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REVIEW PAPER

Smart controlled environment agriculture methods: a holistic review

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Abstract Agriculture is the basic necessity all over the world which provides food for the existence of humans. India is expected to be home to 1.6 billion people by 2050, and India has to double the food production from the current level of 260 MT to feed the entire population. Providing food for growing population is becoming tedious and the deficiency of fertile lands makes it more difficult to increase the production beyond a certain limit. Under such scenario, maximizing the production per unit area using precision technologies in agriculture will help to achieve the same. Smart technologies are getting attention in every domain by the inclusion of advanced technologies like Big data analytics, Robotics, Artificial Intelligence (AI), Internet of Things (IoT) etc. This article reviews the current literature published in the stream controlled environment agriculture like soil less hydroponics, aquaponics, nutrient film technique and aeroponics for the period of 1999–2020. In this article, different types of soilless agriculture, their advantages over traditional soil methods, different types of sensors employed in agriculture, implementation of recent precision technologies in soilless agriculture are discussed. The review suggests that "smart farming" is an emerging trend in the area of agriculture, which makes, every individual to practice farming and grow vegetables and fruits on their own in their house without soil. However, future research ideas should focus on areas of "real time monitoring of nutrition solution management and pest management" for the plants growing in controlled environment to maximize the production are also discussed.

Keywords Hydroponics · Aeroponics · Bioponics · Smart farming · IoT · Sensors

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1 Introduction

The global population is expected to reach 9.75 billlion by 2050 and in order to sustain this growth and feed them, the food production has to be increased and it needs to be doubled from the current level of food production (FAO 2017) Combined with the trend of urbanisation, it becomes increasingly more important to produce more food using the available farmland.

The current high input/resource-intensive farming practices have shown that it is not scalable due to their enormous environmental impacts such as deforestation, ground water depletion, and green house gas emissions (FAO 2017). As such, it is an imperative challenge to increase the crop yield per available area, whilst significantly reducing the usage of resources such as water, pesticides, and herbicides in order to minimize the environmental impact and increase the sustainability of the food production chain. This is evident from the sustainable development goals (SDGs), in which agriculture has gained lot of importance. Goal 2 exclusively deals with the agriculture by stating the policy of End hunger, achieve food security and improved nutrition and promote sustainable agriculture. Besides, the importance of agriculture can also be seen in Goals 6, 12, 13, 14, and 15 (sustainable management of water, sustainable consumption and production patterns, combat climate change, sustainable use of oceans, and protection of ecosystems, respectively).

In this context, researchers and policy makers are looking for alternatives to current practices of intensive agriculture, which has so many reasons for low productivity viz., cultivation in marginal lands, soil related problems, infestation from pest and diseases, farmer management practices etc. One of the options, emerging out from research in these lines are soil less agriculture/controlled environment agriculture (CEA) (Nicholas and Moncef 2021; Shaylin and Matthew 2021).

1.1 Controlled environment agriculture (CEA)

In recent years, CEA is gaining its popularity as it has the advantage of growing any kind of leafy plants in a controlled environment with soil less cultivation. It also requires less water and less area for growing crops, it helps to artificially provide the specific nutrients as per the needs of plants (Shaylin and Matthew 2021). The soilless agriculture reduces the nutritional deficiency in the plants, maintaining pH by adding or reducing the concentration of nutrient solution and also it avoids the inherent problem usually occurs with traditional soil based agriculture in terms of pests and diseases (Li et al. 2020). CEA mainly includes advanced techniques like Hydroponics, Aquaponics, Aeroponics and Bioponics. The methodology attempted is using key words like controlled environment agriculture (CEA), Smart farming, Hydroponics, Aquaponics, Aeroponics and Bioponics, digital agriculture etc., were searched in science direct and the entire list of research articles were compiled. The results revealed that there is a significant increase in number of publications and statistically significant through linear regression from 1999 to 2020. Number of research papers increase from mere 4000 in 1999 to 44,000 in 2020 (Fig. 1).

Hydroponics is a technology of growing plants without soil and adding nutrient or fertilizer in the water solution as per the nutrient requirement of the plants. This nutrient solution is the major ingredient in the hydroponics systems and it helps for the healthy growth of the plants. Aeroponics is the method of growing plants without using soil or aggregate medium in an air or nebula environment. The term "aeroponic" derives from the Greek definitions of aer (friendly, "air") and ponos (friendly, "labour"). Here the nutrient solution are sprayed or fogged to the plants. Aquaponics is a method of cultivation in which plants and fish are grown and the term originated from the two words aquaculture (the growing of fish in a closed environment) and hydroponics (the growing of plants usually in a soil-less environment). Nutrient rich aquaculture water was fed into hydroponics system, so that will provide nutrients to plants.

Soilless cultivation is a growing sector which could be helpful to the human kind and growing cattle feeds with less investment, less spaces, less usage and a profitable technique for farmers. Smart farming by using the emerging technologies like Big data analytics, IoT and Machine Learning reduces the yield gap and maximizes the production of crops (yield) and with superior quality of the produces, which is free from pesticide residues. The major advantage is that in these methods, precise amount of nutrient solution (i.e. optimal use of fertilizers based on the plant requirement) is applied along with very less usage (optimal use) of pesticides resulting in high nutrient use efficiency.. More frequent application of nutrients in small doses is possible under such methods, when compared to conventional agriculture, where the fertilizer doses are applied in one or two doses in bulk quantities, resulting in loss of nutrients by various mechanisms and reducing the nutrient use efficiency. In addition the labour force required to do all the intercultural operations (fertilizer application, weeding, earthing up) in conventional agriculture is not needed under these advanced soil less cultivation methods. These methods can be automated by using

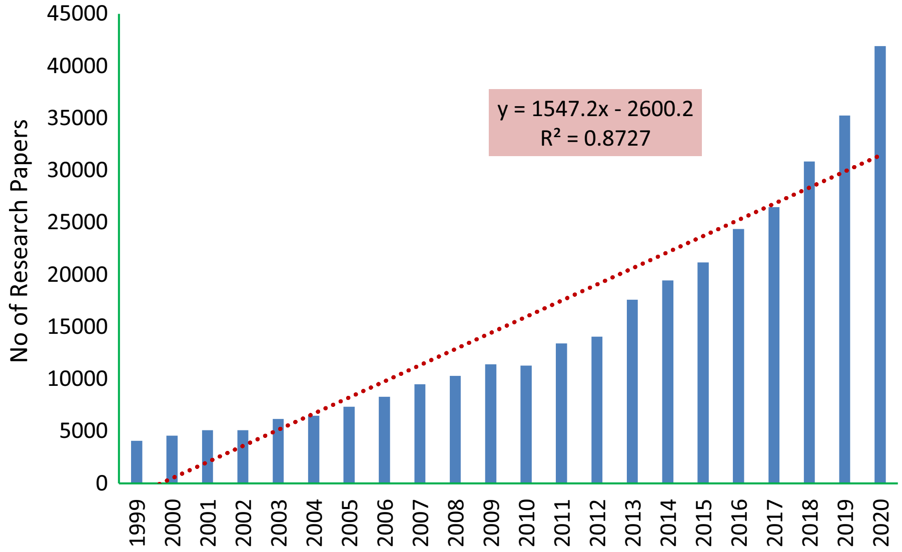


Fig. 1 Number of research papers published for the last two decades in controlled environment agriculture

many machine learning algorithms, Deep neural network techniques, Fuzzy logic which can be useful for farming in soil-less environment without much labour force.

New technologies and many sensors are used in "Real time Monitoring of Hydroponic systems" which generate large data flows which are analyzed for proper utilization of nutrient solutions, with maximum efficiency. Machine learning algorithms (such as neural networks and genetic algorithms) may be implemented to self-analyze and calibrate hydroponic solution parameters based on sensors data. Simulation techniques and advanced big data analytics allow the quality and quantity of vegetables or fruits production to be forecasted under different conditions, which will help the growers to plan their marketing options also. These artificial intelligence (AI) techniques and Internet of Things (IoT) help to create a real/physical hydroponic system –using "digital twin" and in turn helps to monitor optimal parameters, such as the composition and concentration of the hydroponic nutrient solutions and ultimately helping to achieve higher crop productivity .

The Internet of Things (IoT) has created a deep commercial and economic impact on human lives in current scenario. Due to the emergence of smart objects in the present world, the lifestyle and standard of living has been modernized to a great extent and IoT is playing a major role in doing many activities in a faster and smarter ways. IoT is defined as the distributed and interlinked structure of embedded systems interacting through wireless and wired technologies.. IoT plays a key role in the modern world as it entitles energy automation for improving the quality of life (Munandar et al. 2018). The IoT is the popular research domain wherein, the smart components and sensors enabled communication and monitoring are being used (Mohanta et al. 2020). Wireless Sensor Networks (WSNs) are a crucial part of IoT. In these networks, information is gathered from various sensors characterized by a wide level of communication and reduced power consumption. WSNs comprise several sensor nodes, which are capable of detecting parameters such as moisture, temperature, humidity, etc. from the growing environment. The core of every WSN node is microcontroller that processes reading acquired from its sensors. IoT has found prominent application prospects in every domain and agriculture is not an exception. For applications pertaining to agriculture, IoT devices comprise sensors for measuring various environmental conditions that are closely related to plant growth and monitoring these parameters facilitates precision agriculture with reduced water consumption and fertilizers, energy savings, etc. and also supporting efficient plant growth. Although recent survey on IoT based agriculture applications have illustrated that there is still scope for improvement in this sector and it is in a nascent stage only. Agriculture plays a crucial role in country's economy. With the implementation of modern farming wherein plants are grown without the necessity of soil, through nutrient solution, has led to the emergence of these soilless cultivation (aeroponics, aquaponics and hydroponics) technologies. The world needs a sustainable technique and hence using hydroponics will satisfy the future requirements of food security for the rising population. Hydroponics is considered to be a substitute to traditional farming for sustaining the crop production and ensuring food security. It utilizes nutrient and water for optimal growth of plants. The hydroponic technology has expanded globally in present era as a sustainable framework for precision agriculture and controlled environment system (Saraswathi et al. 2018).

Currently practiced conventional (traditional) agriculture has very tough challenges such as achieving higher productivity, optimal use of inputs and environmental sustainability. All these are controversially related. In this type of cultivation, the issues of low productivity is due to deteriorating soil health / fertility, pest and disease infestation, weed problems, unsuitable soil pH and EC (problematic soil), soil compaction, high requirement of labour force, improper drainage, degradation due to soil erosion, leaching, soil borne pathogens, nematodes etc. Besides, conventional agriculture with flood irrigation consumes more water, with improper management of farm inputs such as fertilizers, herbicides and pesticides, which in turn has deleterious effect on the environment.

Hydroponics or soilless culture is a trending innovation for cultivating plants/crops in supplement environments that deliver all supplement components necessary for ideal crop development in the presence or absence of soil media by utilization of other growing media like rock, coconut fiber, vermiculite, saw dust, peat greenery, etc. for providing mechanical support (Son et al. 2020). Moreover, hydroponic cultivation presents various focal points (i.e. grown everywhere) compared to regular cultivation. In hydroponics, crops can be grown in regions with marginal and sub marginal land areas also where soil may be problematic and less fertile. Plants developed hydroponically are of superior quality, since nutrietns are supplied as per the need of the crop and with close monitoring it will be devoid of infections and free from pest and diseases infestation (Nalwade and Mote 2017). Hydroponic systems are considered to be one of the prominent tools for improving the crop productivity and these are considered similar to manufacture industries as plant production factories. pH, electrical conductivity (EC) levels and nutrient compositions are vital factors that need to be maintained for improved plant growth. Thus electrical conductivity and pH supervision for evaluating nutrient status are assumed to be regular practices in hydroponics. Moreover, hydroponic farming offer better provision for water saving by recycling excess irrigation water. As mentioned earlier, hydroponics enables farming without soil requirement and hence it can be practiced even in problem soil areas.

In hydroponics system, essential nutrients are supplied to plants using mineral nutrient solutions as per the need of the crop. Through this technique nutrients can be supplied more efficiently than that of soil, and other losses such as leaching, volatilization and erosion can be avoided, thereby increasing the nutrient efficiency (Richa et al. 2020). IoT emergence has led to the automation of hydroponic systems. IoT enables interaction of machines, sensors and thereby controls hydroponic systems intelligently andefficiently without manual interventions. IoT enables capturing of several parameters that needs to be monitored under hydroponics system through sensors and gives plausible timely information for managing the system for effective plant growth (Sambo et al. 2019). In this article, the types of soil less culture-hydroponic systems (water based farming without soil),, subsets of hydroponic systems, medium in which it is grown, types of crops grown hydroponically, their nutrition solution and their characteristics, intercropping, aeroponic and aquaponics systems are discussed. The Internet of Things (IoT) such as artificial intelligence (AI), machine learning models, data analytical tools and other advanced technologies etc. based implementation of these cultivation, methods used for automation of hydroponics, aeroponics, NFT system, emerging new technology i.e., Bioponics and advantages of soilless agriculture are also reviewed and discussed in this manuscript.

1.2 Classification of controlled environment agriculture (CEA)

The Fig. 2 shows the classification of Soilless Farming or CEA. The boom in soilless agriculture reveals the invention of many methods of farming in recent years, so as to improve the water use efficiency and productivity of crops. The major types of farming

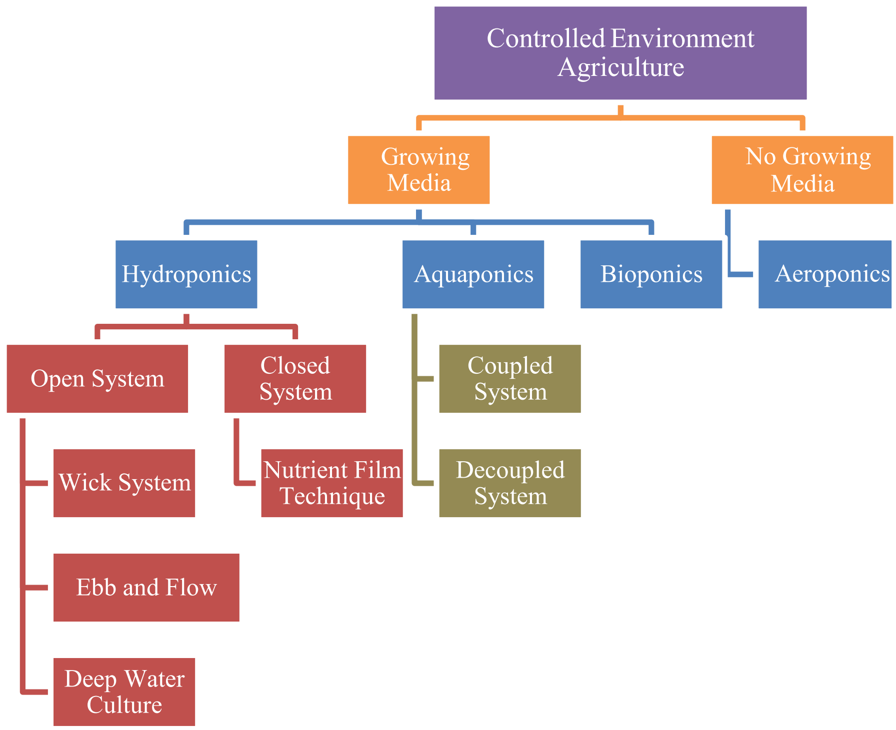


Fig. 2 Classification of different methods of Controlled Environment Agriculture (CEA)

methods includes hydroponics, aeroponics and aquaponics.

1.2.1 Hydroponics

Hydroponics is a growing technology in which the plants are grown in the water based nutrient solution with the mechanical support like gravel, sand, perlite, peat moss, rock wool, vermiculite, coir or sawdust. There are two types of hydroponics system.1. Open System 2. Closed System. In open system the nutrient solution is provided to the plants once and the remaining solutions are drained. In closed system the nutrient solution is reused and recycled (Mohapatra et al. 2019). The closed system or recirculation system is widely accepted techniques as it has the advantages of less impact to the environment, reducing the soil contaminations and nutrients drain to wells, lakes, ground water etc., and also resulting in higher crop production (Saito et al. 2017). The nutrient solution plays a major role in the soilless agriculture like hydroponics. There is a high interrelation between nutrition level concentration and yield of the plant (Moraghan 1985). The process called as fertigation is implemented in hydroponics which is the combination of application of water soluble fertilizers and irrigation. The concentrated solution is injected into the irrigation water (Van Os et al. 2019). Among the total production of vegetables, approximately 3.5% of vegetables are being produced from soilless agriculture with the usage of hydroponic solution under green houses and tunnel (Sambo et al. 2019).The major concerns in growing the plants by hydroponics system are (i) to lower the nitrate content in edible plant tissue, (ii) to ensure the safety of vegetables in terms of quality and (iii) to ensure the balanced nutritional quality of the crop yielded.

The main advantage of this hydroponic method when compared to traditional method are (i) water use efficiency is high, (ii) no use of pesticides, (iii) soil borne pathogens like *Ralstonia solanacearum*, *Fusarium oxysporum*, and *Verticillium dahlia*; nematodes; and many others that can survive in the deeper soil layers can be eliminated (Saito et al. 2017). The complications in conventional soil based agriculture, like deficiency or toxicity of particular minerals in the soil will have a direct impact on the growth of the plants. For example if the phosphorous (P) in the soil is in the higher level, then the soil will have zinc deficiency (Moraghan 1985). Similarly some of the nutrients will be fixed in the soil and may not be available for uptake by the plants. In the case of P in acid soils, it will be fixed as Fe/Al phosphate and in alkaline soils it will be fixed as Ca Phosphate, making them unavailable to plants. The above disadvantages can be avoided in growing plants hydroponically as it has the composition of all nutrient elements mixed in the irrigation water and can be optimized as per the requirement of the types of crops grown throughout the year without any affect in the seasonal changes or environmental changes (Table 1).

1.2.2 Aquaponics

The integration of growing crops along with growing fish is called aquaponics. Aquaponics can be performed in warehouses and other non-traditional areas. The wastes from the fish growing compartment is given as manure to the crops. Ìn this system of cultivation, chemical pesticides, fertilizers or antibiotics is not used to grow plants and fishes (Love et al. 2015). There are two types of aquaponics systems. (1) Coupled system. (2) Decoupled system (Fig. 3a, b). In the coupled system there will be only one loop between the fish growing chamber and the plant growing chamber. In the decoupled system, there is no connection between water from the fish growing chamber and the plant growing chamber. Thus, pest control management is easy in decoupled system rather than the coupled system (Stouvenakers et al. 2019). Tilapia, Carp and African Catfish are the most successful fish species used in aquaponic systems. These fishes are successful as a result of their ability to handle high levels of nitrate and low oxygen (Yep and Zheng 2019).

1.2.3 Aeroponics

In aeroponics, the plants are suspended and the nutrient solution are made to continually spray on the roots of the plants by the sprayers, foggersor emitters. It is a subset of hydroponics technique. The liquid fertilizer from a common container is provided to all the roots of the plants (Kratsch et al. 2006). Major parts in aeroponics involves pipes, a pump, spray nozzles and a timer which distributes the

Table 1 Merits and demerits of hydroponics, aquaponics, aeroponics and NFT system of cultivation

Merits	Demerits
Hydroponics	
1. The plant roots are immersed in the nutrient solution which reduces the death of the plant due to lack of moisture	1. Lack of oxygenation to the roots
2. The nutrient solution can be prepared as per the crop needs	2. Type of media finalise the efficiency of absorbing the nutrients from the nutrient solution
Aquaponics	
1. Plant nutrients are created from the swimming fishes	1. The level of ammonia should be monitored continuously so as to reduce the death of plants as well as fishes grown
2. The benefits are twice when compared to hydroponics method as it is a hybrid of aquaculture and hydroponics	2. Types of media influences the growth of the plant
Aeroponics	
1. No medium is needed in this method since the plants are about to hang and the solutions are sprayed through the sprinkler system to the roots on the time basis	1. The system needs a backup system and an extra pump because the plants completely depends on the sprinkler system for their nutrition needs
2. It overcomes the problem of poor Oxygenation	2. Cost of the system is higher when compared to other methods
3. Water usage efficiency is less as compared to other methods	
NFT	
1. The plant roots are partially merged in the nutrient solution	1. Knowledge required as the system complexity is high
2. A closed system NFT reduces the amount of nutrients used and hence reduces the cost of the system	2. Not suitable for large tap root system plants

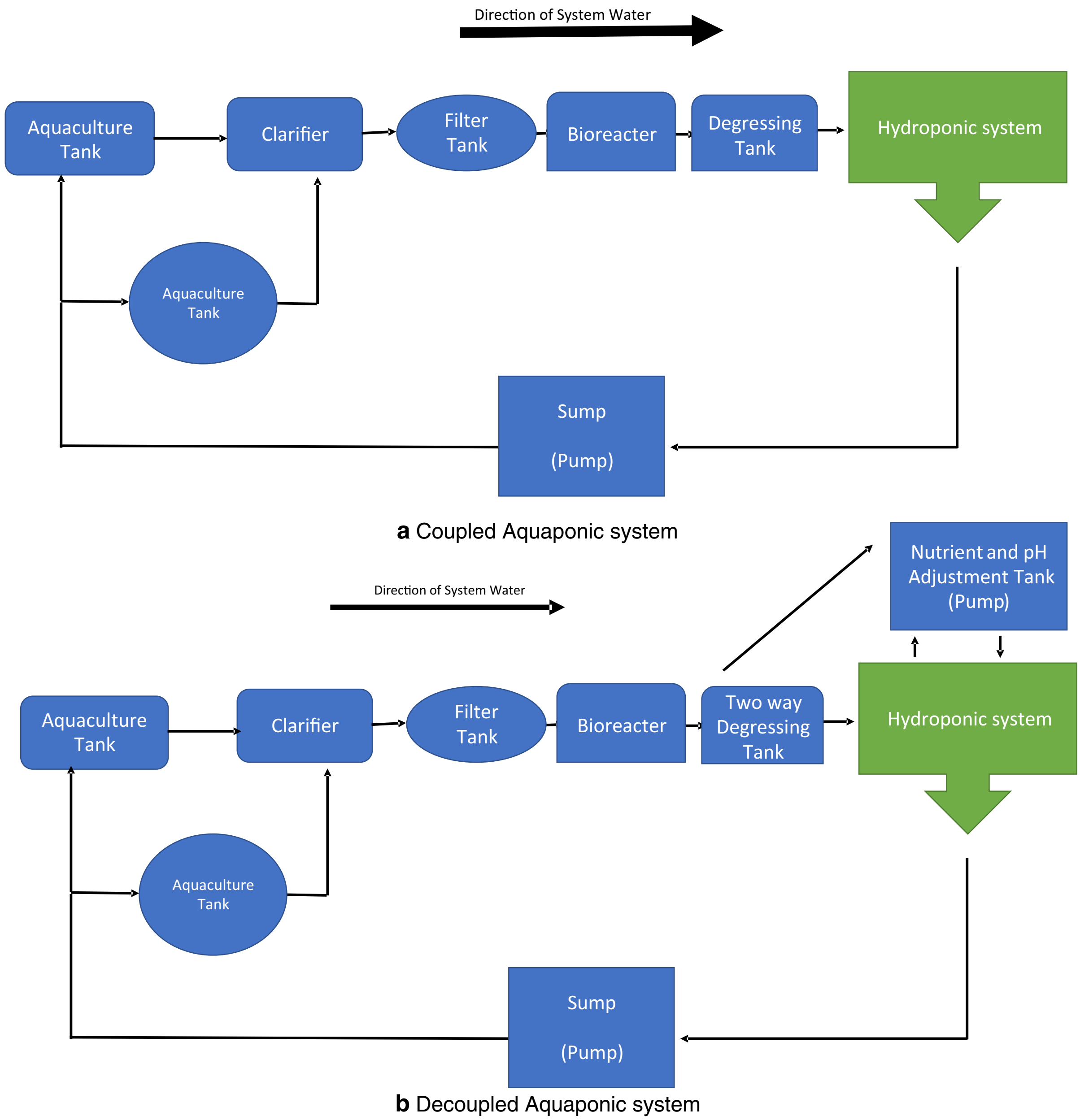


Fig. 3 **a** Coupled aquaponic system. **b** Decoupled aquaponic system

nutrient solution from the storage tank. The roots are easily accessible in aeroponics hence it has been used as a research tool since 1940s, growing of vegetable crops with this technique started commercially from the year 1970s and become popular in 1980s. The plants harvested are uniform all round the year as the roots have easy access. Chlorogenic acid concentration is high in aeroponically grown crops which ensures that these plants play a valuable production in herbal dietary supplement and phyto-pharmaceutical industries (Hayden et al. 2002).

Some major advantages of aeroponics are (i) soilless farming. (ii) The nutrient solution can be reused which is stored in the common storage tank. (iii) Pest infestation will be less so healthier plants can be obtained. (iv) Easy harvesting and energy efficient

(Pala et al. 2014). The important mechanism noted in aeroponic system is gas-dispersal mechanism which provides a precise and accurate control of concentration of nutrients to the root zone of individual plants. The plants in aeroponics system get nutrients from the thin mist formed by the sprayer at the root zone (Fig. 4). The timer helps in maintaining the cycle of nutrient supply to the plants so that to prevent roots desiccation.

1.2.4 Nutrient film technique (NFT)

Under NFT, the nutrients are made to re-circulate the nutrient solution to the roots of the plants for the roots to absorb the nutrients and continuous monitoring of the nutrient solution is needed to check the deficiency of the ions in the nutrients so that addition of the particular ingredient is made to optimize the nutrient solution. NFT and aeroponics have promising applications in the potato industry seed production and for NASA's controlled ecological life support systems (CELSS) program (Wheeler et al. 1990). The major drawback of this system are lack of buffer in the nutrient solution and outbreak of plant diseases. The slope of the trough is made to be 0.3–2% (Van Os et al. 2019), so that the optimization of nutrient is possible. The nutrient solutions are made as a thin film and are made to circulate in the vicinity of the roots of the plants. The remaining solutions are drained and stored in a tank for reuse of the solution. The flow rate of the nutrient solution should be optimized properly so as to ensure the growth of the plants. The plants in NFT system get nutrients from the thin film nutrient solution at the root zone (Fig. 5). The timer helps in maintaining the cycle of nutrient supply to the plants (Bikram et al. 2019). Merits and demerits of all the systems discussed above are shown in Table 1.

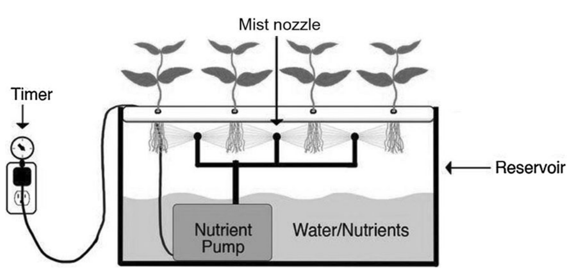


Fig. 4 Aeroponics system

1.2.5 Bioponics

Bioponics is a hybrid of organic farming and hydroponics. It is a combination of aquaponics and hydroponics. However, it has some dissimilarities when compared to the hydroponics and aquaponics. The nutrients are derived from plant-based, animal-based and mineral natural substances that are released by the biological activity of microorganisms. Hence this combination of aquaponics and organic hydroponics fit the definition of bioponics.

The hydroponics and aquaponics systems mainly rely on chemical synthesized fertilizers and does not involve adequate amount of microbial activity in the plant production processes. In aquaponics only fish excreta are used and other nutrients are obtained from chemical nutrient solutions as in hydroponics. The special term bioponics which involves soil-less growing plants with a maximum usage of microbial activity and biological process as in the organic farming for the entire spectrum to grow plants. This is the recent emerging technology in hydroculture which yields a chemical free plants and crops for a healthy next generation. Bioponics treatments diminishes the concentration of nitrate and increased the fresh mass of the leafy vegetables. BIO N and BIO NK are some of the examples of bioponic certified organic fertilizers (Fang and Chung 2017).

2 Growing substrates

The crops are grown hydroponically in an inert media without soil. The soil is replaced by organic or inorganic substrates. The advantages of using substrates in the place of soil is reduction in the water usage as the water holding capacity of the substrates is higher when compared to the soil and its reusable year after year. The major characteristics of the growth medium should be taken under consideration are their Water holding Capacity (WHC), Air Porosity and Density. Table 2 shows the nature of different growing medium used in CEA. The most commonly used mediums are perlite, rock wool, coco-coir, gravel, sand, pebbles, nutmegs, coco-pits, hydrocorn or grow rock, clay balls. Each substrate has their own advantages and disadvantages. For example: due to the porous nature of perlite, the roots of the plants have a healthy growth. Coco-Pit is also becoming more

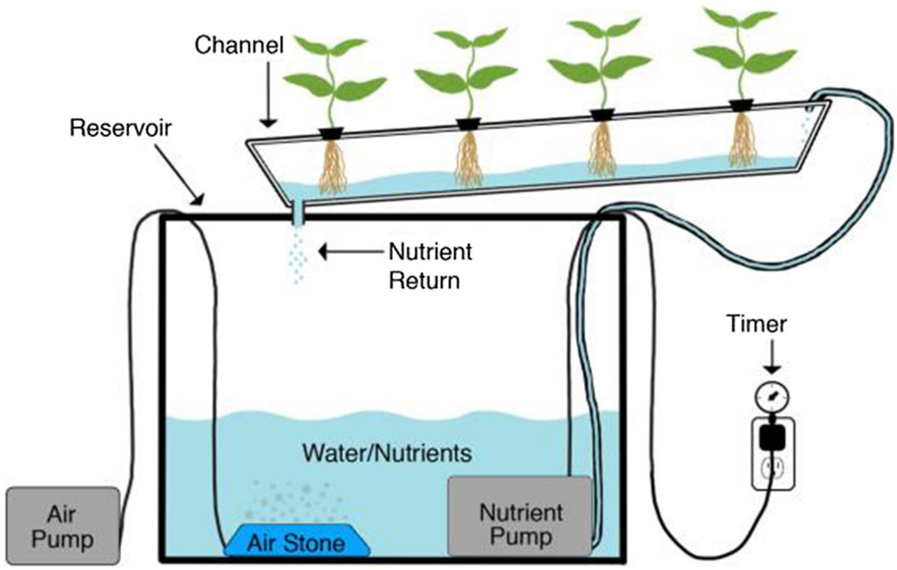


Fig.5 NFT system

Table 2 General characteristics of growing media

Growing media	Overall porosity (%)	Aeration porosity(%)	Density (g cm^{-3})
Rockwool	*94*	*83.9*	0.06
Coco coir Peat	*92*	*79.8*	0.16
Perlite	*90*	*77.0*	0.11
Sand	*66*	*25.2*	0.13

popular as it retains the wetness for a longer time that other mediums which reduces the dryness of the roots in hydroponic gardening. Irrigation cycles are reduced by using high water holding capacity medium like perlite, rock wool, coir pith etc.

Nutrient concentrations need to be greater in production systems requiring fewer irrigations, compared to systems requiring more frequent irrigations. The growing media should be chosen properly as per the nature of the crops grown so as to avoid the clogging of irrigation. Horticubes are often used as growing media because of its characteristics such as having stable pH, sterile and easy to handle (Kane et al. 2006). Organic substrates such as coco-pit, coir, husk have their own chemical properties which will in turn influence the microbial richness, functions and suppress the effect on pathogens. The moisture content is an important variable which should be measured for each growing media before selection and it depends on the crop (Kane et al. 2006). General characteristics of the growing medium is shown in Table 2.

3 Nutrient solution

The nutrient solutions are the major ingredient for the healthy growth of the plants in hydroponics. These solutions are obtained from the water soluble salts. The nutrient solution may be prepared in both form as inorganic and organic nutrients. The major essential nutrients needed by most of the plants are macronutrients viz., Nitrogen (N), Phosphorous (P), Potassium (K) commonly called as NPK Solution and micronutrients viz., Iron, Copper, Boron, Magnesium, Zinc, Molybdenum (Fe, Cu, B, Mg, Zn, Mo etc.,) (Grewal et al. 2011). The other macronutrients like Carbon (C), Hydrogen (H) and Oxygen (O) are obtained from air and water. Hydroponics technology allows us to gain the knowledge of the nutrients needed by the plants and the optimization of the nutrients is needed to grow the nutritionally rich plants. The healthier plants are produced when compared to the traditional soil method crops which are grown by lots of fertilizers and pesticides.

3.1 Nutrition deficiency and their corresponding nutrients and characteristics of nutrient solutions

Sources of nutrients and their deficiencies are shown in Table 3. The plant growth can be affected by the different characteristics of the nutrient solutions and the quantity of ion concentration present in them. Some of the important quality of solutions are their pH, temperature, Total dissolved salts (TDS), ion concentration, electrical conductivity (EC), solubility etc., The optimal pH range for most of the plants to grow healthy is 5.5–6.5.EC should be approximately less than 2.5 dS m^{-1}.

4 Hydroponic grown plants

Some of the plants which can be grown hydroponically i.e., without soil are mentioned in Table 4. All types of crops have their own nutritional needs and a controlled environment like temperature, climatic conditions, humidity in air, carbon and oxygen present in atmosphere, recirculation of air. The nutrient solution concentrations vary for different types of crops and there may be two or three stages of growth for different crops. Each stage poses distinct and unique concentration of nutrient solution in the irrigation water for their optimal growth. The below table shows an example of preparing the solution along with their nutrient contents (Table 5).

5 Methodologies needed for smart farming in CEA

The recent technologies are growing rapidly in every sectors like smart homes, smart machines which are able to communicate with other machines and making the human existence very comfortable. These are possible and can be implemented in agriculture sector too. So that farming can be done with less human efforts. The technologies like machine learning, deep learning, IoT are implemented in soil-less agriculture sector so as to produce higher yield with less human intervention. Some of the process involved in automation of soilless agriculture by using smart sensors and IoT technology are shown in Fig. 6. Some important equipment needed to perform smart farming are discussed briefly.

Table 3 Sources of Macronutrients and their deficiencies and toxicities

Macronutrients	Sources	Deficiency and toxicity and their effects
Nitrogen	Calcium nitrate [Ca $(NO_3)_2$] Potassium nitrate (KNO_3) Ammonium nitrate (NH_4NO_3)	High levels of N causes cracks in stems and distorts the leaves which causes soft rot and Blossom end rot. Excess N can boost foliar growth and depress the growth of onion bulbs
Phosphorous	Monopotassium phosphate (KH_2PO_4),Phosphoric acid (H_3PO_4), bone meal, rock phosphate, manure, and phosphate-fertilizers	Decreasing of root growth, stems and reduce in uptake of other Nutrients. Stunning of plant growth during early stage. Dark red–purple leaves appear burnt at the tips with older leaves and low collection of fruit
Potassium	Potassium nitrate (KNO_3), Monopotassium phosphate (KH_2PO_4), Potassium sulphate (K_2SO_4),Potassium chloride (KCl)	Increased levels of Potassium concentration in the nutrient solution increase dry matter in the fruits and increase the concentration of lycopene in tomatoes
Calcium	Calcium nitrate [Ca $(NO_3)_2$] Calcium chloride $CaCl_2$	Calcium imbalance causes BER which indirectly depends on the concentration of potassium
Sulfur	Potassium sulphate (K_2SO_4), Magnesium sulfate ($MgSO_4$)	Uniform pale green chlorosis,pale green in veins
Magnesium	Epsom salt ($MgSO_4$)	Yellowing between leaf veins, plus scorched and curling leaf edges and pulpy fruit

Table 4 Types of crops grown without soil

Type of crops	Name of the crops
Vegetables	Onion, tomato, cucumber, lady's finger, brinjal, potato, carrot etc.
Cereals	Rice, wheat
Leafy vegetables	Spinach, parsley, lettuce, amaranthus
Herbal plants	Basil, mint, brahmi, bringaraj, aloevera

Table 5 Contents of nutrient solution

Nutrients	mg L^{-1}
Nitrogen (N)	210
Phosphorous (P)	70
Potassium (K)	300
Calcium (Ca)	180
Magnesium (Mg)	67
Manganese (Mn)	1.25
Iron (Fe)	3.0
Copper (Cu)	0.26
Boron (B)	0.5
Zinc (Zn)	0.40

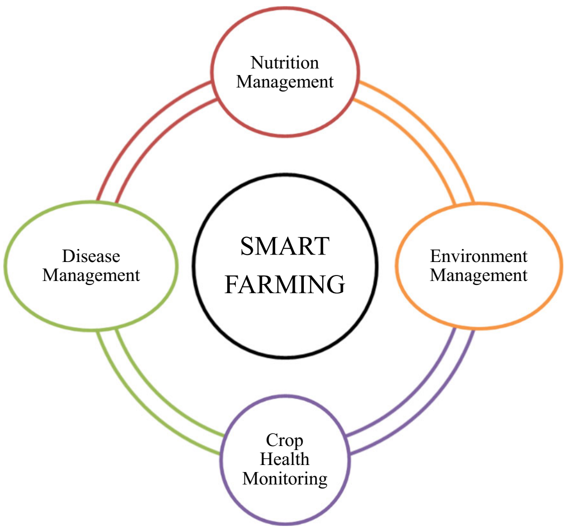


Fig.6 Processes involved in automation of soil less agriculture by using smart sensors and IOT technology

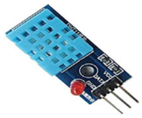
5.1 Recent smart sensors used in precision CEA

The smart sensors are a promising equipment which helps in the achievement of smart precision agriculture both in traditional method and controlled environment agriculture (CEA). The soil-less agriculture driven by data collected from sensors gives a more accurate and precise farming. In recent times, the number of new smart sensors manufactured and its usage has increased triple the times as before 2016. In agricultural industry, at present scenario shows a major decline in the shortage of labors and scarcity of water and this problem can be overcome by sensors which play a major role in automation which reduces the human efforts and save water. The common sensors used for CEA are pH sensor, DHT 11 (temperature and humidity sensor), Water level sensor, EC sensor. Many new sensors like ISE (ion selective electrode), leaf temperature sensors, plant sensors, dissolved oxygen/Carbon-di-oxide sensors, imaging sensors, ammonia sensors (Table 6) are further employed in hydroponics, aquaponics and aeroponics. System for more precise farming and to improve the quality of crop yield, minimize the usage of fertilizers and pesticides and improve the water use efficiency (Saiz-Rubio and Rovira-Más 2020).

5.1.1 pH sensors

The important parameter for growing crops in controlled environment depends on the nutrient solution for the growth of the plants. The pH of the nutrient solution is a definite variable which should be monitored continuously for the optimal growth of the plant. The pH of the solution give a detail of the acidic and basic nature of the fertigation water. The optimum range of pH maintained in the plant production is 5.5–6.5 (Domingues et al. 2012). pH of the nutrient solution is more sensitive to nutrient availability and uptake by plants, when the range of pH triggers out of the specified range, then it will affect the nutrient uptake and in turn affect the plant growth. pH sensor facilitates the monitoring of the pH ranges of the solution and sends data regarding addition or reduction of chemical concentrations in the nutrient solutions. If the recommended range of pH is not maintained then it may affect the growth and productivity of the crop, which needs to be altered and

Table 6 Most commonly used sensors in CEA and their specifications

Name of the sensors	Specifications	Purpose	Images
pH	Measuring range: 0–14 pH Temperature range: − 5 to + 95 °C Pressure range: 0–100 psig Maximum flow rate-10ft/s Sensitivity: 0.002 pH	It measures the hydrogen ions present in the nutrient solution.The optimal range of pH for the crops to grow lies between 5.5 and 6.5 depending on the types of crops	
Water level sensors	Supply voltage: 3.5 V to 20 V_{dc} Power consumption: 20 mA Operating temperature: − 40 to 85 °C Accuracy: ± 2%	It measures the level of water which is nutrient solution in the case of hydroponics.It uses the magnetic float which reads the level of water whether it is in the maximum level or minimum level in the storage tank	
Temperature and humidity sensor (DHT 11)	Humidity measuring range: 20–90%, temperature measuring range-0–50 °C, accuracy- ± 2%, Operating voltage: 3.3–5.5 V, resolution-1, and interchangeability	It has two sensors to measure temperature and humidity. The resistance between the Electrodes changes, whenever humidity changes occurs	
Electrical conductivity	Supply voltage: 3.6–15 V EC accuracy: 1% at 25 °C Temperature accuracy: 0.2 °C	It measures the total dissolved salts present in the solution, which influences a plant's ability to absorb water. EC is a indicator of water quality, salinity and fertilizer concentration. EC levels can help plant production and lead to more cost-effective use of plant inputs and less shrinkage	
Ion selective electrode	Nitrate ISE: measuring range (mol/L): 10^{-1} to 10^{-5} Temperature range (°C): 5–60 °C Connector: BNC	It measures the concentration of macronutrients presents in the fertigation solution. Therefore, by knowing the concentrations one can easily detect the deficiency of nutrients in the solution and can add the particular macronutrient to the solution	
Multispectral image sensors	Operating voltage: 12 V Operating temperature: 0–65 °C Control input: RS232 Pixel size: 4.655 × 4.65 micron	It detects the disease/pathogens in the plants and the identification of the types of the plants in real time	

maintained as optimum pH for improving the crop productivity (Bikram et al. 2019).

5.1.2 EC sensors

The Electrical Conductivity (EC) measures the total concentration of the salts in the nutrient solution. It calculates the amount of salinity (Silber and Bar-Tal 2008) present in the solution whose optimal range should be maintained between 1.5 and 2.5 dS m^{-1} for the growth of the plants. Example: for the cultivation of Lettuce recommended range of EC is 1.5 dS m^{-1} (Domingues et al. 2012). For most of the crops EC should be less than 1.5 dS/m and some of the salt tolerant crops can survive upto 2.5 dS m^{-1}. However the knowledge of pH and EC measurements are not sufficient for the farming as EC provides only the total strength of the concentration in the solution not exactly which ions present or absent in the solution (Bamsey et al. 2012). This drawback can be overcome by ion selective sensors which is to be discussed in the next section.

5.1.3 Ion selective sensors

The Ion selective electrodes (ISE) and ion selective field effect transistor (ISFET) (Neto et al., 2014) are used to measure the individual ion activity in the nutrient solution and not the concentration of the solution as in the case of EC sensors. The basic principle of ISE is to create an electrical potential equivalent to the activity of specific ions dissolved in the solution. ISE sensors measures the cations and anions activity in the roots and its surrounding environment. Each and every macronutrients and micronutrients are needed for the development of crops. If even a slight variation either excess or deficit of nutrients in the solution leads to toxicity or deficiency in the plants which may cause the several diseases to the plants and eventually destroy the plants**.** Being controlled environment, plant will be more susceptible for even small change in the concentration of these cations/anions. Visually it is very difficult to detect the deficiency of nutrients in the cases of CEA grown crops. Hence these sensors provide an excellent knowledge of plant ecology and biology. It also helps in the reduction of usage of fertilizers solution (Bamsey et al. 2012).

5.1.4 Leaf temperature sensors

In 1875, the concept of leaf temperature assessment was given by German E. Askenasy for analyzing the physiological activities of the plants (Yu et al. 2015). There are basically four types of sensors used for measuring the leaf temperature. (1) Thermal resistance. (2) Thermal sensor. (3) Infra-red temperature measurement. (4) Infra-red thermal imaging temperature measurement. Among all these the infra-red sensors are used for sensitive leaves like lettuce and Geranium. These methods can be implemented for other types of crops like tomato, cucumber, basil etc., which will help to understand any type of stress related to water, and ultimately improves the crop productivity.

The promising advantages of analyzing leaf temperature are

1. Guidance given for number of cycles of irrigation needed by the plants based on site-specific location.
2. Provides health status of the plants.
3. Identifying pathogen stress in the plants before detecting visually.
4. Selection of drought resistance plants
5. Analyze nutrient deficiency.
6. A non- destructive method to detect abiotic/ biotic stresses including diseases or pathogens.

The climatic factors is a variable factor which alters the leaf temperature dynamically with respect to the time. A continuous leaf monitoring is required based on leaf temperature and climatic variables (Rojo et al. 2016), and in such instances the IoT based sensors can play a major role for recording this parameter. The Fig. 7, shows a schematic model of IoT based root stress detection in lettuce. The real time monitoring using IoT based controller to find the internal change temperature of the lettuce was implemented using the infra red and light intensity sensors.

5.1.5 Dielectric sensors

In soil-less farming many types of growing substrates are used in the place of soil for nurturing the plants. There are different types of substrates available which was already discussed in the Sect. 2. The important characteristics of the growing medium considered is their moisture content. The moisture content is a prominent variable which determines the uptake of water by the roots of the plants. It is considered as necessary so as to manipulate the irrigation cycles, quantity of fertilizers, time taken for harvesting required by the plants grown under CEA (Stacheder et al. 2009). A sensor which is used for measuring the moisture content of the growing medium is known as Dielectric Sensors. It measures the water content of the medium by determining its dielectric properties or change in the weight of the substrate is known**.** The basic principle of Dielectric sensor is the growing medium acts as the dielectric material with the two electrodes placed between them. The corresponding electric voltage and the dielectric properties provides the detail of ionic conductivity and that is correlated with the moisture content of the medium used. Commonly it is called as Time Domain Reflectometry (TDR) method, but is costly, whereas capacitance

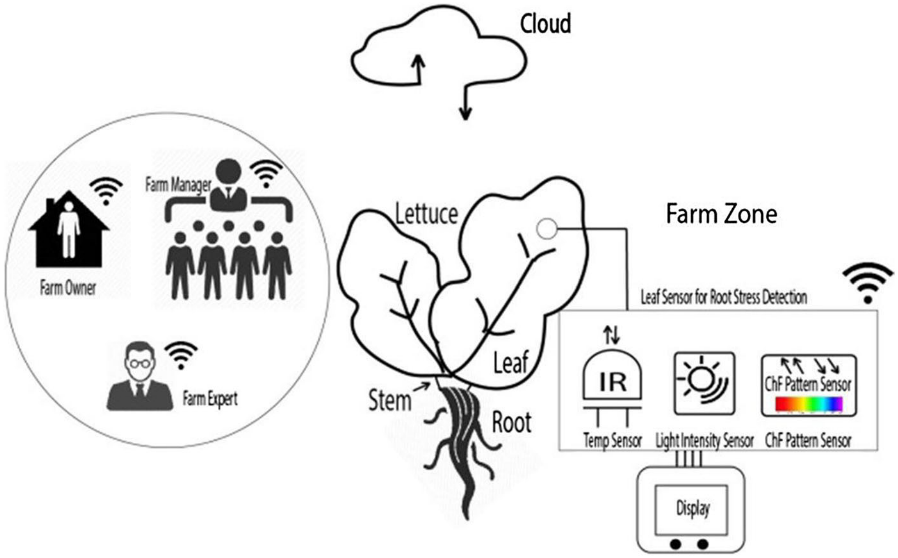


Fig. 7 Internet of things (IoT) based system for root stress detection in Lettuce using leaf temperature sensors

based probe sensors are also used, which are relatively lesser in cost.

5.1.6 Dissolved oxygen sensors

The amount of dissolved oxygen (DO) present in the irrigation water plays a vital role in the plant growth. In hydroponics, the plants roots should be supplied with the optimal amount of oxygen which reduces the cropping time. The temperature of the fertigation water also directly play a role in the amount of dissolved oxygen present in the water. The higher temperature above 35 °C reduces the leaf water content and induce some physiological disorders in the plants root system because higher the temperature, lower the dissolved oxygen in hydroponic solution followed by decreased respiration rate in the root system (Yumeina and Morimoto 2017). The basic management considered most important for the hydroponic system is the "Nutrient Management" which can be achieved not only by focusing on the concentration and composition of ions but also other conditions like "dissolved oxygen concentration, microbial activities and temperature"(Tsukagoshi and Shinohara 2020). All hydroponic cultures rely on a nutrient solution to deliver essential elements to the plant. In addition to the nutrients, the roots also need a steady supply of oxygen. When roots become anoxic they are unable to take up and transport metabolites to the rest of the plant body (Nguyen et al. 2016). From the Table 7, it is clearly observed that increase in temperature reduces the concentration of dissolved oxygen in the water. A decrease below 3 or 4 mg L^{-1} of dissolved oxygen, inhibits root growth and produces changes to a brown color, which can be considered as the first symptom of the oxygen lack (Trejo-Téllez and Gómez-Merino 2012). In an experiment, when tomato seedlings were grown in nutrient solutions containing dissolved oxygen (DO) concentration ranging from 5.3 to 40 mg L^{-1} for 4 weeks and observed for the plant growth. There were no visible symptoms observed on the leaves or stems in any of the treatments, and concluded that DO content was optimum for the growth of the tomato.

5.1.7 Imaging sensors

Current crop defense research focuses on the development of sensors for real-time near-range (proximal) sensing of crops and diseases. An essential step towards online applications will be the integration of different sensor techniques and image analysis combined with global positioning systems (GPS) and geographic information systems (GIS). Infrared thermograph is well optimized for disease-induced alteration detection using the images. The detection of many types of plant diseases, deficiency / toxicity of nutrients and the identification of the varieties of

Table 7 Oxygen solubility in water at various temperatures

Temperature (°C)	Solubility of oxygen in pure water (mg L^{-1})
15	10.09
25	8.25
35	6.97
45	5.94

plants can be easily achieved by using these types of modern image sensors which makes the task more comfortable in the area of precision agriculture for effectively managing the crop and taking a timely decision. This can be applied both in traditional geoponics (soil based cultivaton) and the emerging CEA (hydroponics/aquaponics/aeroponics). Optical Sensors are employed for the primary identification of disease focal points in the plots and the areas varying in the severity of diseases in the plant production factories (Mahlein et al. 2012). Some of the different types of image sensors which are popular in agriculture domain are RGB (Red–Green–Blue) imaging sensors, spectral imaging sensors, thermal imaging sensors and fluorescent imaging sensors (Mahlein et al. 2012).

5.1.8 Light intensity sensors

The plants growing in the soil-less environment may or may not be exposed in sunlight. If the plants are grown in a closed environment, the artificial lights promotes the effective growth of the plants and the light intensity should be in a optimal range in order to maximize the economic benefit of yielding high quantity and quality of plants in the plant production factories (Kang et al. 2013). Light intensity affects the photosynthetic behavior, antioxidants capacity and physiological characteristics of the plants. In the plant factories, mostly predominantly used LEDs (artificial light) are red, blue and white colour. A photosynthetically active radiation (PAR) quantum light sensor Li-COR Li-190 was used to conduct an experiment with different light intensities and the corresponding changes in the plants were observed. These kind of studies helps to identify the suitable light intensity essential for optimum growth of the plants (Harun et al. 2019). Optimal range of light intensity of wheat seedlings was 600 μmol m^{-2} s^{-1} based on the chlorophyll content and water use efficiency (Yi et al. 2020).

5.2 Development of current trends in smart precision CEA

The promising improvement in agriculture is being improved day by day as the population increases and the researchers are fond of implementing the emerging technologies like Internet of Things (IoT), Artificial Intelligence (AI), Block Chain, Big data in agriculture domain to increase the crop production (quantity) and the quality of food to consume. These techniques are domesticated also for the CEA i.e., Soilless agriculture for the automation of the system and for the optimal growth of the plants. It is forecasted that nearly 6 trillion US Dollars will be spent on IoT solutions in the next five years. In India also hydroponics is titled as the “Tomorrow’s Indian Agriculture” so investing the technologies in future trending farming helps the farmers and all the individuals to gain knowledge about these farming methods and Government of India is also encouraging the IoT ecosystem by providing lot of credit facilities to the investors and enabling the start ups(Sharma et al. 2019).

5.2.1 Role of internet of things (IoT), machine learning and artificial intelligence in CEA

The production of food is affected by many factors which includes weather parameters such as temperature rise of the environment, alteration in relative humidity, spatial and temporal variability in rainfall, non availability of water in time the particular region, soil health etc., The only option to overcome this existing problem in food production is to accommodate many methods of farming rather than depending on conventional agriculture (geoponics). The future trends in farming can be enhanced by domesticating Internet of Things (IoT) artificial intelligence (AI) and machine learning (ML) according to the need in the methods of farming such as hydroponics, aquaponics and aeroponics. The traditional soilless farming have many limitations such as insufficient data sharing, huge labour work, absence of data centralization. These drawbacks can be overcome by implementing Internet of Things (IoT) concept in controlled environment agriculture. The Fig. 8 shows the summarization of smart Controlled Environment Agriculture (CEA) and Fig. 9 shows the general terms used in CEA.

5.2.1.1 Machine learning based IoT in CEA Machine learning (ML) may be regarded as a novel process for machines simulating learning activitiesbased on the input data provided, gaining new knowledge, improve the performance continuously based on data analytics, and achieve specific target of crop productivity. ML has been very good in the recent years and introduced in CEA by using successful in algorithms, theories and combined applications and other farming methods to reduce cultivation costs and increase the crop yield. Machine learning is a data analytics technique that learn from experience directly from the background data without relying on a predetermined equation as a regression models. Machine learning (ML) and Artificial Intelligence (AI) models are capable of disentangling the effects of co-linear variables and analyzing hierarchical and nonlinear relationships between the independent variables and the dependent variable, and usually result in better performance compared with conventional linear regression models. The algorithms used in ML adaptively improve their performance as the number of samples available for learning increases compare to other predictive models and this ML models process without a predetermined set of rules and regulations. Analyzing of the quality and purity of the products, their life time and product freshness can be done by using Machine learning algorithm. Machine Learning algorithms such as naive bayes, Support Vector Machine (SVM), K-nearest neighbor, discriminant analysis, K-means clustering, fuzzy clustering, artificial neural networks (ANN), decision making, deep learning and Gaussian mixture models. Hybrid ML and IoT gives an optimized and controlled environment for plant management system. ML applications on soilless farms can be widely used in areas such as disease detection, irrigation planning, crop detection, weather forecasting and crop quality.

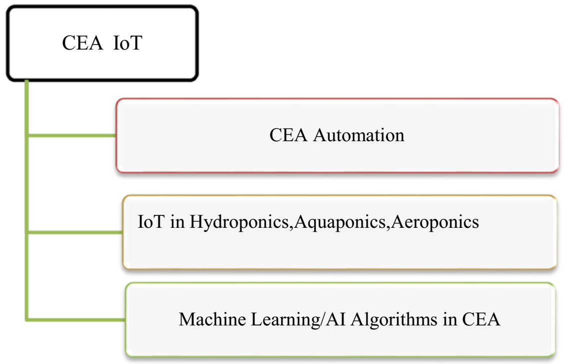


Fig. 8 Summarization of smart CEA system

From a monitoring and control perspective, greater precision is required in this CEA/smart farming. Many current works on designing and evaluating monitoring and control systems for temperature and humidity adjustment, CO_2 concentration, moisture of the media, nutrient content and other environmental parameters by using Internet of Things, are being developed as technological and economic revolution (Fig. 10). It is suggested that the environmental conditions should be regulated for a particular form of crops through IoT, Sensors and Actuators. The prediction analysis and conditions can be performed by machine learning models such as Artificial Neural network model and IoT Cloud set up, which will enhance the crop production. ML blended with IoT can be applied for the following:

a. Management of crop production

ML-based productivity mapping could be applied via GPS-connected productivity monitoring in plant factory based on the data collected over the IoT network. The data collected which reveals the details of the production can be mapped according to the types of growth medium used, nutrients supplied, environmental settings etc. Besides that, ML systems can be used together with IoT to predict and improve agricultural yields. In general, the human experts are involved for decision making in the growing of plants, and most of the times farmers predictions are failed, because of the extreme climate variability and lack of awareness about modern technologies. Machine learning algorithm eliminates the human experts and the machines can give the knowledge of the plants to be grown in the factory i.e., which medium can be used for which plants, the nutrient solution composition for different plants, how plants can be managed if any

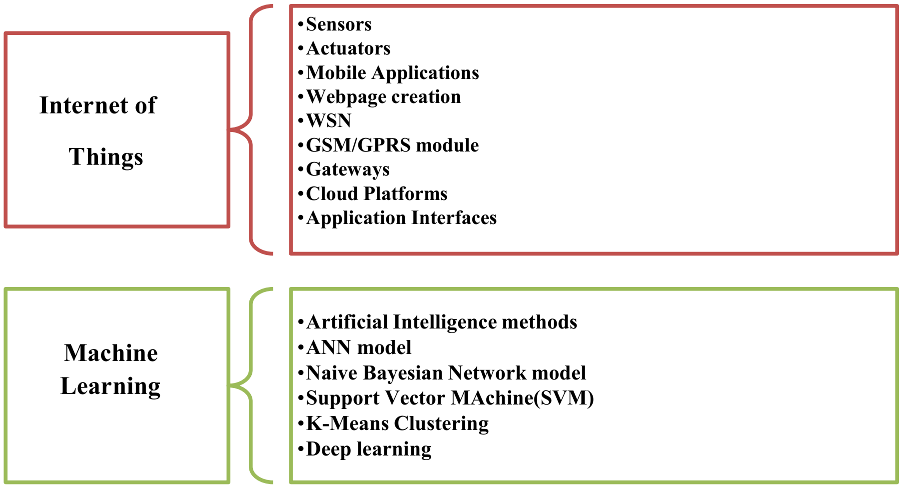


Fig. 9 General terms used in IoT, ML, AI inflated CEA

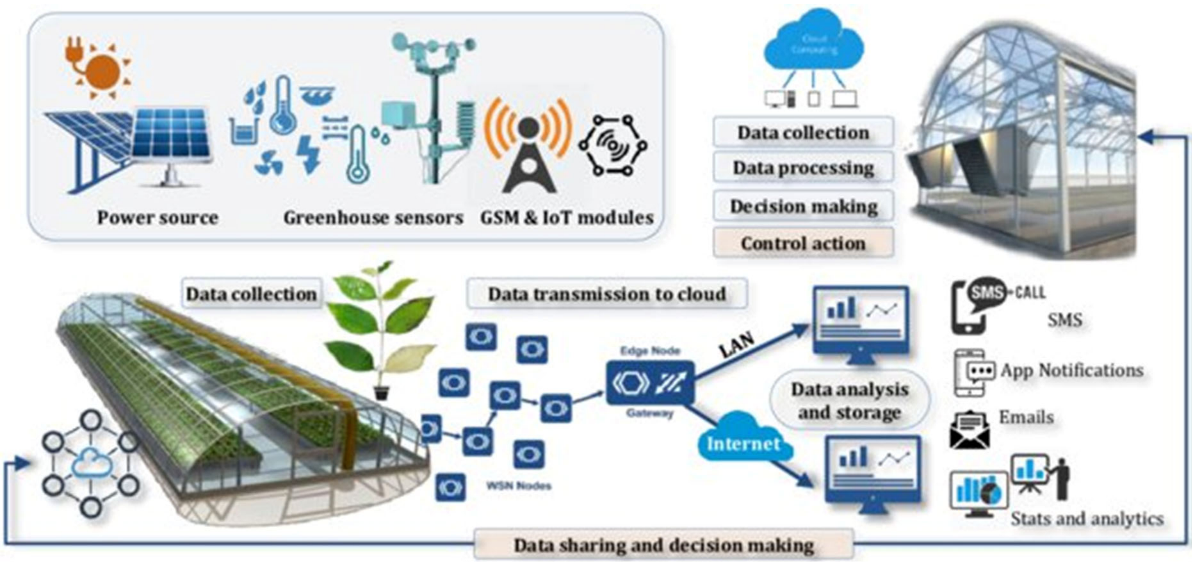


Fig. 10 An internet of things (IoT) based controlled environment agriculture (CEA)

biotic/abiotic stress happens etc., which in turn increases the yield of the plants.

b. Management of diseases in palnts

Hybrid ML and IoT can be applied for identification and management of diseases in CEA. ML methods helps to identify which diseases has been affected the plant based on the images stored in the database by using the technique of similarity analysis and suggest suitable management strategies, estimates the appropriate amount of nutrients needed to protect crops from the infections and reduce the death of the plants. ML based system assists the rate at which the nutrient solution should be circulated accurately and identify the disease and providing accurate fertigation so that the water and nutrient usage is reduced to a great extent. Based on the images stored in the database for pest and diseases infestation, nutrient deficiency and toxicity can be identified and even the dosage of nutrients/agrochemicals can be planned according to the severity of the infestation and need of the plant.

c. Management of water quality

Many systems have implemented on controlling water supply for a CEA as well as analyzing the water quality using ML. The development of intelligent systems that detects the nutrients, Salinity, pH, Electrical conductivity and environmental conditions using IoT sensors helps to a great improvement in managing the water quality. Additionally, hybrid machine learning and IoT can be used to adjust the optimum water temperature needed for the healthy growth of the plants in a smart way.

5.3 Work done on smart controlled environment agriculture with recent technologies

Work done on controlled environment agriculture (CEA) with recent technologies are presented in Table 8. Alipio et al. (2019) proposed an intelligent hydroponics system for automating the process of growing crops through Bayesian Network (BN). In this work, the farm parameters like humidity, water temperature, light intensity, electrical conductivity and pH were controlled and monitored using actuators and sensors. Further, these collected sensor values were used for BN construction through which optimum value present in every actuator was predicted and classified for intelligently controlling hydroponics system. Results demonstrated that fluctuations with respect to sensor values in intelligent control were reduced through BN. The proposed technique attained 84.53% prediction accuracy and improved the yield of the plants (Table 9).

Srivani and Manjula (2019) presented a review on distinct hydroponic methods. Further, several environmental and physical variables affecting plant growth were reviewed for efficient and sustainable farming system. Furthermore, techniques for controlling, automating and monitoring parameters essential for optimal growth of plants were highlighted. Moreover, prediction models utilizing ML methods were proposed for analyzing the growth dynamics of plants. This work emphasized on various challenges encountered during smart farming for enhancing productivity and reducing energy inputs.

Khudoyberdiev et al. (2020) presented an optimization method for adequate energy consumption using fuzzy logic for hydroponics system. In this work, humidity and water level sensors were used for determining hydroponic environment conditions. Furthermore, by controlling operational duration and working level of actuators, humidity and optimal water solution were achieved in hydroponics with effective energy consumption. Results illustrated that this method exhibited better performance by minimizing the energy consumption. Further the need for implementing this method in complex environments like greenhouse, fish farm, etc. was suggested.

Wongpatikaseree et al. (2018) presented ML techniques for determining freshness of plants grown in hydroponic environments. In this work, ML and image processing methods were employed for distinguishing withered and fresh vegetables. Comparison of Deep Neural Network (DNN) and three conventional ML techniques like multi-layer perception, naive bayes, and decision tree was presented. Further, conventional ML techniques were used for extracting features and raw images were fed as input to DNN. Results illustrated that decision tree exhibited better performance achieving 98.12% test accuracy. However, DNN exhibited poor performance due to smaller training dataset. The need of further improvement of DNN performance through addition of dropout layers or data augmentation was suggested in future analysis.

Adidrana and Surantha (2019) proposed a method for controlling nutrients in hydroponics using K-Nearest Neighbor (KNN) and IoT. In this work, nutrient temperature, overall dissolved solids and pH values in nutrient film were measured using sensors. Lettuce vegetable was used for analysis and KNN was applied for classifying nutrient conditions. Furthermore, the prediction results were fed to microcontroller for activating the nutrient actuators. Results demonstrated that 93.3% accuracy was achieved by KNN method. Furthermore, the need of conducting more experiments using huge amount of data in different nutrient conditions for boosting system accuracy was suggested for future analysis.

Changmai et al. (2018) presented a method for intelligent hydroponic farming using IoT. for lettuce. The proposed method monitored the environment for lettuce growth and adjusted air humidity, temperature and nutrient solution depending on the situation intelligently. Results illustrated that the lettuce grown using this method had 13.9% greater stem diameter, 17.2% more leaves and 36.59% greater weight compared to those grown in regular farm. Moreover, this method produced 8.24% better nitrate content.

Gertphol et al. (2018) proposed models for predicting the quality of lettuce from IoT dependent

Table 8 Research works carried out in controlled environmental agriculture (CEA)

Authors	Techniques for smart farming	Precision soilless agriculture/crops involved	Method
Herman et al. (2019)	IoT and fuzzy logic	Smart control and monitoring of water need and nutrients in Boychok and lettuce plants	Hydroponics
Chang (2019)	Plant talk, an Intelligent IoT based monitoring	Smart phone-controlled plant care system is developed for Devil's Ivy	Hydroponics
Marques et al. (2019)	iHydroIoT, IoT monitoring system for hydroponics	This system offers a feasibility method to monitor hydroponic agriculture systems in real-time and to guarantee the conditions for increased productivity	Hydroponics
Harun et al. (2019)	IoT,LED light spectrum	IoT monitoring system for monitoring the growth of Brassica Chinensis	Indoor Farming
Foughali et al. (2019)	Cloud-IoT, BlightMOTE sensor	Decision support system for pest prevention of late blight disease in potato	Hydroponics
Mehra et al. (2018)	IoT, deep artificial neural network machine learning algorithm	Intelligent monitoring by using machine learning algorithm for tomato plants	Hydroponics
Francis et al. (2018)	Iot, Zigbee	Smart Aeroponic system	Aeroponics
Tembe et al. (2018)	IoT, Arduino Mega2560, sensors	Red and blue LED spectrum were used to find the difference in chlorophyll pigment in plants	Hydroponics
Zaini et al. (2018)	IoT, sensors, ammonia sensor MQ-137	Comparing pakcoy vegetable growth with the hydroponics and NFT aquaponics	NFT aquaponic
Kerns and Lee (2017)	IoT,wireless Sensor,Mobileinterface,Rasperry Pi0	Automation of aeroponic system to measure and control the environmental factors	Aeroponics
Alipio et al. (2017)	IoT,Bayesian Network	Predictive analysis by using bayesian network for monitoring and automisation of Hydroponic farm	Hydroponics
Crisnapati et al. (2017)	Iot,RaspberryPi,Arduino UNO	Green energy i.e., Solar energy was used in the hommons	NFT hydroponic
Laksono et al. (2014)	Wireless sensor and actuator network (WSAN) for the control, monitoring, and conditioning of growing chambers inside of a greenhouse	G0 potato seed cultivation in aerponicmethos were implemented by wireless sensor and actuator network (WSAN)	Aeroponics

Table 9 Comparison of Gain Difference between manual and smart controlled hydroponic system

Parameters	Manual control interface	Automatic control interface	Gain difference (%)
Number of leaves developed	10	14	40
Number of crops yielded	6	10	66.67
Weight (g)	0.35	0.44	27.25

hydroponic farm. IoT technologies were used for controlling real-time farm's operation and for gathering environmental data. Features used for analysis included humidity, light intensity, temperature. Furthermore, leaf area, total weight and nitrate content were considered as target variables. Models were developed using various linear regression schemes and ML techniques. However, the results were not satisfactory as plant's growth measurement involved few errors in lettuce's height, stem's width. Moreover, high temperature and more sunlight led to unfolding of plants and withering of lettuce's leaf. Authors suggested that further analysis and fine tuning is required for more accurate results. Nurhasan et al. (2018)

presented IoT implementation in monitoring water circulation of hydroponic plants. In this work, data of elements pertaining to plant growth were obtained through sensors connected using Raspberry pi. Further, data pertaining to pH, water level, humidity and temperature in hydroponic reservoir were displayed on website during monitoring process. Furthermore, humidity and temperature were considered to be the control parameters for water circulation and were processed by fuzzy sugeno technique. Results illustrated that this method intelligently controlled water circulation and monitored elements necessary for plant growth in real-time and helped to improve the crop productivity Adhau et al. (2017) proposed an intelligent hydroponic system. In this work, real-time information was imported from AVR microcontroller and Labview for automating and controlling the process and for sending information over network. The control was provided by tuning conventional PID controller. Moreover, the entire set-up was completely automated and self-controlled without the necessity of human intervention. Additionally, system was equipped with user-friendly interface for easy data reading and control. This system was cost-effective due to the use of microcontroller dependent DAQ card.

Jaiswal et al. (2019) proposed a scheme for completely automated greenhouse using ML and IoT. In this work, distinct parameters influencing crop productivity were controlled, monitored and coordinated through arduino and raspberry pi. Furthermore, IoT facilitated real-time information gathering from automated greenhouse. This scheme achieved 100% success rate through maintaining appropriate parameters in suitable range regardless of outdoor environment. Moreover, through this method it is possible to remotely control and monitor the factors, which directly influences the crop growth. The security feature employed in this work prevented unauthorized entry thereby providing desirable system operation. However, authors have suggested the need for analyzing the relation between different sensors for reducing the hardware complexity and sensors utilized thereby enhancing cost efficiencyand improving the profitability.

Ruscio et al. (2019) presented a low-cost supervision method for hydroponic farming. In this work, sensor information pertaining to air temperature, pressure, water, light intensity, water level, humidity, electric conductivity and pH were collected without human intervention. Furthermore, the sensor information gathered was utilized for decision making by system and this could be assessed through web interface. Moreover, the system was designed such that additional actuators and sensors could be added if required. This method was used for automating few maintenance activities and for optimizing farm set-up quantitatively.

Sisyanto and Kurniawan (2017) proposed a technique for hydroponic farming using ML and IoT technologies to monitor, significant parameters like electrical conductivity, nutrient temperature, room temperature, pH, light intensity and humidity online through telegram messenger. Raspberry Pi3 connected with sensor modules like LDR, pH, DHT11 was used for prototype designing. However, this technique failed to exhibit expected performance as it required additional data from relays for increasing moisture and required internet connection for monitoring crops.

Palande et al. (2018) proposed an intelligent hydroponic system with IoT and in this work, the system was designed such that it can function without the need of outside climate and is capable of growing common vegetables and plants. Moreover, sensors and microcontrollers were used for system automation and to maintain minimum human interventionfor facilitating remote control and monitoring and for enhancing reliability, IoT network was established. However, planting seedlings and initial parameter setting was required to be performed by users by their perception. Thus, need for exploring techniques that can completely automate the process was suggested in future analysis.

Marques et al.(2019) proposed an approach for hydroponics using IoT and in this work, data was gathered and analyzed using mobile application. The gathered data was stored in a visualization and data analytics library known as plotly. Similar to other studies, here also the system is enabled to monitor the temporal variations in temperature, ECy, CO_2, light, water level, pH and humidity. Furthermore, real-time messages were sent in order to alert farm manager while farm conditions were unfavorable. Thus, this approach helped in analyzing hydroponics condition and appropriate decision making thereby increasing the yield. Compared to traditional methods this approach helped in enhancing productivity by sending timely notifications to farm manager and by establishing and monitoring suitable conditions required for crop growth. However, this approach had few shortcomings, which were also discussed in the paper. It required further validation for enhancing accuracy and system calibration. Additionally, quality control and quality assurance were also needs to be incorporated for tracing the product quality. Moreover, hardware and software improvements for customizing this system to particular laboratory tests through thermo graphic experiments are also needed.

Namgyel et al. (2018) proposed IoT dependent hydroponics for lettuce farmingand this intelligent hydroponic system was developed using LED lighting method facilitated by IoT. Crops were hydroponically grown under several treatments. Further, morphological parameters were characterized and measured. It was noted that plants treated using blue LEDs led to larger accumulation of pigment content, leaf density, leaf area and biomass. Software applications and IoT components were incorporated for sending and displaying system data online. Moreover, real-time information access and display facilitated by IoT in this work was successful.

An arduino dependent intelligent data acquisition method was developed for an intelligent data acquisition technique for hydroponics system Tagle et al. (2019). The information gathered through sensors was stored in SD card presenting variations in environmental conditions intervening in system thereby helping in monitoring system. Results demonstrated the hydroponic tower performance with respect to humidity, temperature, water level, air temperature, pH and light intensity. Moreover, the distinct parameters measured through sensors presented less error percentage. However, the need of exploring techniques for further improvement was highlighted in this study.

Van et al. (2019) presented a smart phone-controlled plant care system named as Plant talk and it is an IoT based intelligent hydroponic plant factory. This allows sharing of IoT devices among applications and this has a both hydroponic plant box and a smart aquarium tank. An off-shelf IoT devices can be included or changed as per the flexibility of users. The knowledge can be easily generated to manipulate the raw data from the sensors to push the actuators to display interesting results so that the users know their plants better and accordingly device their management options.

The effect of different light emitting diodes (LED) intensity on optimal growth and development of different crops was studied earlier in controlled environment ecosystems. In addition to light sensors, for measuring optimum temperature, humidity and Carbon-di-oxide different sensors were also mounted. These light sensors and other actuator controller were used to detect the light intensities and to control the intensities respectively. Artificial light source for plant growth was provided by Light Emitting Diodes. The artificial indoor plant system performance were analysed by two Zigbee and WiFi networks. The sensors data were captured by the IoT device and were sent over to the WiFi network. Cloud database called JSON protocol was used for structuring the data and organization of data before sending to the database server which is a internet based server. Light treatments were carried at different intervals of light intensities and durations. Effects of different light treatments on quantity of leaves, height of the stem, photosynthesis rate, water use efficiency, chlorophyll content, leaf transpiration rate, leaf stomata conductance were experimented and optimal light intensity which influences were identified.

Foughali et al. (2019) proposed a Cloud-IoT based decision support system (DSS) for late blight in potato was designed. This system allows to record the live happening in the plant factory, which will help to monitor the seasonal changes and prevention against the late blight diseases in potato. Thus Ulrich model was adopted to observe time intervals or pest attacks on potato crops. Input for the model were humidity and temperature in crops and output as value called "risk value". BlighteMote sensor design consists of NodeMCU and DHT11 sensor. If the risk value reaches a threshold value, a coding has been done to send a notification to the farmer to see and to initialize the phase of curing the late blight disease in the potato crops.

Mehra et al. (2018) proposed a deep neural network (DNN) system to create a smart IoT hydroponics device for *Solanum lycopersicum* (tomato). Sensors used are water level sensor pH, light intensity, temperature and humidity. The data were captured and sent to the microcontroller. Fitting model of neural network which was educated in the cloud on the data collection which were gathered. The suitable model in the Raspberry Pi three make an smart choice to give arduino the output recommendations to activate the correct water pumping control system, turn the lights on, turn the fan on and so on. The collection of data were received by Raspberry Pi three. Storage and monitoring of data was done on the cloud based server. A special open source called Tensor Flow was used to program artificial neural network programs.

Francis et al. (2018) devised an automated aeroponic system by controlling the humidity, temperature, and light cycles automatically. A centre HUB was used in which all the sensors communicate and then the data were send to the cloud server. DHT-11 Humidity and Temperature Sensor, analog pH sensor were the major sensors used. The IoT gateway, Raspberry Pi 3 connects the each arduino-based sensor nodes with the cloud. Communication medium between the each sensor nodes was served by Zigbee module.

Tembe et al. (2018) implemented the automated hydroponics system based on IoT and smart phone for planting hydroponic vegetables. Sensor data were measured and displayed through mobile phone to manage and control the sensor devices. This system used sensors like temperature, humidity, light, ultrasonic sensor module and water level sensor. The application system automatically mix the selected solution to obtain the desired value and also collects data about the amount of solution mixed at the time of planting. Arduino Mega 2560 was used as an interface for all the sensors. The cost of growing vegetables and the profit of each vegetable to make the decision to grow were also estimated. Red and Blue LED strips were used as a light source for the growth chamber.

Zaini et al. (2018) designed and implemented Internet of Things (IoT) and smartphone mobile application for monitoring and controlling the NFT Aquaponic system for pakcoy (Brassica rapa) vegetables. Controlling the level of ammonia, temperature, pH, and nutrients were done. This system maintains the nutrition and stabilizes the water condition. Central processing unit (CPU), a water level sensor, temperature sensor, pH sensor, ammonia gas sensor, ultrasonic sensors were used. Actuators were used to on/off peristaltic motor of H_3PO_4 and peristaltic motor of KOH, servo motor for feeding fish. Plant growth were monitored on aquaponic NFT and ordinary hydroponics and the parameters such as plant growth, the leaf growth, the root growth, and the plant height and weight ratio were compared between these two systems and found that IoT based system is better.

In another study, a mobile interface was designed and linked with sensors using IoT so that a user can easily check every sensor's value in each aeroponics system through a service platform (Kerns and Lee 2017). The main Components used were mobile interface, service platform and IoT devices with each a sensor. This service platform stores the sensor's data such as temperature, humidity, pH balance, nutrient levels. HTML5, CSS Flexbox, Javascript, and SVG are used as service platform Raspberry PI Zero, an IoT device was used to gather information (pH balance, temperature, and humidity) from the sensors and to control a water pump and dosing pump to add nutrients and water, as per the crop requirement.

A NFT hydroponic farm management system monitoring water temperature, water level, higher densities of nutrient solution were created and the acidity of a nutrient solution using sensors were collected and connected to the microcontroller via a website (Crisnapati et al. 2017). Hydroponic farming management system allows the user to perform control and monitor from a distance. In addition, in this method, green energy i.e., Solar energy concept was used. All the devices were turned on by using the Solar cell. The sensors used were ultrasonic sensors, pH, temperature, and the EC.

Laksono et al. (2014) proposed a wireless sensor and actuator network based on ZigBee, a wireless protocol were implemented for monitoring and controlling of green house growing chamber of Potato Seeds in a Aeroponic System. The sensors used were temperature sensor, pH sensor and humidity sensor. The basic actuators used were water pump, nutrient pump, mist maker, blowers, disposal valve. ATMEGA128 microcontroller was used as the control system for sensors and actuators. The ZigBee parent node was configured with a microcontroller to facilitate message coding, and then connected to a GSM module to send the coded message via GSM network to the awaiting database server.

The comparison of manual and automatic control interface for operating actuators was done by Alipio et al. (2019) and the gain difference of the crops yielded were tabulated. The Table 9 shows the gain difference of the crops produced by manual control and automatic control by bayesian network. This work confirmed the influence of automation and how the productivity increases by using Bayesian network, a Machine learning algorithm was understood.

The traditional method of hydroponics and smart controlled hydroponics were compared and the results showed that significant improvement in the production of the crops (Lettuce, Boy Chok) by implementing IoT and smart sensors in the system (Herman et al. 2015). The late blight risk value is calculated and according to the risk value a threshold was set in the user interface and a alert is given to the farm manager for the human intervention (Foughali et al. 2019). The plant productivity is compared between controlled NFT aquaponic and uncontrolled NFT aquaponic System (Tembe et al. 2018). The experimental set up was done and the comparison of traditional instruments such as infra red thermometer, Electrical pH meter, temperature measurement, pH measurement, ruler which is used for height measurement respectively was compared with Internet of Things such as Temperature sensor, pH Sensor and height sensor for accuracy test and found that the IoT based control system performs better than the traditional one.

Crisnapati et al. (2017) created the webpage for hydroponic monitoring system. A solar panel set up was done which gives supply to the electronic devices which is used in the NFT farming such as sensors, actuators etc., which reduces the power consumption of the overall system. Laksono et al. (2014), created a webpage page to obtain the data of light intensity sensor, pH sensor and the activation of mist maker. A GSM/GPRS module was implemented to communicate the data to the internet from the aeroponic farming system.

6 Future scope

Some of the major problems encountered in traditional method of agriculture are soil borne pathogens, high usage of chemical fertilizers, root diseases in plants, pest infestation, labour availability, water scarcity etc. Soil health degradation is prominent phenomena observed over the years and decline in soil fertility is not noticed like other natural disasters such as floods, drought etc., since this is a slow natural process. However, the decline in crop productivity confirms the degradation of soil fertility and making most of the fertile lands into marginal and sub marginal lands. These problems can be overcome by CEA or soil-less agriculture which can be used for growing plants in the same area for long years as it does not need any specific type of land or soil. The Soil-less agriculture is the future of agriculture sector. Declining of land available for food production makes the advance method of farming more important. Due to the increase in world population nearly 9.2 billion by 2050, food production should be increased to a great extent which is possible to adopt new method like hydroponics, aeroponics along with the traditional method of soil based agriculture. Looking into the positive side of these techniques, National Astronautical Space Administration (NASA), has set a target of fulfilling the space exploration dream and moving to Mars and in these explorations, this CEA will help to provide food to the space astronauts. Growing plants in an enclosed environment, are the most productive and reliable way of getting food, and plants are an ideal food source for astronauts; they extract carbon dioxide from the oxygen inside the spacecraft.

7 Research gaps

Strengths, weakness, opportunities and threats (SWOT) associated with CEA is explained in Fig. 11. Based on the review of existing literature and in depth analysis confirmed that there are few research gaps, which needs to be addressed in coming years to ensure the food security.

1. Different types of crops needs different composition of nutrients. A slight variation in the ion concentration of the solution may adversely affect the growth of the plants. Thus, a perfect optimization of nutrients for different types of crops is needed.
2. Automation of preparing of nutrient solution for different stages of plant growth and its requirement needs to be evolved.
3. Analyzing of diseases in the plants using leaf temperature in the hydroponic farms are some of the research gaps which are to be explored in future so as to improve and get higher yield of

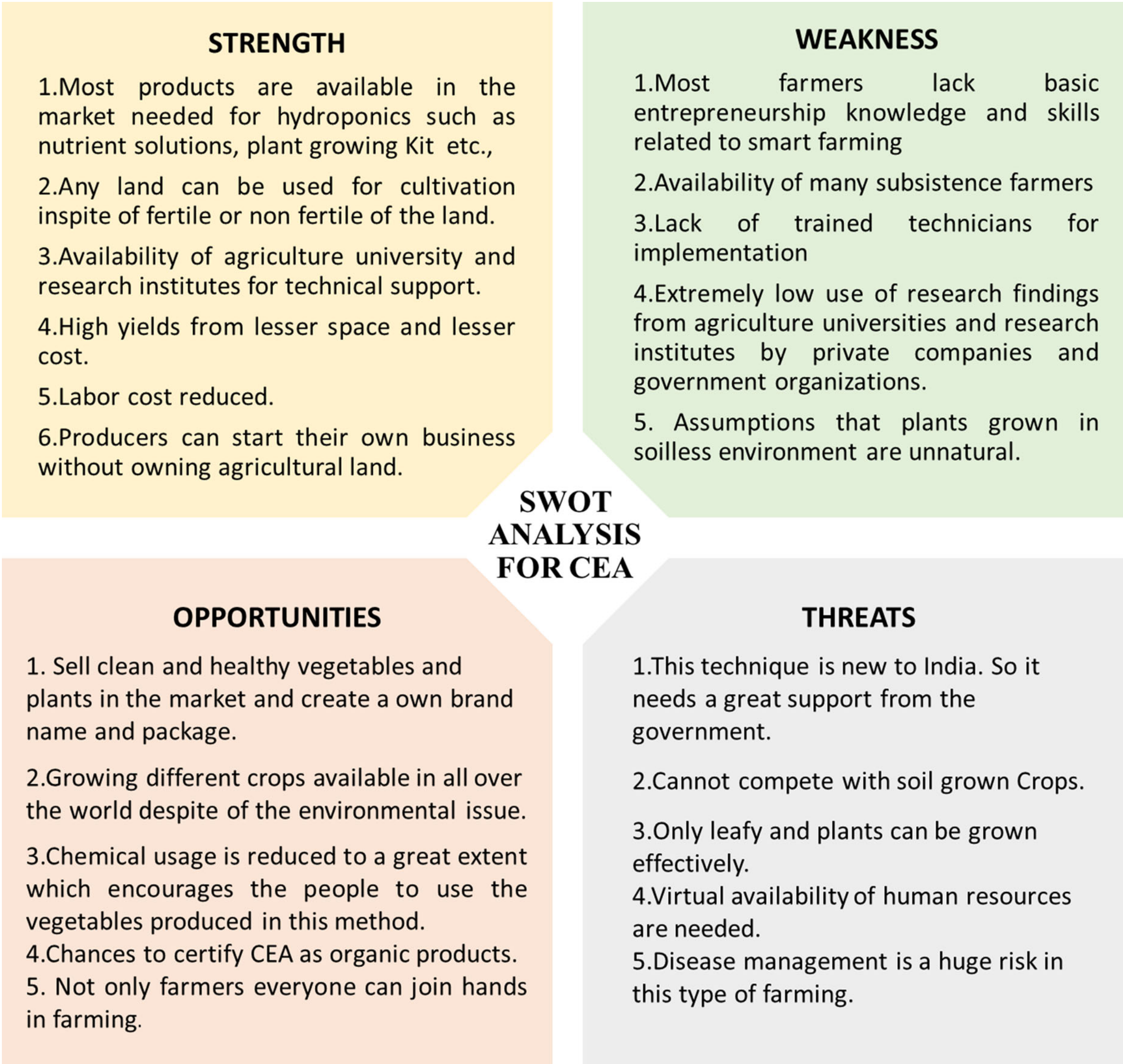


Fig. 11 Strengths, weakness, opportunities and thresats (SWOT) analysis for controlled environmental agriculture

production. Thus, making farming easy for everyone and grow plant without the need of soil.

4. Detection of diseases needs some special sensors and image processing technique may also be used to find the affected plants and to remove it before it ruins every plants in the vertical farming in hydroponics.
5. The data security is the main concern in the IoT. Researchers are focusing more on the date security problem to built up the agriculture for the trendy generation.

The new emerging technology is "Bioponics" which includes usage of only organic nutrient solutions which comes from the wastages of animals like fishes, vegetable matters wastages etc., This does not include any lab synthesized chemical nutrition solution. Thus, increasing the quality of crops and a chemical free food for our next generation. Bioponics is a hybrid of hydroponics and biofertilizers which is getting attracted by farmers now-a-days. The area to be explored is implementing "Smart Bioponics Systems" in future using new emerging technologies like machine learning (neural networks, genetic algorithm etc.,) and finally IoT and cloud to collect the data for precision agriculture. Various technologies like IoT, Machine learning, Deep learning, Neural networks. Blockchain techniques can be combined to form a dependent intelligent hydroponic systems with improved intelligence and create a controlled environment for better crop quality. The potential for early infection before the visible symptoms has not been fully exploited.

8 Conclusions

In this paper, the recent works that have done in the field of soil-less agriculture or controlled environment agriculture using Internet of Things have been discussed. The scarcity of fertile land and water shortage leads to the new development of methods in the agriculture line, for growing plants and feeding the huge population which are becoming popular nowadays in a developing country like India. This is one of the method which is gaining its popularity for growing herbal plants like brahmi, ashwaganda etc., which are more useful for ayurvedic medicines. In a apartment culture, the plants growing become a tedious process as the process needs the traditional method of soil and fertilizers. So, the advantage comes here is that in future every individual can grow their own vegetables and fruits for their personal needs without the search of good soil. The technology like Iot, Sensors, Actuators, Smart Phone applications makes the soilless farming even more easy so that no need of special knowledge is needed for farming for a normal individual. Thus, everyone can do farming without soil and with less knowledge when compared to the traditional method of agriculture.

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Availability of data and materials All the data related to the manuscript is presented.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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