters below the streets of London, at a growth stage of 2 weeks old, microgreens are the new "fast-foods", harvested using Hydroponic techniques. These are Carbon Neutral and B Corp Accredited salads that reach our plates and palates via the mainstream UK supermarkets. There are many more cases projecting the success stories of Hydroponics right from the frosted polars to the deserted equatorial regions. Some of the weirdest places that people have used to build hydroponics are - discarded garages, mines at Kansas (Robert Vicino's RV Park), top of a city bus in Spain (Landscape artist Marc Grañén's succulent, mosses and ornamental grasses), underground bank vault in Japan (Pasana O_2), abandoned church in England (Installation artist John Newling's plantation of 32 Pinot Noir grape vines) to name just a few.

Some of the leading hydroponic commercial leaders in this domain are AmHydro (https://amhydro.com/) [US], Heliospectra (https://www.heliospectra.com/) [Sweden], Scotts Miracle-Gro (https://scottsmiraclegro.com/) [US], LumiGrow (https://www.lumigrow.com/) [US]. Thanet Earth (https://www.thanetearth.com/) [UK], Jones Food Company (https://www.jonesfoodcompany.co.uk/) [UK], Junga FreshnGreen (https://jungafreshngreen.com) [India], Hydroproduce (https://www.hydroproduce.com.au/) [Australia], Benfried International [Netherlands] (https://www.benfried.com/en-us), Ezfarm [South Korea] (https://www.crunchbase.com/organization/ezfarm).

Table II contains the details of various hydroponic farms that are well established and have sustained the test of time. Their major details and crops are highlighted.

TABLE II. COMMERCIAL HYDROPONIC FARM DETAILS

Name	Estd	Major Highlight	Prime Crop
Junga FreshnGreen, India	2016	Pesticide free products	Fruits and vegetables
Thanet Earth, UK	2008	Huge Power plant; Self-sufficient in terms of electricity	Cucumbers Peppers Tomato
Jones Food Company, UK	2016	High care, vertical farm using renewable energy	Herbs, Leafy greens
Benfried International, Netherlands	1991	Drip Tape, transport Horticulture belt conveyor	Horticultural Agricultural produce
Hydroproduce, Australia	1992	Hydroproduce family network across Australia	Asian greens, vegetables
AmHydro, US	1987	Clean food manufacturer	Leafy green, vine crops
VeggieTech, UAE	2015	Combat agronomicity	Greens
EzFarm, South Korea	2000	TAPKIT-affordable solutions	Vegetables

III. S TUDY OF HYDROPONICS

A hydroponic system is expected to interface existing conditions and based on the monitored samples, additional input in terms of water, nutrients, pH enhancers, oxygen, carbon dioxide and light can be altered. It is generally aimed to be self-sufficient in terms of energy requirements mostly using renewable sources of energy. The power of Hydroponics lies in the following major three factors- reduced water intake, reduced land occupation, insect free zone. When this is coupled with the technological wonders associated with electronic devices, sensors, pumps and interfaces, communication protocols, networking nodes, blockchain, machine learning, robotics - it removes the risk of agricultural run-off.

Fig. 2 shows a typical modern setup for Hydroponics where every component is under closed control system. It clearly indicates how each and every parameter is under observation using electronic sensors, interfacing devices and recorders in monitoring setups, programming nutrient flows and maintenance of desired conditions for growth of the plants in Hydroponic system.

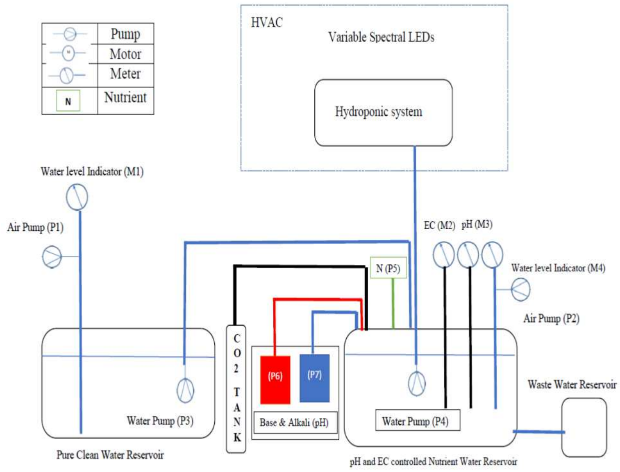

Fig. 2: A typical modern day Hydroponics setup

A detailed study of Fig. 2 reveals the following components- Every pump is indicated by P and in all, there are five pump actions shown in the figure. Pumps P_1 and P_2 are air pumps and their main function is to ensure aeration and thus the correct oxygen supply in the aqueous solution. Pumps P_3 and P_4 are both water pumps and their tasks are to ensure the supply of water to the desired locations - the nutrient water reservoir and the plant system respectively in the present setup. Two types of pumps are required for a hydroponic system - a water pump for water and nutrients while an air pump to infuse oxygen into the water system. A submersible water pump can be placed underwater. It is cheap but heat generative. Its performance is measured in Gallons Per Hour (GPH) - the liters of water it can displace to variable head heights. An inline pump is essentially placed outside the system but is associated with high power delivery and durability. The origin of pumps began with the shadoof in the 2000 BC in Egypt [6]. In today's world, Integral Variable Speed Drives (VSDs), Supervisory Control And Data Acquisition (SCADA) systems and Condition Monitoring equipment dominate the markets thanks to parallel progress in Computer Aided Design (CAD) and Computational Fluid Dynamics (CFD) based design understanding and implementation.

Pump P_5 is meant to control the nutrient content in the nutrient water reservoir and is generally connected to the Nitrogen Phosphorus Potassium (NPK) water soluble contents. In the early 20th century, botanists experimented with the nutritional requirements and the techniques to enhance their delivery to the plant. Through experiments, it was deduced that instead of soil, it is the minerals present in the soil and the corresponding spaces in between (for oxygen) that was necessary for growth. Dr. Victor Tiedjens, in the 1920s, with experimentation concluded that nutrients when dissolved in water was best absorbed by plants [7]. This was the beginning of liquid fertilizer. In 1929, W. F. Gericke successfully converted his nutriculture laboratory into a commercial crop production unit using hydroponics thus confirming optimal results and faster growth [8]. A water solution containing salts of Nitrogen (N), Phosphorous (P), Sulphur (S), Potassium (K), Calcium (Ca) and Magnesium (Mg) together with elements Hydrogen (H), Oxygen (O), and Carbon (C) derived from air and water make up the macronutrients. Iron (Fe), Chlorine (Cl), Manganese (Mn), Boron (B), Zinc (Zn), Copper (Cu) and Molybdenum (Mo) are the micronutrients. Every plant has a different need of nutrition at various stages of development and their continuous monitoring is best achieved through electronic sensors and interfaces. Pumps P_6 and P_7 ensure the correct pH (acidic/alkaline nature) of the nutrient solution.

A CO_2 tank is used to supply the optimum value of carbon dioxide that helps in the process of photosynthesis. Motors M_1 and M_4 are meant to maintain the correct water level in the Pure Clean Water Reservoir and pH/EC controlled Nutrient Water Reservoir respectively. The same is monitored using water level indicators also.

Motors M_2 and M_3 are desired to control the level of EC and pH respectively in the pH/EC controlled Nutrient Water Reservoir. The concentration of salts (Nutrients generally dissolve in water) is measured by an EC or ppm meter. The positively charged ions conduct electricity that is measured in ppm. Electro-Conductivity (EC) or Conductivity Factor (cF) can be expressed as either milliSiemens (mS), cF, or parts per million (ppm) where 1 mS = 10cF = 700ppm [9]. There are; in all three water tanks – pure clean water Reservoir, pH/EC controlled Nutrient Water Reservoir and Waste Water Reservoir.

The greenhouse or the net house contains the plants that are either exposed to regular daylight or to Artificial lighting systems. In the domain of artificial light-most popular is the Variable Spectral LEDs. LED technology came up during the 1960s - a working option provided by Nick Holonyak Jr-a 33-year-old General Electric (GE) scientist [10]. LED or any kind of supplemental lights contributes by increasing photon accessibility to our plants. Moreover, they don't radiate much heat- so the requirement of high-power coolers can be waived away. Also, they can be easily operated on renewable sources of energy instead of being dependent on high power supply. Our regular plants respond to spectrum variation in the sunlight in terms of growing leaves, growing tall, flowering or fruiting throughout the days, months and years of their lifetime- cycles. Spectrum variable LEDs do the same by feeding our indoor plants the correct wavelength. This light modulation can be controlled externally. This allows producers to manipulate growth in specific parts of the plant- thereby making your food more sweet, tangy, mild, fragrant and/or color vibrant.

Apart from LEDs, the greenhouse contains the Heating, Ventilation and Air Conditioning (HVAC) system that is the heart of a Hydroponic setup. It essentially ensures a smooth balance between the inside and the outside atmosphere and also provides compression, blowing and filtering using ducts. In the 1800s, Dr. John Gorrie proposed cooling cities during summer months, patented it and planned automatic humidity and temperature control [11]. In 1932 H.H. Schultz and J.Q. Sherman offered a portable unit that could fit in a window like space and this is how large-scale HVAC units developed through the years [12].

Media bed acts as a medium to support the root system of plants and also doubles up as a mechanical and biological filter. The medium is expected to be chemically inert, permeable to air and water. The media can be used as a platform to fit electronic sensors (communicable using wired or wireless networks) to monitor the overall health and growth of the crops. Thus, a set of parameters affect the overall growth of the plants in a Hydroponics system.

Table III indicates the various parameters (biotic/abiotic) that are related to the growth of plants in hydroponic systems. There is also a detailed explanation on how these components generally affect the growth, the budding, the flowering and the fruiting of the plant.

TABLE III. VARIOUS BIOTIC AND ABIOTIC FACTORS RELATED TO THE HYDROPONICS SYSTEMS.

Criteria	Ups	Downs
Harvests	Huge growth in production and quality of the product harvest.	Compromised health of the Ecosystem & reduced Biodiversity
Effects due to the changes in atmosphere	Greenhouses are safe of drastic changes due to physical isolation.	Cannot take advantage of favorable climatic influences seasonally.
Infections due to soil microbes	Soil less farming provides controlled medium for growth.	No symbiotic/parasitic relations with soil micro-organisms.
Infections due to other plants	For multiple crops, sufficient physical separation is imposed.	If the nutrient medium is contaminated, the infection spreads fast.
Attack by micro organisms	Less chances of attacks due to closed system.	Spreads fast in contaminated medium; pathogens in greenhouse.
Temperature	Optimized plant growth using Controlled temperature.	Insufficient heat tolerance of plants causes irreparable damages.
Humidity	Sprinkler/Mistifiers can offer flexible humidity to meet the plant growth.	Pathogen & Pest attack increases; Transpiration rate reduces
RO Water	Only desired nutrients and that too in desired quantities to be added.	Influence of local minerals is absent in the growth of the plant.
pH	An optimum pH value based on plant variety and growth stage is set	Near acidic solutions are known to be favorable for growth of few plants.
LED lighting	Provides flexible day length adjustments	Extra heat is released by the lights in greenhouse
HVAC	Maintain temperature; Mimics outdoor climate	Consumes lots of power and energy
CO_2 supply	Increases production by enhancing plant capacity	Increases indoor temperature
Nutrient solution	Easy absorption by the roots of the plants	Regular change of the nutrient solution is must
Transplanting seedlings	The roots of the seedlings can be physically wrapped by the soilless medium.	Too young seedlings (without a pair of leaves) need special care when they are transplanted.
Allelopathy	Weed control, crop protection, crop survival.	Illness, Autotoxicity, Biological invasion
Mycorrhizae fungi (powder /root solution)	Can survive in aqueous solutions that is well aerated.	It cannot replicate and grow in aqueous solutions
Electrodes used for sensing	Water-resistant, submersible, waterproof electrodes	Open Junctions and connectors (of optimal length) to be well fitted.
Effect of Bacteria		
Harmful	Restricted entry hence no bacterial diseases.	Fast spread if water/air borne bacteria enters.
Useful	Useful bacteria can be deliberately introduced to propagate through a cultivating medium.	Soil based good bacteria that improves plant nutrition processing cycles are absent.
Mucilage	Plant roots exude mucilage. As long as roots exist; mucilage would survive-soil/water/any medium.	

A detailed study of the Table III reveals that a hydroponic system that is isolated from the rest of the atmosphere is exposed to various lows and highs when compared to a soil medium of growth. Apart from the attacks by microbes, some specific micro-organisms affect the plant growth. Consider the Pseudomonas Fluorescens- a good bacterium that helps the plant in defense and nutrient uptake. It is found in large colonies in soil, water and on plant surfaces. By releasing a soluble greenish fluorescent pigment, it can retard plant diseases by protecting the seeds and roots from fungal infections [13]. Mycorrhizae fungi is involved in a symbiotic exchange between roots and fungi at the microbiome level. Mycorrhizal fungi are capable of forming mycelial networks not only in soil but also in inert mediums used in hydroponics like coco coir, rockwool, clay pellets, perlite, sand, gravel, sawdust [14]. Bacteria are generally responsible to enhance the nutrient intake and processing capabilities of a plant. In their absence, the plants become prone to attacks, diseases and may face problem in nutrient intakes.

Sterility (absence of microorganism) is defined as a negative influence in agriculture, as micro-organisms support both the growth of the plant and also the overall health of the ecosystem [15]. Such a phenomenon can be controlled in hydroponics. Allelopathy is a vital phenomenon where every plant produces a set of biochemicals called allelochemicals. These chemicals play a significant role in growth and survival of the plant itself and also of its neighbors [16]. A plant species can interfere with the growth cycle of other plants as they compete for resources. Every microflora has its own unique role in the biome. Absence of microflora in the root neighbourhood may increase toxicity to levels so high that the plant can actually kill itself.

It is observed that CO_2 is the most commonly forgotten factor related to Hydroponics. A deficiency in its concentration can drastically affect the plant growth.

Mushrooms are reputed to produce tons of CO_2. A noble approach could involve growing mushrooms with regular plants. However, the darkness factor required for the growth of mushroom is a complete contrast against lighting needs of regular plants.

Mucilage is defined as a complex mix of carbohydrates, amino acids and organic nutrients found in the roots of plants and released into the environment. This is popular for medicinal use.

Heat is one of the major abiotic stresses that gives rise to drastic damage at cellular and intermolecular level and this in turn hampers the plant growth and reduces overall development, fruiting and flowering of the specimen. Apart from growing crops, hydroponics and closed greenhouses can be used to particularly grow good variety of seeds- both disease resilient and having better survival rates.

IV. TYPES OF HYDROPONICS

At a specific level, the various hydroponic types are Wick system, Deep Water Culture (DWC), Nutrient Film Technique (NFT), Ebb and Flow method, Drip irrigation system, Aeroponics, Krafty method and Fogoponics. Fig. 3 contains all the different methods of hydroponics. Various sub systems are associated with each such individual unit to ensure its smooth functioning.

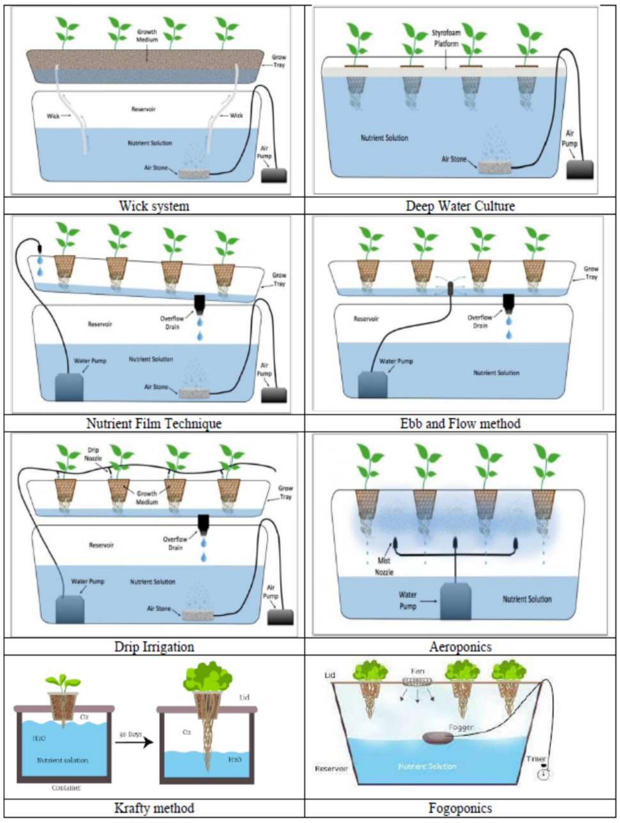

Fig. 3: All the different types of Hydroponics [18, 19]

In hydroponics, the size of the water nutrient droplet that comes in contact with the roots is vital as it plays a very significant role in deciding the optimal growth of the root. Nutrient charged aquatic solution is flushed across the roots in each of these systems, the only difference is the manner in which it is done and how long it stays in contact with the root of the plant.

Of all the stated systems, it is the Krafty method which is the only passive approach as it does not require any electronic devices for sensing and control. Details pertaining to the various other techniques is listed in Table IV. Of all these methods, Fogoponics is a sub branch of Aeroponics and is a promising upcoming branch of Hydroponics.

V. CROPS

Hydroponics is applicable to various crops – leafy, fruit based, flower based, ornamental and various cash crops. Leafy greens and herbs are the most convenient to grow and groom as the need of pollination is not involved in such cases. Further, crops like beans and peppers can be pollinated manually or even using wind (using fans in the indoor structure). However, for other crops that require flowering and/or fruiting, we must opt for either exposure to the outside atmosphere for limited time duration or expose them to trained bees using small portable bee hives specially designed for hydroponics that have controlled bee movement. It has also been observed that due to better eyesight, bumblebees are a better substitute to honeybees. Moreover, experimental results have proved that fruits pollinated by bumblebees taste better.

One crop that has continued to be grown hydroponically since 5000 BC when it was first known to evolve till date is Rice, or Paddy- a water intensive crop that happens to be the staple diet of approximately half of the world population, followed by wheat and maize. As on date, one of the biggest challenges to the Agricultural, Biotechnological and Climatic sector is to cultivate Paddy. The minimum water requirement to grow 1 Kilogram of rice still happens to be in the range of 4000-5000 liters. As the amount of irrigable water is limited, sea water (66% constituent of the Earth's surface) is investigated as a substitute for cultivation of rice. In a recent breakthrough, scientists from the Chinese Academy of Agricultural Sciences and the China National Rice Research Institute have been able to halve the growth cycle of rice using controlled setup in indoor cultivation mode [17].

The list of crops that can be hydroponically grown are definitely unending as the technological edge has helped to overcome most of the hindrances faced during cultivation of specific plants. Few common crops quoted in Table V, contains associated information about these crops like their comparative harvest ratios, the EC, the pH and the ppm. The crops are classified as

Flowers - Orchids, Iris, Daffodils, Chrysanthemums, Gerbera, Carnations, Peace Lily.
Fruits – Blueberries, Strawberries, Melon, Watermelon,
Vegetables – Tomato, Peppers, Beans, Cucumber, Pea
Herbs – Thyme, Parsley, Mint, Chive, Lemongrass, Celery
Fungi – Mushrooms.

TABLE IV. DETAILS PERTAINING TO ALL THE METHODS USED IN HYDROPONICS

Technique	Medium for nutrient supply	Works well for	Root exposure to nutrients	Pumped Water supply	Water demand	Disease
Wick system	Wick	Small plants, Home grown	Root receives nutrient water through wicks	No	Nominal	Fungal disease and root rot
Deep water Culture	Plants held in netted pots	Compact and scalable	Roots throughout dipped in water nutrient solution	Filled container	Maximum but reusable	Insufficient oxygen content
Nutrient Film Technique	Sloping channels for nutrient water	Domestic and Commercial hydroponics	Partial thin film of exposure to nutrient solution	24 X 7 pumping through a sloped channel	Nominal	Root Rot
Ebb and flow method	Flooded and drained with nutrient water	Small scale and large-scale implementation	Root exposure in bursts	Intermittent supply of water	On and off	Healthy Root development
Drip Irrigation	Drip line via pump & timer	Commercial application;	On and Off exposure to Nutrient solution during the drip	Pipe supply and drip emitter	Nominal	Fungi/Bacteria infection in media bed
Aeroponics	Atomizers are required	Commercial application	Exposure in bursts	Sprinkler with mist nozzles	Minimum	Healthy roots
Krafty method	Direct contact	Home and small scale	Continuous	Not needed	Nominal	Infection due to direct contact
Fogoponics	Fog Atoms of nutrient water	Commercial	In bursts	In bursts	Minimum	Healthy roots

TABLE V. BASIC DETAILS ABOUT FEW MOST COMMON HYDROPONICS CROPS

Crop	Traditional medium	Alternate medium	pH value	EC	ppm
Vegetables					
Tomato	10-12 tons/acre	180-200 tons/acre	5.5-6.5	2-5	1400-3500
Peppers	10-12 tons/acre	120-140 tons/acre	5.8-6.3	2-3	1400-2100
Cucumber	15-20 tons/acre	200-220 tons/acre	5.5-6.0	1.7-2.5	1190-1750
Green leafy vegetables					
Lettuce	9-10 tons /acre	300-400 tons/acre	6.0-7.0	0.8-1.2	560-840
Cabbage	6-7 tons/acre	10-12 tons/acre	6.5-7.0	2.5-3	1750-2100
Pakchoi	10-12 tons/acre	280-320 tons/acre	7.0	1.5-2	1050-1400
Fruits					
Strawberries	20-25 tons/acre	50 tons/acre	6.0	1.8-2.2	1260-1540
Blueberries	20-25 tons/acre	55 tons/acre	4.5-6.0	1.8-2.0	1260-1400

VI. MONITORING AND AUTOMATION

Monitoring of Hydroponics is the heart of the entire system and is; at times quite challenging, especially for new learners. Any minor error in any of the intermediary process may result in spoiling the entire harvest and may cause irreparable losses. Thus, various techniques are proposed to monitor their automation under supervision. Table VI projects various such monitoring actions and their associated technological advancements. Initial contribution by Researchers have depicted comparative growth of hydroponic plants with traditional soil medium [31]. Further advances have led to transmission of locally collected variable values to remote locations for analysis using wireless techniques [20-29, 31, 32, 36, 38]. Significantly cloud based applications are having bright perspective in this regard [32, 36, 38]. The major parameters that need continuous monitoring are the nutrients, the alkinity/acidity of the solution, temperature of the nutrient solution, external temperature and humidity. The most popular processor is the Arduino because of its open-source characteristics and dynamism [25, 26, 29, 31, 32, 33, 37, 38, 42]. This is followed by the Raspberry Pi [21, 22, 23, 27, 31, 36, 42]. These are further supported by the communicating protocols-MQTT, WSN, Web interfaces and the Cloud support systems. All readings are then available to users, supervisors, controllers and many more individuals, simultaneously or singularly.

VII. AI/ML/ROBOTICS

Monitoring and Automation generates tons of data that can be used to perceive the performance of various commercial and small-scale hydroponic initiatives undertaken by amateurs and experts. Various evaluation techniques using Artificial Intelligence, Machine Learning and Robotics can be used to ensure a closed loop response system that can generate corrective actions to overcome the variation in any of the parameters. Table VI tabulates them. Few of the popular techniques are Fuzzy logic based [21, 22, 30]. ML techniques like Genetic Algorithms (GA) started featuring as their applications spread across multiple areas including Hydroponics. Consider for example, the growth optimization obtained in terms of the ratio Total Leaf Length to Stem Diameter (TLL/SD) for single and multiple input using a hybrid combination of GA and Neural Networks [34]. Motor controllers and actuator movements are investigated to reach out to unreachable heights and corners of the alternate farming arrangements.

TABLE VI. MONITORING OF HYDROPONICS CROPS USING AI/ML/ROBOTICS

Ref No	Technique	µcontroller/ µprocessor	Technology	AI/ML/Robotics	Plant
20	Nutrient Film Technique	ESP 32	Blynk App	-	Lettuce
21	DWC - pH, EC, Water control	ESP 8266, Raspberry Pi	MQTT	Fuzzy Logic	Lettuce, Bok choy
22	DWC- pH Water control	ESP 8266, Raspberry Pi	MQTT	Fuzzy Logic	Lettuce, Bok choy
23	Nutrient Film Technique	ESP 8266, Raspberry Pi	Web Technology	-	Tomato
24	Nutrient Film Technique	ESP 8266	Hybrid WiFi WSN	-	Mustard Green, Pak choi, Mint, Lettuce.
25	Nutrient Film Technique	Arduino	IoT Edge	AI Cloud, Deep learning	Strawberry
26	Nutrient Film Technique	Arduino	Android & Web	-	Kale
27	Nutrient Film Technique	Raspberry Pi	Android	-	Lettuce
28	Continuously watered rockwool	WSN Microprocessor	HTTP Rest API	Machine learning	Tomato
29	-	Arduino, ESP 8266	Web Interface	TDS Servomotor control	-
30	-	MATLAB tool +LABVIEW	-	Mamdani FIS valve control	-
31	Hydroponics Vs Soil	Arduino, Raspberry Pi	Domoticz; NRF24L01	-	-
32	-	Arduino, Node MCU	LED effect; Wi Fi using Cloud	-	Butterhead lettuce
33	Nutrient Film Technique	Arduino, ESP 8266	IoT	K Nearest Neighbourhood	Lettuce
34	Deep Water Culture	-	-	Genetic Algorithm & NN	Tomato
35	-	-	-	Linear Regression Algorithm	Green Oak
36	Nutrient Film Technique	Raspberry Pi	Cloud based websites	Bayesian Network	Iceberg Lettuce
37	-	Arduino	-	Machine Learning	Lettuce
38	-	Arduino Nano, Node MCU	Cloud	Multiple Linear Regression	-
39	-	-	-	Vertical Actuator movement	-
40	DFT, NFT	Monitoring the UV Sterilization unit			-
41	Nutrient Film Technique	Machine learning for crop growth detection			Tomato
42	-	Arduino, Raspberry Pi	Firebase	Agile Software Development Life Cycle	-

VIII. CONCLUSION

Hydroponics has evolved towards various other linked scaled versions like the vertical tower, the Dutch bucket system and stacked NFT setup using one or more of the aforementioned methods.

Although Hydroponics initially started with water as the medium for cultivation, other techniques are gradually germinating, growing, flowering and resulting into fruitful ventures due to parallel growth in hardware and software interfaces components, interfacing possibilities and government as well as NGO initiatives and support system in the Indian subcontinent. Even the lockdown has actually provided options to learn and grow.

Consider the various success stories- Ajay Naik [Letcetera Agritech], Sakina Rajkotwala and Joshua Lewis [Herbivore Farms], Linesh Pillai [Terra Farms], Sriram Gopal [Future Farms], Rahul Dhoka [Acqua Farms], Dhruv Khanna [Triton Foodworks] have shown remarkable progress in the domain of Hydroponics in India.

Refer the contribution by Ex. Navy personnel, Alumnus National Defence Academy, India, C V Prakash [19] (CV Hydro Training Centre, Bengaluru) who in his experimental setup substituted regular soil by cocopeat in grow bags and converted a gift of rhizomes of the Tiger Claw Salem turmeric variety into a whopping crop harvest success story. Eurofin labs, Bengaluru have confirmed the curcumin content (known for its cancer fighting properties) of 5.91% (almost double of the regular 3% generally seen in the Salem variety) and no trace of heavy metals contributed largely by the precision irrigation, correct leaching fraction and the use of beneficial microbes. Mission Turmeric 2021 is his new venture which is also fondly called the Orange revolution.

And this would not have been possible without the sensors, the stabilizing setup arrangements, the microprocessor program-based monitoring, feedback, HVAC, the wired and wireless communication protocols, machine learning techniques, Artificial Intelligence and robotics - all gifts of the technological advances in the Monitoring and Automation industry.

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