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Application of sensors in automated soilless cultivation of high-value vegetable crops

Soilless cultivation technology refers to growing high-value horticultural crops in different soilless medium which is totally devoid of soil. It includes grow bag technology, pure hydroponics, aeroponics and aquaponics. Popular soilless growing medium used are cocopeat, perlite, vermiculite, rockwool, cocochip, sand, stonechip etc. in different combinations or alone itself. It is used mainly inside protected structures to grow high-value horticultural crops round the year for maximizing production, productivity, quality and overall income. Currently, it is urgently required mainly inside protected structures to overcome rampant soil borne diseases and nematodes. It is used for efficient water and nutrient management as well as for overall control by modern IT based tools like sensors, automation and IoT. Sensors are commonly used by growers for overall supervision and management of the growing system for high-value vegetables, flowers, spices and greens.

THE main purpose of protected cultivation is to create a favourable environment for the sustained growth of crop so as to realize its maximum potential under conducive climatic conditions. Protected cultivation technology offers several advantages to produce vegetables, flowers, hybrid seeds of high quality ensuring efficient use resources with minimum risks from uncertainty of weather. It is relevant to farmers having small land holdings who will be benefitted by this technology, which helps them to produce more crops each year from their land, particularly during off-season, when retail prices are higher. This kind of crop production system could be adopted as a profitable agro-enterprise, especially in urban and peri-urban areas. Protected cultivation technology is based on greenhouse effect and being practiced inside greenhouse structures. The common greenhouse structures used for soilless cultivation are naturally ventilated greenhouse, insect proof net house, tunnel type greenhouse and nursery greenhouse.

'Soilless' system refers to cultivation of plants without growing medium; i.e. soil, either in water or based on various soil-less medium. It is a technique for growing plants without natural soil. Utilizing this technology, the roots absorb balanced nutrients dissolved in water that meets all the plant developmental requirements. The word 'hydroponic' was derived from the Greek words, 'Hydro' (water), and Ponos (labour), literally 'water working'. Soilless system is scientifically possible because in the photosynthetic process, soil is not required.

Soilless (or soilless culture) is a broad term that includes all techniques for growing plants in solid medium other than soil (substrate culture) or in aerated nutrient solution (water culture). Soilless cultivation refers to growing wide range of horticultural crops in different growing media or substrates inside grow bags, plastic pots, conduits, pipes and trays. Soil is usually the most common growing medium used for growing plants throughout the world as it provides adequate support for growth, nutrition, air and water required for optimum growth of the plants. However, soil do pose some serious limitations mainly in sustainable growing of crops in protected cultivation due to presence of soil-borne diseases, nematodes, drainage issue and other factors. Soilless culture provides optimal conditions for plant growth and therefore, higher and better quality produce

Greenhouse soilless cultivation of cucumber and capsicum with climate and fertigation sensors

Soilless cultivation of tomato inside greenhouse

can be obtained compared to soil grown in protected or open field cultivation. Soil-borne diseases and nematodes are two most devastating problems being faced by farmers and growers in protected cultivation. Farmers are adopting costly and risky chemical treatments, soil sterilization and soil amelioration for sustainable protected cultivation. In such a scenario, soilless cultivation provides cost-effective and environment-friendly option for protected cultivation. The basic requirements of any hydroponic system are optimum ECe and pH, optimum aeration and temperature, buffer action of water and nutrient solution on the growing medium, and adequate supply of all micro- and macro-nutrients to the plants.

Soilless culture is a technology for growing plants in nutrient solutions that supply all nutrient elements needed for optimum plant growth with or without the use of an inert medium such as gravel, vermiculite, rockwool, peat moss, sawdust, coir dust, coconut fibre etc.

Design and classification of soilless cultivation depends upon type of substrates and container, nutrient delivery system to the plant and drainage of the solution.

Solution culture or Liquid hydroponics

Circulating methods (closed system) include Nutrient film technique (NFT) and Deep flow technique (DFT).

Non-circulating method (open systems) include Root dipping technique, Floating technique and Capillary action technique.

Solid media culture (Aggregate system): This system includes Hanging bag technique, Grown bag technique, Trench or trough technique and Pot technique.

Aeroponics is established as Root mist technique and Fog feed technique.

Soilless cultivation offers several key advantages, making it an increasingly popular choice in modern agriculture. By eliminating soil, growers can avoid soil-borne pathogens and diseases, reducing the need for soil disinfection and treatment. This method enables the cultivation of greenhouse crops in areas with poor soil quality, using inert media that allow precise control over plant nutrition. Soilless systems also provide optimal control of environmental parameters, leading to higher yields and superior product quality. Additionally, they enhance water and nutrient-use efficiency, supporting sustainable practices while enabling year-round production for continuous supply.

Soilless cultivation, while advantageous, comes with several limitations. It requires a high initial investment, which can be a barrier for small-scale or resource-limited growers. The systems are also highly technical, demanding specialized knowledge and skills for effective setup and operation. Additionally, soilless cultivation requires precision surveillance to monitor and maintain optimal nutrient levels and environmental conditions, adding to the operational complexity and oversight needed for successful implementation.

Effective management of a soilless system relies on several key components. First, the design and suitability of the protected structure, as well as the type of soilless or hydroponic setup, are crucial to ensure optimal growth conditions. Choosing suitable crops and varieties tailored for soilless cultivation enhances productivity, while implementing advanced production and protection technologies safeguards plant health. Integrated Pest Management (IPM) and Good Agricultural Practices (GAP) are essential to maintain sustainable and safe practices. An efficient fertigation system, along with carefully scheduled protocols, ensures precise nutrient delivery, while artificial light management supports plant growth under controlled conditions. Lastly, using fertigation and climatic sensors enables automation, allowing precise monitoring and adjustment of environmental factors for consistent crop performance.

Application of sensors in automated soilless cultivation

Machine learning (ML), Internet of Things (IoT) and Artificial intelligence (AI) based automation have been the recent most successful approaches for controlling soilless cultivation-based greenhouses and urban farming models for maximizing the quality crop production of high value vegetables, flowers and seedlings as well as

Table 1. Important characteristics of diferent soilless system

Type of soilless system	Relevance	Crops grown	Initial investment	Operating cost
Soil-less grow bag system	High	Vegetables and flowers	Low/Moderate	Low/Moderate
Soil-less pot system	High	Vegetables and flowers pot plants	High	Moderate/High
Pure hydroponics NFT system	Low	Leafy vegetables	High	Moderate
Pure hydroponics floating system	High	Leafy vegetables and bulbous fowers	Low	Low
Aeroponics	Low	Vegetables	Very High	Very High

efficiently controlling the entire related business models. These recent techniques incorporate and integrate the human expertise, sensors, online and *in-situ* data, softwares and hardwares from different sources for the efficient management of all the related inputs and maximize the output in terms of both quality and quantity. The future of smart, efficient and precision agriculture is mainly based on automation linked with IoT and AI. Sensors are the most integral part of the automation required for overall management of fertigation, microclimate, IPM, harvesting and overall supervision and monitoring of the system. Sensors data are used for AI, ML and IoT based modelling for overall management of the soilless cultivation based models.

Smart urban farming in soilless cultivation often utilizes a variety of specialized sensors to optimize plant growth and health. Climatic sensors monitor environmental factors like temperature, humidity, and light levels, ensuring ideal growth conditions. Fertigation sensors regulate nutrient and water delivery systems for precise plant feeding, while water quality sensors maintain safe pH and mineral levels. Disease monitoring sensors provide early detection of potential issues, allowing timely interventions. Plant and leaf sensors measure plant health metrics such as hydration and nutrient absorption, and fruit quality sensors monitor parameters like size and ripeness, helping to ensure high-quality produce. Together, these sensors create an integrated approach to efficient and sustainable urban farming.

Centre for Protected Cultivation Technology (IARI) has developed complete system and package for vegetable crops.

Sensor-based soilless vertical farming of leafy vegetables in greenhouse

SUMMARY

Sensors are now commonly used for overall supervision, monitoring and management of soilless cultivation based commercial greenhouse entrepreneurship for growing high-value vegetables and flowers. Sensors are integrated with controller for IoT based app popularly used by growers, which can be integrated with smartphone. AI and ML based advanced modelling also requires sensor data for the efficient management of the system. Fertigation, climatic, IPM, Plant health based sensors etc. are commonly used by farmers and growers in soilless cultivation based growing system.

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Vertical expansion of nursery under protected conditions using soilless rooting medium

An efficient technology for multiplication of clonal rootstock (M-9, MM-106, MM-111, P-22, B-9, M-27) of apple under greenhouse conditions was standardized. The technique involves wounding/incision on branches with diameter of 5 mm at 30 cm above ground level using sharp knife/blade to remove the bark followed by application of 2,500 ppm IBA as rooting hormone. The treatment starts from the second week of June till the last week of August. Small polybags (filled with rooting medium) are fastened at the points where rooting needs to be initiated. A lightweight substrate (cocopeat) having high moisture holding capacity is used as rooting medium. Staking is accomplished with the help of bamboo poles to hold the bags in a proper position and to keep the plants straight. This technology is very useful in promoting the vertical expansion of the nursery in greenhouse conditions and the multiplication of number of plants per unit area has increased by three to four times with minimum utilization of extra inputs and area. One more additional benefit of this technology is that under the greenhouse conditions, the rootstocks attain sufficient girth (> 6 mm) and all the plants are suitable for budding. The technology not only produced the additional 3-4 rootstocks but also the budded plants which have added advantage to this technology.

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