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Hydroponic agriculture in controlled environment: A review

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Abstract

World's population is rapidly increasing result in urbanization, decrease in land holdings, low crop productivity, polluting water, air and soil while food demand has increased. To feed increased population new innovate techniques are important for the protecting environment and produce more in a limited area. Today protected cultivation in greenhouses is one of the most intensive farming technique in the world. Mostly horticultural crops are grown under controlled environment in a greenhouse where the variables such as temperature, humidity, light, soil, water, fertilizers etc. are manipulated to achieve maximum output and continuous supply during off-season. The use of latest technologies with high levels of output in greenhouses is of utmost importance to produce healthy, pest and damage-free plants. Greenhouse provides control environment than growing in the field. Therefore by keeping in view the profitability of the farmer, health of the consumer and sustainability of the environment hydroponic system in the greenhouse should be adopted for improving the cultivation process of crops.

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Introduction

Controlled environment is vital for the year round off-season crops production. To attain controlled environment greenhouses are usually constructed and managed by using innovative technologies like hydroponic. Greenhouses provide better control of environment by preventing crop from pest and diseases. Due to the increase in diseases of crops in traditional agriculture hydroponic agriculture plays a vital role to provide better yield of crop.

Due to increase in population there is much need to adopt innovative techniques for the cultivation of horticultural crops. Hydroponic agriculture is best option when compared to other techniques because in this system there is rapid growth of crops in a short period as compared to traditional agriculture. There is no risk of diseases in hydroponic agriculture due to controlled environment.

Greenhouse Structure for Hydroponic Agriculture

A greenhouse is a well-designed structure used for the cultivation and protection of plants in a controlled environment. Greenhouse is covered with plastic sheet which protect it from the rain. Greenhouse also provides most favorable conditions for the better growth of crops and there is no effect of external environment. Greenhouse consist of side vents and total plastic enclosure. (Ponce *et al.*, 2014).

The increasing requirements for land and water can be managed by land and water management systems. This is only possible by using efficient technologies and high efficiency irrigation systems. Over the last 50 years, world agriculture production has increased from 2.5-3 times, while only 12% of the cultivated area (permanent cropland and arable land) increases. Irrigated areas increases more than 40% of food production. Due to these outcomes precision agriculture techniques like hydroponic agriculture using a greenhouse system are very important for marketing of all kinds of food and economic crops (FAO, 2012b).

Protected cultivation in controlled environment is the most contemporary approach to produce mainly, horticultural crops qualitatively and quantitatively and has spread extensively the world over in the last few decades. Protected cultivation also known as controlled environment agriculture (CEA) is highly productive, conservative of water and land and also protective of the environment (Jensen, 2002).

Greenhouse production using hydroponic system is useful method because in this system crop can be grown in every season. In winter and spring growing seasons glass house effect of shading on production and nutritional quality of crop under mediterranean climate conditions was of great importance. In both seasons, plants were cultivated hydroponically under four different levels of photo synthetically active radiation intensities (26, 47, 73 and 100% of incident light intensity). In both seasons (winter and spring) the accumulation of nitrates in the leaf tissues was significantly higher in lower irradiance intensity treatments compared to the control. Furthermore, nitrate concentration was significantly higher in plants grew during the winter period compared to those in spring irrespective the light intensity applied, indicating that different growing seasons affect nitrate content. These higher values of nitrate concentration during the winter season could be attributed to lower intensity exhibited during that period and to differences in other microclimatic parameters (Kosma *et al.*, 2013).

Crops can be grown hydroponically in open atmosphere but due to extreme environment, climate change cropping season can't be lengthen for year-round and off-season crop production. The paper is mainly focused to study the effect of controlled environment on hydroponic cultivation. Due to increase in diseases of crops controlled environment has become a very important factor in hydroponic agriculture for protected cultivation of crops. Furthermore, this is first such type of paper to study prospects of controlled environment needed for hydroponic agriculture.

Advantages of Greenhouse under Controlled Environment

Currently, commercial greenhouse vegetables producers use various cultivation techniques.

The most common techniques are upright container culture, trough culture, rock-wool, vertical culture, nutrient film technique and ground culture. All these techniques are modified from time to time except ground culture. Environmental control requires in all greenhouses like shade structures, support wires and general techniques. The core difference is in the irrigation and nutrient supply and control. Mostly nutrient film technique consists of growing plants in a plastic channel which re-circulates nutrient solution continuously for 24 hours. In the advanced NFT, channels and plants are placed in the greenhouse like bag or rock-wool culture (Fenneman *et al*., 2018).

Hydroponics vegetable production usually takes place in greenhouses and initially started from the Northeast. Production has moved to the Southwest due to greater light intensities. Tomatoes are mostly produced in hydroponics, followed by cucumbers, leafy lettuce mostly grow in cold regions and other famous crops like peppers, aubergines and basil herbs (Dickerson, 2001).

Temperature is very important factor in the greenhouse conditions. When temperature varied during the day, it did not affect growth, except when the minimum temperature was at dawn (Miller & Langhans, 1985). There was no interaction of effects of day and night, or air and root temperatures in hydroponics (Hicklenton & Wolynetz, 1987), but the leaf area-to-dry weight ratio increased with both day and night temperatures to 23/19^{o}C day/night. Under tropical conditions, the longer the period with temperature controlled at 20 ^{o}C, the higher the biomass (Qin *et al*., 2002). There was no effect of day to night temperature differences on lettuce growth when it changed because of light intensity (Eguchi *et al*., 1997).

The pH or concentration of various elements could affect growth in hydroponics under greenhouse system. The concentration of elements is related to EC. A solution EC of 1.2 to 4.8dS·m^{-1} did not affect photosynthesis process (Park & Yong Beom, 2001). Yield decreased when EC increased from 2.8 to 3.8 or 4.8dS·m^{-1} (Scuderi *et al*., 2009). However, mostly crops had faster growth in summer than in winter when nitrate was raised from 2.5 to 10mM (Van der Boon *et al*., 1990). There was a linear relation between the maximum rate of nitrate inflow into plant roots and RGR, as affected by radiation, temperature, or plant size, but there was little relation with the nitrate concentration in the plant (Steingrobe & Schenk, 1994).

Greenhouse cultivation provides more environmental control than cultivation in the field. NFT system work more efficiently but the issues like extreme weather and pest pressure may cause production problems. NFT is therefore mostly installed in the greenhouse, where the protected environment give optimum production. (Morgan, 2007; Resh, 1995).

Crop Growth in Hydroponic Agriculture

Hydroponic requires less water for optimum growth with full control of plant nutrients. There are no weeds, no water stress on plants, and greater shelf life in a hydroponic system under greenhouse environment. If the land available to construct a greenhouse and grow commercially becomes a serious alternative, then it is essential to plan for potential market products to assess the possible levels of production and the space needed to achieve these figs. (Morgan, 2007).

Use of fruits and vegetables has increased due to consumer habits, changes in lifestyle and increased needs. New Customers require items of excellent quality with a better taste. The increasing demand for these items pushed companies to integrate innovative production methods like protected agriculture (Lucero & Sánchez, 2012).

Size and the proper location of greenhouse are important for proper cultivation. In the winter months a greenhouse is best suitable for production, particularly when placed with full sun light. This provide the maximum amount of light for giving the maximum energy for photosynthesis process and plant growth. The location should be chosen with the minimum amount of wind in an area and the maximum amount of sunlight during the day. A site close to a large population enables the grower to sell locally (Resh, 1995).

The greenhouse system requires to be monitored on a regular basis to maintain an existing view of greenhouse state. Great responsibility needed for the great rewards of hydroponics (Morgan, 2007). Monitoring of household day and night temperatures to better understand plant growth and for the proper control of nutrient solution (Morgan, 2007; Resh, 1995).

Installation of Hydroponic systems are very much expensive due to the plastic channels, concrete greenhouse floors, return-piping system, sump tank and sump pumps. Installation may be little more expensive than the growing media rock-wool, but the NFT materials only have a initial expenses. In a greenhouse to provide efficient operation of the system, good irrigation and fertilization are necessary to prevent root flooding. For this a higher degree of management and expertise is required (Fenneman *et al.*, 2018).

In Hydroponic system a pump should be installed with the required flowrate for the water head in an ideal greenhouse system and the channels should be kept properly clean to prevent blockage problems in the lines. It is also necessary to regularly monitor the water flow through and out of the channel as roots can damage the channel or algae biofilm may disturb the flow of water back to the reservoir. The system operate properly with the proper reuse of the nutrient solution. Nutrient solution is not properly re-circulated sometimes because water inside the channels effect the root oxygenation, or may be water overflow the return drain running onto the floor. Due to blockage in channels there is no proper re-circulation of water resulted in drain of reservoir, and burn out pumps. (Mayall, 2010).

The light was intense for greenhouse production and the temperatures should be increase or decrease according to the conditions. For the spring harvest season, media uses only oasis and new plugs were planted into the system. Applications for pesticides are an important tool for control of environment, but these tools are used as a last option in effective integrated pest management program. Nutritional formulations are important and must be maintained as a top priority throughout the life of the crops. Stressed crops do not grow as abruptly as crops without stress. Allocating the required fertilizer is a good choice because deficiency of fertilizers causes problems (Mayall, 2010).

Protected Agriculture

Protected agriculture may be described as “An integrated subject of engineering” that requires different engineering fields in greenhouse structure. To maintain the most suitable environmental conditions, control conditions are very necessary inside the greenhouse. The selection of greenhouses depends mainly on the environment factors and the cost of controlling which determines the market value of the crop. (Ponce *et al.*, 2014).

The major difficulty faced by designers of greenhouses is the construction of a structure that allows the correct regulation of the environmental conditions. The structure, automation systems and control should be closely linked; if the structure or automation systems are not properly installed, the control strategy could be the best (Cepeda, 2013).

In the recent years the environmental control and irrigation methods has a great importance. Greenhouse are designed particularly to improve the environmental conditions for the growth of plants. Environmental conditions of greenhouses can be improved with climate and irrigation control by using necessary instruments (Javadikia *et al.*, 2009).

All the major greenhouse vegetable crops can be grown effectively in different systems. No single system is better from the others. The cost of every system is comparable and there is better growth from all systems when managed properly (Fenneman *et al.*, 2018).

Horticultural crops have showed a leading trend in recent years for getting off-season production under control environment as compared to those grown in field. Due to this there is a well-planned structure is required to protect plants from diseases and for getting better quality and good production (Juarez *et al.*, 2011).

Recently protected agriculture has continuously decrease due to the advancement of old methods and

also due to unskilled labor. The development of advanced techniques e.g. Hydroponics in a greenhouse system to increase the performance of crops. Hydroponics also provide a better control of the environment in the greenhouse relates to the life cycle of crop (Cepeda *et al*., 2010). Hydroponic farming becomes the most adopted method for better crop growth in today industry. When combined with the greenhouse hydroponics is highly efficient method and need only basic knowledge of agricultural (Moreno *et al*., 2011).

Crop Growth in Greenhouses

The greenhouse cultivation of vegetables, being an intensive activity, entails perfect planning and numerous phases of operation for its success. Greenhouse design varies depending on its location, whether in a desert, the tropics or in a temperate region (Jensen, 2002). The highly controlled greenhouses sprang up initially in the temperate regions, as growing of vegetables in the freezing temperatures was impracticable (Albright, 2002) while the simpler greenhouses provided minimal climatic control and helped in producing an economic yield of the vegetable crops (Enoch, 1986).

In the temperate regions of the world, glasshouses are preferred more while in other sub-tropics and tropics, 'shading effect' and 'windbreak effect' are provided by greenhouses. Rain shelters are the usual protective structures in the rainy tropical regions to avoid flooding (Garnaud, 1987), whereas in the arid regions, the temperature and humidity inside the greenhouse provides an 'oasis effect' compared to the hot and dry heat outside the greenhouse (Sirjacobs, 1988).

Vegetable crops often need to be protected against a combination of weather conditions. In addition to protection against fluctuating temperatures, protection is also required against solar radiation, heavy rain, hail and strong wind. Thus, selection of suitable location for greenhouse construction is of utmost importance. Greenhouses should be away from industrial and over populated areas. Leveled ground where the light intensity is at its maximum is the priority. But even if the greenhouse has to be constructed on a slope, care should be taken such that surface runoff is directed away from it. Ensuring proper drainage to a lower area is essential around the site. Adequate water supply and a power source should be available nearer to the terrain selected for greenhouse construction (Sabir & Singh, 2013).

Greenhouse for vegetable production encompasses: glasshouse, polyhouse, insect-proof net house, low tunnel polyhouse, zero energy polyhouse. Protected structures are of different kinds, viz. open-ventilated; closed polyhouse with fan and cooling-pad system; shade net house; sloped roof, rain shelter etc. Greenhouse structures are of different kinds based on shape (lean to type, evan span type, ridge and furrow type etc.), utility (temperature and humidity controlled), construction (wooden, pipe or truss framed), covering material (glass, fibreglass, plastic-film). Plastic film covering materials are of different types such as acrylic, polycarbonate, fibreglass reinforced polyester, polyethylene film and polyvinyl chloride film (Montero *et al*., 2005).

Plastic glazed greenhouses have many advantages over glasshouses, the main one being cost. Plastic also is adapted to various greenhouse designs, usually resistant to breakage, light weight, and fairly easy to use. Most greenhouse crops grow best in light whose wavelengths range from 400 to 700 nanometers and hence the glazing materials should be highly transparent (Sabir & Singh, 2013).

Vegetables can be produced in greenhouses under different methods which include planting in the greenhouse soil directly and the latest technique of hydroponic cultivation which involves either planting in different soilless mixtures using containers or using liquid nutrient media. Soil degradation, over-fertilising or soil borne diseases in greenhouse systems required frequent replacing of greenhouse soils which ultimately paved the way for soil-less cultivation where different local materials like rockwool, peat, perlite, coconut fiber were used as substrates. Recent developments in soil-less cultivation refers to hydroponic cultivation which resorted to the use of either an aerated nutrient

solution or an artificial soil composed of chemically inert materials (peat moss, coir, sand, sawdust, rock wool, perlite, vermiculite) moistened with nutrient solutions (Sabir & Singh, 2013).

This hydroponic method of greenhouse cultivation is mostly followed in developed countries and is very expensive. Of fertilizers applied commonly to the soil, only nitrogen can be recovered totally, but in hydroponics, all the nutrients provided to plants can be retained. The reuse of drainage nutrient solution in hydroponically grown greenhouse crops is very much essential to prevent environmental pollution. Hence, to recycle the nutrient solution, it is crucial to disinfect the drainage solution prior to reuse (Runia, 1995).

Thorough knowledge about plant physiology, growth habits and nutrient requirements should be known to the growers for adopting hydroponics, it requires intense monitoring. In future all systems are likely to be closed, with no drainage, preventing any loss of mineral elements and the contamination of groundwater (Sabir & Singh, 2013).

Drip irrigation technology has come to stay in greenhouse production systems and it not only helps in using water efficiently but also can be responsible for reducing diseases that develop in rather moist conditions. Fertigation, i.e. irrigation combined with fertilizer application, requires consideration of plant needs, soil properties and technological requirements. It allows a precise and homogeneous application of nutrients in the area where the active roots are concentrated. The high potential efficiency of fertigation results from the possibility of using the optimal concentration of nutrients and a high density of roots (Bar-Yosef & Sagiv, 1982; Bravdo, 1993).

Hydroponics system are generally closed circuit with respect to nutrient-solution supply wherein the solution is re-circulated continuously or intermittently for a period of days or weeks. Fertilizer programmes for greenhouse systems must supply all nutrients required by the plants. Liquid medium systems used in greenhouses such as NFT and gravel-bed culture use complete nutrient solutions prepared from soluble inorganic salts containing various elements (Sabir & Singh, 2013).

The yield reductions in greenhouse at low frequency irrigation and fertigation results from nutrient deficiency, rather than water shortage, and high irrigation frequency can compensate for nutrient deficiency (Silber *et al.*, 2003). High levels of salinity in the nutrient solution reduces the plant growth and final yields, hence a balance between these factors should be maintained (Stanghellini *et al.*, 2005). Specific fertigation programmes based on the basic nutrient solution required for some greenhouse crops have been developed (Voogt, 2005).

Greenhouse production systems requires good agriculture practices because exhaustive cultivation in greenhouses often involves excessive use of chemicals since the stakes are high due to intensive inputs and high expectations on quality front. The food chain of fresh fruits and vegetables being a complex issue due to its perishable nature, the implementation of good agriculture practices becomes crucial (Nichols, 2007).

Diseases and their Control in Greenhouse Crops

Greenhouse vegetable crops grown the world over are vulnerable to various diseases and pest attacks as the environment inside is conducive for their rapid multiplication. The losses caused due to pests in greenhouses are tremendous. Crop losses are mainly due to arthropod pests like mites, whiteflies, thrips, aphids and diseases caused by virus, fungi, bacteria, nematodes etc. The amount of losses due to virus can vary from 5% to 90% depending on number of factors such as the strain of virus, the crop variety, age of the plant at infection time and temperature during disease development (Averre & Gooding, 2004).

Pest situations are often more severe in older greenhouses and hence maintaining economic profitability of farms is difficult as pest multiplication is much faster compelling growers to resort to excessive chemical use, thereby requiring even stricter adherence to good agriculture practices (Sabir *et al.*, 2010).

The pest control in greenhouses are also controlled by grafting technique. Grafting of vegetable seedlings is a

unique horticultural technology to overcome soil-borne diseases and nematodes and to add extra vigour to the plants under various environmental stresses. It is a process involving, the choice of rootstock and scion species, creation of a graft union by physical manipulation, healing of the union and acclimation of the grafted plant (Lee & Oda, 2003). Vegetable grafting is a recent innovation adapted on a commercial scale though grafting of fruit trees has been practiced since thousands of years (Sakata *et al.*, 2007).

Pollination of flowers is very important and is needed for optimal fruit set and production of quality greenhouse vegetables. In greenhouses it can be achieved manually, mechanically (electric vibrators and air blowers) or through use of bumblebees, depending upon crop. It is assumed that electric vibrators or 'mechanical bee' are more effective, less time consuming and economical compared to air blowers and also produce greater marketable yield (Hanna, 2004). But the mechanism of pollination with bumblebees is an effective alternative and has surpassed all other methods (Banda & Paxton, 1991, Dogterom *et al.*, 1998).

Issues and Challenges in Hydroponic Agriculture

Protected agriculture has many benefits but the world is lagged in adopting this technology. Traditional agriculture is estimated to about 1.5 billion hectares cultivated area in the world while protected agriculture covers only 3 million hectares which is equal to 0.2% of total agriculture growth. Due to the issues of climate change, land and water depletion, projects about developing greenhouse cultivation are gradually in progress. Therefore, this is responsibility for higher authorities worldwide to encourage these projects in the future (Ponce *et al.*, 2014).

In the world about 115 countries are into greenhouse vegetable cultivation commercially. The worldwide trend shows the protected cultivation area to be nearly 623 302 hectares while total expected world greenhouse vegetable production area is 402 981. From the total world greenhouse vegetable area, only 95 000 ha account for soilless/hydroponic culture system (Hickman, 2011).

Greenhouse technology has opened new opportunities in various fields of research like environment control systems, mechanical system, digital sensors, wireless connections and many other fields. There should be proper control in greenhouse structures for solving greenhouse major problems. By developing better greenhouse structures and controllers, optimal crop conditions could be achieved. Because of the importance of excellent environmental control environmental parameters should be controlled properly but it requires more cost and crop production cost increases. The objective is to develop a control environment design that control crop parameters at the optimum level of accuracy (Ponce *et al.*, 2014).

Insects and diseases being a major problem to greenhouse production, managing them is of utmost importance to produce healthy, pest and damage-free plants. Presently, throughout the globe, integrated pest management is being followed for almost all greenhouse vegetable crops like tomato, cucumber, sweet pepper, brinjal, lettuce etc. (VanLenteren & Woets, 1988; Albajes *et al.*, 1999; Sabir *et al.*, 2011).

There is major challenge for the growers to control plant diseases relatively at low cast and without constant resource to pesticides. Pesticides are still useful but only in fully integrated programs of environmental and biological control, together with resistant germ plasm and disease escape mechanism. Several vegetable growers not used insecticides or fungicide for some period except for the soil fumigant methyl bromide for nematode control. The growers relied on resistant cultivars, biological control of insects and manipulation of environment for the disease control (Jarvis, 1992).

Conclusion

Keeping in view the profitability of the farmer, health of the consumer and sustainability of the environment there is much need of controlled greenhouse structures. On the other hand, management of greenhouses is quite difficult because insects and diseases are major problem in greenhouse production.

To solve this problem hydroponic system is the only option to control greenhouses. Therefore, it is concluded that for the proper control of greenhouses with more production can only be done with the adaptation of hydroponic system.

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