Review Article

Innovative Soilless Culture Techniques for Horticultural Crops: A Comprehensive Review

Abstract

Soilless culture, a modern greenhouse cultivation technology, has rapidly developed in the past 30-40 years and offers a closed-loop system with several benefits, including the recycling of 85-90 percent of irrigation water. As the world population continues to grow at a rate of over 1%, the reduction in land availability per capita for soil-based agriculture has become a major problem, particularly in countries like India with a high population density. Soilless farming offers a viable alternative for growing high-quality vegetables, fruits, and flowers year-round on a variety of substrates, requiring limited space. This approach also aims to eradicate greenhouse soil-related problems such as soil-borne infections, poor soil fertility, and salinity. With several advantages over traditional soil crops, including shorter growth times, year-round production, and fewer diseases and pests, soilless farming comprises various methods such as hydroponics, aeroponics, and aquaponics. The technique has the potential to improve people's lives and boost economic growth by encouraging innovative businesses to engage in agriculture. Therefore, soilless farming has gained traction as an innovative solution to address land scarcity issues while producing high-quality crops sustainably.

Keywords: Aeroponics, Economic growth, Hydroponics, Soilless culture and Sustainable agriculture.

Introduction:

In the 21st century, one of the most immediate challenges in agriculture is the need to increase crop yield per unit of surface area while simultaneously improving both water use efficiency (WUE) and nutrient use efficiency (NUE). This is particularly crucial in countries with limited water resources (Savvas and Gruda, 2018), where competition for irrigation water is intense due to other economically competitive activities and human needs (Morison et al., 2008).The imperative to enhance WUE and NUE is further underscored by the necessity to reduce nutrient losses, which contribute to pollution (Fageria et al., 2008). The cultivation of fruits, vegetables, and flowers plays a vital role in agricultural production, influencing both human diets and economic well-being. However, in the modern era, agricultural land is dwindling rapidly due to population growth, making it increasingly challenging for scientists and agricultural researchers to ensure an adequate and balanced diet for everyone. To achieve high yields, soilless cultivation emerges as a significant technique for producing healthy and high-quality crops.

Soil serves as the natural growth medium for plants, providing essential nutrients, oxygen, and water necessary for their growth and development (Ellis et al., 1974). Soilless culture, on the other hand, involves growing plants in a medium other than soil. The integration of soilless systems into horticultural production offers the potential to maximize the efficient use of water and nutrients (Gorbe and Calatayud, 2010; Urrestarazu, 2013; Van Kooten et al., 2004). Soil can sometimes pose significant limitations to plant growth due to various biotic and abiotic factors, such as soil-borne diseases, insect larvae, soil erosion, high salinity, alkalinity, and poor drainage. In urban or peri-urban areas, cultivating crops can be particularly challenging due to adverse soil conditions and a shortage of cultivable arable land (Beibel, 1960). Soilless culture provides an effective solution in such circumstances (Butler and Oebker, 2006).

Growing crops in soilless conditions, such as greenhouses, requires advanced technology and skilled labor for efficient operation, along with substantial initial investments for installation and maintenance. However, these methods offer high productivity, efficient water and space utilization, and, in closed-loop systems, contribute to preventing soil and groundwater pollution (Resh, 2012).

To address the significant difficulties and challenges associated with soil-less culture techniques for horticultural crops, several key obstacles must be surmounted. First and foremost, it is imperative to ensure an appropriate nutrient balance in the growth medium, as it has a direct and substantial impact on plant growth and productivity. The maintenance of optimal pH levels and nutrient concentrations necessitates vigilant monitoring and precise adjustments.Secondly, effective management of soil-less systems requires a comprehensive understanding of irrigation practices to avert the pitfalls of both overwatering and underwatering, both of which can have detrimental effects on plant health.

Moreover, disease and pest management in soil-less setups can be intricate, as the absence of soil may disrupt natural biological controls. Hence, the implementation of effective and sustainable pest control strategies becomes indispensable.Lastly, the initial investment and operational costs associated with soil-less culture techniques can be considerably higher when compared to traditional soil-based methods, potentially presenting financial challenges for growers.Notwithstanding these formidable hurdles, mastering soil-less culture techniques holds the potential to yield higher crop outputs, reduce water consumption, and enhance overall resource efficiency, rendering it a promising and advantageous approach for horticultural crop production (Arumugam et al., 2021). Consequently, it is highly advisable that the paper undergo comprehensive grammar checking, stylistic refinement, and meticulous editing to enhance its overall clarity and readability.

Historical background of soil-less culture

The practice of cultivating terrestrial plants without soil has a historical origin dating back to the book 'Sylva Sylvarum' or 'A Natural History' by Francis Bacon, which was published a year after his death. Subsequently, this technique gained widespread popularity for plant cultivation. In 1969, John Woodward successfully grew spearmint plants in a soilless water culture in England. By 1842, researchers had identified nine essential nutrients/elements crucial for plant growth and development. The soil-less culture technique, as we know it today, was developed by Julius Von Sachs, a German Botanist, and Wilhelm Knop between 1859 and 1875 (Douglas, 1975).

The practice of growing terrestrial plants without soil in nutrient solutions was later termed "solution culture" by Breazeale in 1906. In 1929, William Frederick Gericke, a researcher at the University of California, publicly advocated for the use of solution culture in agricultural crop production (Dunn, 1926 & Thiyagarajan et al., 2007). Initially, he used the term "aquaculture" for this technique, but later he discovered that the term was already being used for the culture of aquatic organisms. He introduced the term "hydroponics" in 1929 when he successfully grew tomato vines measuring 7.6 meters in length in a nutrient solution instead of soil (Turner, 2008). The term "hydroponics" is derived from the Greek words "hydro," meaning 'water,' and "ponos," meaning 'working,' literally translating to 'water working' (Resh, 1991). The nutrient solution technique was first established by Sachs and Knap in 1938. In India, hydroponics was first introduced in Kalimpong, Darjeeling (W. B.) in 1947. However, it's worth noting that many authors still use the term "hydroponics" interchangeably with "soilless culture" (Savvas, 2002).

Soilless culture can be categorized into two main types: (1) Water culture and (2) Substrate culture. In the 1960s, Allen Cooper of England developed the "Nutrient Film Technique" (Cooper, 1979). In 1985, Jensen and Collins introduced the "Aeroponics" technique, which is suitable for growing spinach, lettuce, and even tomatoes.

Advantages of soil-less culture

There are several compelling advantages to cultivating plants in a soil-less environment, each contributing to the innovation and efficiency of modern agriculture:

Mitigated Risk of Pathogens and Weeds: Soil-less culture eliminates the risk of infections caused by soil-borne pathogens and the hassle of weed infestation, ensuring a cleaner and healthier crop.

Alternative to Soil Disinfection: It serves as a viable alternative to soil disinfection methods, reducing the need for chemical treatments that can harm the environment.

Nutritional Precision: Especially beneficial for crops grown on inert substrates or in pure nutrient solutions, soil-less culture allows for precise control over nutrient delivery, optimizing plant nutrition and growth.

Reduced Tillage: Dispensing with the requirement for tillage not only conserves energy but also reduces soil erosion, contributing to sustainable farming practices.

Enhanced Root Zone Temperatures: Higher temperatures in the root zone during the day facilitate early production for crops sown during colder seasons, extending the growing calendar.

Resource Efficiency: Nutrients delivered directly to the roots result in accelerated plant growth with smaller root systems. This allows for closer plant spacing, utilizing just one-fifth of the space and a mere one-twentieth of the water when compared to traditional soil-based cultivation (Raviv et al., 2008).

Multiple Crops per Season: Soil-less cultivation enables the possibility of harvesting more than one or two crops per season, increasing overall agricultural productivity.

Environmental Compliance: Adherence to environmental policies is facilitated as it reduces fertilizer application and minimizes nutrient leaching from greenhouses into the environment. In many countries, closed hydroponic systems within greenhouses are legally mandated, especially in ecologically sensitive regions or areas with limited water resources.

Optimized Planting Density: Soil-less cultivation allows for more efficient planting density, leading to higher yields per acre and the production of healthier, top-quality crops.

Resource Conservation: Particularly valuable in regions with limited arable land and water for agriculture, a soil-less culture offers a sustainable solution to maximize agricultural productivity (Schwarz, 2012).

Limitations of soil-less culture

While soil-less culture offers numerous benefits, it is essential to acknowledge its inherent drawbacks(Mir et al. 2022), which include:

High Installation Costs: The initial setup expenses can be relatively high, making it less accessible for smaller-scale operations or those with limited resources.

Technical Expertise Required: Successful commercial implementation demands a level of technical expertise and the involvement of skilled professionals to manage and optimize the system effectively.

Ongoing Maintenance: Continuous and proper maintenance is imperative to ensure the system's functionality and to prevent potential issues or failures.

Energy Consumption: Soil-less culture systems necessitate energy inputs to maintain optimal conditions, including temperature, humidity, and nutrient delivery, which can increase operational costs.

Pathological Risks in Closed Systems: In closed systems of soilless culture, the risk of pathogen-related issues is elevated. Therefore, meticulous care and stringent cleanliness protocols are essential to mitigate this risk (El-Kazzaz and El-Kazzaz, 2017).

Despite these challenges, ongoing advancements in technology and agricultural practices aim to address and mitigate these drawbacks. Innovative solutions in system design, automation, and disease control are continually emerging, contributing to the ongoing development and viability of soil-less culture techniques.

Therefore, it is crucial to recognize both the advantages and challenges associated with this approach while staying abreast of the latest developments in the field.

Classification of Soilless Culture

Soilless culture techniques offer diverse methods of cultivating plants, each with its own unique advantages and applications. In this classification, we explore some of the prominent techniques, shedding light on their distinct features and contributions to modern agriculture.

1. Hydroponics

Hydroponics involves the cultivation of plants in nutrient solutions—water enriched with fertilizers. This method can be employed with or without the use of inert mediums, such as sand, gravel, vermiculite, rock wool, perlite, peat moss, coir, or sawdust, which provide mechanical support for plants (Sharma et al., 2018). The term "hydroponics" originates from the Greek words "hydro," meaning water, and "ponos," meaning labor, thus signifying "water work." Coined in the early 1930s by Professor William Gericke, hydroponics describes the practice of growing plants with their roots suspended in water containing essential mineral fertilizers.

Types of Hydroponic Systems

Wick or Passive System: The wick system is the simplest form of hydroponics, requiring no electricity, pumps, or aerators. It relies on capillary action and fibers to transport the nutrient solution to the plants. This low-cost method is advantageous in regions with limited access to electricity and is suitable for small-scale production (Shrestha and Dunn, 2013).

Deep Water Culture (DWC): Also known as Deep Flow Technique, this method involves growing plants in a container with a 10-20 cm nutrient solution and a floating or hanging support structure. Plant roots are continuously submerged in the nutrient-rich solution, with precise control over oxygen levels, conductivity, and pH for optimal growth (Jones, 2005).

Drip Hydroponic System: This system comprises two containers, one above the other. Nutrient solutions are poured into the bottom container, and plants are placed in the top container. The addition of an aquarium stone aids in oxygenating the solution, making it suitable for plants with extensive root systems (Lee and Lee, 2015).

Ebb and Flow System: Similar to the drip hydroponic system, the Ebb and Flow system consists of two containers, one for plants and one for the nutrient solution. However, in this approach, nutrients are intermittently flooded onto the plant roots, creating a changing environment that can promote robust plant performance (Jones, 2014).

Nutrient Film Technique (NFT): NFT is a closed hydroponic system developed by Allan Cooper in the 1960s. It recirculates nutrient solution through a slanted PVC pipe channel, providing well-oxygenated nourishment to plant roots. This efficient system allows plants to absorb essential nutrients and oxygen from a thin film of nutrient solution. Run-off solutions are collected and returned to a holding tank at regular intervals, ensuring optimal growth conditions (Morgan, 2009).

These diverse hydroponic techniques offer unique advantages and cater to various plant species and growth requirements, contributing to the versatility and innovation of soilless culture in contemporary agriculture

2. Aeroponics

The term 'aeroponics' finds its roots in the Latin words 'aero' (air) and 'ponic' (labour). Aeroponics presents itself as a compelling alternative within the realm of soilless cultivation, particularly in controlled growth environments. This innovative technique finds its niche as optional equipment for soilless production in precisely controlled settings, such as greenhouses (Deeptimayee Sahoo, 2020).

Aeroponics stands out due to the unique way in which plant roots interact with their environment. In this method, plant roots are suspended in air, deriving their nutrients from an aerosol mist. The key to successful aeroponics lies in the continuous misting of plant roots, maintaining moisture and aeration to prevent drying out (Nandwani, 2018; Lee and Lee, 2015). Remarkably, even crops as substantial as potato seed tubers have been successfully cultivated using aeroponics in Korea.

Aeroponic systems are particularly celebrated for their efficient water utilization when compared to traditional hydroponics. Nutrient solutions are directly sprayed onto suspended roots using various nozzle types at regular intervals, ensuring the root zone remains adequately moist and avoiding dryness. Several nozzle options are employed, including ultrasonic atomization foggers, high-pressure atomization nozzles, and pressurized airless nozzles. These systems maintain a static pressure typically ranging from 60 to 90 psi, meticulously controlled by automated systems (Liu et al., 2018).

While aeroponics boasts remarkable potential, it is more commonly employed in the cultivation of small horticultural crops. The relatively high initial investment and operational expenditures have limited its widespread adoption (Rakocy, 2012).

3. Aquaponics

Aquaponics represents a harmonious blend of aquaculture and hydroponics in a soilless culture environment designed to cultivate both fish and vegetables (Rakocy, 2007). The term 'aquaponics' amalgamates the Latin and Greek words for water, 'aqua' and 'hydro,' which respectively denote aquaculture (fish farming) and hydroponics, defining modern horticultural production—plant growth in water without soil.

In the aquaponics ecosystem, water circulates from the fish tank to the plant growth container, passing through a biofilter where nitrifying bacteria thrive, breaking down harmful compounds. Excess water from the growing container is recycled, and plant nutrition is sourced from the water enriched with ammonia-rich fish excreta. Beneficial bacteria such as Nitrosomonas sp. and Nitrobacter sp. play a pivotal role, converting ammonia into nitrites and nitrites into nitrates through metabolic processes (Rakocy et al., 2016).

Aquaponics has gained prominence in recent years, with countries such as India, Israel, China, and various African nations emerging as leaders in this innovative cultivation method (Singh and Singh, 2012).

Inorganic and Organic Growth Media in Soilless Cultivation

In soilless cultivation, the choice of growth media is pivotal to plant development and productivity. These media can be categorized into inorganic and organic types, each with distinct attributes and applications.

Inorganic Growth Media:

Inorganic growth media primarily originate from natural sources, with only a small portion undergoing industrial processing before application. Notably, rockwool, initially developed as an insulating material for the construction sector, has risen to prominence as the predominant growth medium for greenhouse fruit and vegetable production worldwide. Its popularity owes much to its lightweight nature and ease of handling (Gruda et al., 2016b).

Another notable inorganic medium is perlite, well-known in European horticulture. However, it finds broader utilization in the Mediterranean region due to its cost-effectiveness (Grillas et al., 2001).

Organic Growth Media:

Organic growth media encompass both artificial and natural materials. Artificial options include polyurethane, while natural alternatives comprise peat, wood-based substrates, composts, bark, and wood wastes, among others (Schmilewski, 2009; Maher and Thomson, 1991; Gruda and Schnitzler, 2004).

Critical Characteristics of Growth Media:

Regardless of the chosen medium, any growth media suitable for soilless cultivation must exhibit the following essential characteristics:

a) Nutrient Provision: The medium must furnish an adequate supply of essential nutrients to support optimal plant growth and development.

b) Water Retention Capacity: It should possess a significant water-holding capacity, ensuring that moisture is readily available to plant roots.

c) Aeration and Gas Exchange: The growth medium must facilitate the exchange of both water and gases, ensuring that roots receive the necessary oxygen for respiration.

d) Structural Support: It should provide adequate mechanical support to anchor the plant securely, promoting stability and upright growth.

These fundamental traits guide the selection of growth media in soilless cultivation, playing a pivotal role in fostering healthy and productive plants.

Table 1: Characteristics of organic and inorganic media used in soilless cultivation

Nature of media	**Substrate/ media**	**Origin**	**Advantages**	**Disadvantages**	**References**
Organic	**Coco peat**	Natural anaerobically processed plant residues	Physical stability, good air and water holding capacity: TPS (85–97% V/V), low microbial activity, light volume weight (60–200 kg m-3). Improves soil aeration and increase soil buffering capacity.	Finite resource, environmental concerns and contribution to CO2 release, increasing cost due to energy crisis, may be strongly acidic, shrinking may lead to substrate hydro-repellence	Xu *et al.*, 1995
	Rice hull	Plant based byproduct of rice milling industry	The rice milling business produces it as a by-product. Rice hulls, despite their low weight, are quite useful in improving drainage	Slow break down relatively resistant to decomposition	Xu *et al.*, 1995
	Bark	waste by-product of the wood-processing industry	It has high air content and water retention capacity, as well as a high total pore space (TPS) (75–90% V/V). However the pH range is slightly acidic to neutral, with a long-lasting average volume weight (320–750 kg m-3)	Slow decomposition in soil	Gianquinto and colleagues, 2006

	Coconut coir	by-product of fiber coconut processing	high water holding capacity, as well as a subacid-neutral pH (5–6.8)	May contain high salt levels, energy consumption during transport.	Gruda and colleagues, 2016b
	Biochar and hydrochar	Solid material derived from biomass pyrolys	Production is energy-neutral, helps with carbon sequestration, biologically very stable, wet material can be used for hydrochar; hydrochar has low EC	hydrochar has low EC. Properties vary dependent on feedstock (biochar), high production costs, biochar often has high pH, can be dusty.	Gianquinto et al., 2006; Gruda *et al.*, 2016)
	Saw Dust	Plant origin (Waste product of wood industry)	High water retention, Lightweight, Adaptable to fertilizer	Tend to clot, Chemical cleaning is required, Susceptible to biological breakdowns	Ashok and Sujitha, 2020
Inorganic	**Perlite**	Siliceous volcanic mineral sieved and heated to 1000°C	Light volume weight (90–130 kg m-3), sterile, neutral in pH (6.5–7.5), no decay, TPS (50–75% V/V).	Low nutrient capacity, energy consuming product, expensive.	Maucieri *et al.*, 2019
	Sand	Natural with particles of 0.05–2.0 mm	Relatively inexpensive, good drainage ability	Low nutrient- and water holding capacity, high volume-weight (1400–1600 kg m-3)	Gianquinto *et al.*, 2006; Gruda *et al.*, 2016b
	Vermiculite	Mg+, Al + and Fe + silicate sieved and heated to 1000°C	Light volume weight (80–120 kg m-3), high nutrient holding ability, good water holding ability, good pH buffering capacity, good aeration: TPS (70–80% V/V)	Compacts when too wet, energy consuming product, expensive.	Gianquinto *et al.*, 2006; Gruda *et al.*, 2016b. George and George, 2016)
	Rock wool	Melted silicates at 1500–2000°C	Light volume weight (80–90 kg m-3), high total pore space (95–97% V/V), ease of	Disposal problems, energy consumed during	Gianquinto *et al.*, 2006; Gruda *et al.*,

			handling, totally inert, nutrition can be carefully controlled.	manufacture.	2016b

Application of Nutrient Solutions in Soilless Cultivation

The success or failure of horticultural crops in a soilless environment-hinges entirely on the availability of well-balanced nutrient solutions suitable for all stages of plant growth and development. Fertilizers designed for soilless cultures must encompass all 13 essential nutrients necessary for robust and healthy plant growth. Maintaining the pH range of the solution culture between 5 and 6 is of critical importance, in accordance with the recommended dilution rates on the labels. Fortunately, pH test kits and pH modifiers are readily available at fish supply stores.

In soilless cultivation, certain nutrients within the fertilizer solution are depleted at varying rates, contingent upon the plant's growth stage. Thus, it is imperative to regularly monitor the nutrient levels within the system, ideally every two weeks. Any deficiencies should be promptly addressed, and the nutrient solution should be replenished to its original volume. Over time, the concentration of nutrients can rise, potentially compromising the root system and its function due to reduced water availability. To counteract this, purified distilled water can be added to restore the nutrient solution to its original composition.

It is essential to use nutrient formulations specifically designed for hydroponics in hydroponic systems. Plants grown in soil source most of their nutrients from the soil. Consequently, nutrient compositions for soil-based cultivation significantly differ from those tailored for soilless culture.

In both hydroponics and soilless culture, the absence of soil necessitates entirely different nutrient compositions. Some nutrients in traditional soil-based fertilizers are insoluble in water and do not constitute comprehensive plant nutrition. For instance, urea, a common source of nitrogen, is generally water-insoluble. Therefore, in soilless culture and hydroponics, plants primarily absorb nitrogen in the form of nitrates.

In nature, plant roots grow below ground, and it is crucial to maintain the root zone temperature within the range of 20-22 degrees Celsius to facilitate root development. While temperatures slightly above this range won't necessarily harm plants, it is advisable to keep them as close as possible to this optimal temperature. Excessive nutrient temperatures, exceeding 23 or 23.5 degrees Celsius, can lead to issues such as yellowing and dropping of flowers, damaged fruits, and stunted growth. Thus, precise temperature control within the specified range is vital for ensuring healthy and productive plants in soilless cultivation.

Methods of Application of nutrient solution

1. Nutrient Film Technique (NFT)

The Nutrient Film Technique (NFT) stands out as a quintessential and widely embraced hydroponic cultivation method. In this system, a nutrient solution flows along and circulates within a narrow 1-2 cm layer of water (Cooper, 1979; Jensen and Collins, 1985; Van Os et al., 2008). NFT offers several key advantages, including the efficient recirculation of nutrient solutions and the absence of any solid substrate.

2. Fertigation System

Fertigation represents a versatile method of fertilizer application applicable to both soil-based and soilless cultivation systems. It involves the precise application of fertilizers through water delivery, typically via drip irrigation systems. This technology has revolutionized fertilizer application, particularly in soilless cultivation.

Within this system, fertilizers are meticulously distributed to crops cultivated in grow bags and containers within the soilless medium. Fertigation schedules demand careful calibration, especially in various soilless mediums, underscoring the need for diligent fertigation management. Through fertigation, water and nutrients are delivered directly to the root zone, facilitating enhanced nutrient uptake by the crops. Remarkably, fertigation boasts an impressive fertilizer efficiency, typically ranging from 80 to 90%, resulting in significant nutrient savings of up to 25%.

Fertigation has emerged as a dynamic and sustainable approach to nutrient management, offering precise control and resource efficiency, making it a valuable asset in modern cultivation practices.

Table 2: Sources of nutrient elements with their characteristics used in fertigation

Source	**Nutrients**	**Characteristics**
$Ca(NO_3)_2$	N, Ca	higher soluble salt
H_3BO_3	B	Good source of boron
Iron chelates	Fe Cit	Good sources of iron
KH_2PO_4	P, K	Deficiency of phosphorus
$MgSO_4$	S, Mg	highly soluble, Cheap and pure salt
KNO_3	N, K	higher soluble salt
NH4 NO_3	P, K	Good soluble in water

Table 3: List of crops grown in soil less cultivation (Hydroponics)(Khan *et. al.,*2018)

	Group of crops	**Name of crops**	**Scientific Name**
1	**Vegetables**	Vegetable Peas	*Pisum sativum var. hartense*
		Tomato	*Lycopersicon esculentum* L.

		Bell pepper	*Capsicum annuum* L.
		Beet	*Beta vulgaris* L.
		Chili	*Capsicum frutescens* L.
		Green bean	*Phaseolus vulgaris* L.
		Potato	*Solanum tuberosum* L.
		Onion	*Allium cepa* L.
		Cucumber	*Cucumis sativus* L.
		Cauliflower	*Brassica oleracea var. botrytis*
		Lettuce	*Lactuca sativa* L.
		Kang Kong	*Ipomea aquatica*
		Radish	*Raphanus sativus* L.
		Cabbage	*Brassica oleracea var. capitata*
		Melons	*Cucumis melo*
2	**Fruits**	Strawberry	*Fragaria ananassa*
3	**Flowers**	Chrysanthemum	*Chrysanthemum indicum* L.
		Marigold	*Tagetes patula* L.
		Carnation	*Dianthus caryophyllus* L.
		Roses	*Rosa indica*
		Bermuda grass	*Cynodon dactylon*L**.**
4	**Condiments**	Parsley	*Petroselinum crispum* Mill.
		Mints	*Mentha spicata* L.
		Sweet basil	*Ocimum basilicum* L
5	**Medicinal plants**	Aloe	*Aloe vera* L.
		Coleus	*Solenostemon scutellarioides*

Government of India (GOI) initiatives for soilless culture

Soilless culture holds a lot of promise for Indian agriculture. It's one of the technologies that could treble a farmer's income. As eating preferences and fads for green vegetables, herbs, and fruits evolve, hydroponics technology will become increasingly important in ensuring sustainable and year-round production in urban and peri-urban areas. Because this technology requires a lot of finance and technical know-how, the Indian government has set up a variety of programs to promote it through various agencies.

In India, several organizations and schemes promote soilless farming and contribute to the development and adoption of soilless culture techniques. Here are some of the important ones:

1. **National Horticultural Board (NHB):** NHB works towards the overall development of horticulture in India and supports initiatives related to soilless farming and horticultural projects.
2. **National Horticultural Mission (NHM):** NHM focuses on promoting holistic growth in horticulture and implements schemes like the Mission for Integrated Development of Horticulture (MIDH) to support soilless farming practices.
3. **Horticulture Mission for North East & Himalayan States (HMNEH):** HMNEH aims to enhance horticulture productivity in the North Eastern and Himalayan regions by promoting advanced farming practices, including soilless techniques.

4. **National Mission for Sustainable Agriculture (NMSA):** NMSA supports sustainable agricultural practices and provides assistance for the adoption of innovative techniques like soilless farming.
5. **Integrated Horticulture Development Programme (IHDP):** IHDP aims to integrate various aspects of horticulture development, including soilless farming, to enhance productivity and income of farmers.
6. **National Agricultural Innovation Project (NAIP):** NAIP, implemented by the Indian Council of Agricultural Research (ICAR), focuses on promoting innovation and technology adoption in agriculture. It supports research and development initiatives related to soilless farming, hydroponics, and other innovative agricultural practices.
7. **Centre of Excellence for Vegetables (CoE):** CoE is a scheme implemented by the Ministry of Agriculture and Farmers' Welfare, Government of India. It establishes centers of excellence across the country that serve as model demonstration sites for advanced horticultural practices, including soilless farming. These centers provide training, technical assistance, and knowledge sharing platforms to farmers.
8. **Indian Society of Soilless Agriculture (ISSA):** ISSA is an organization dedicated to promoting and disseminating knowledge about soilless agriculture in India. It conducts seminars, workshops, and training programs to educate farmers, entrepreneurs, and researchers about soilless farming techniques, technologies, and best practices.
9. **State Horticulture Departments:** State-level horticulture departments across India play a crucial role in promoting soilless farming. They implement various schemes, provide financial assistance, and offer training and technical guidance to farmers interested in adopting soilless culture techniques.
10. **Pradhan Mantri Krishi Sinchai Yojana (PMKSY):** PMKSY is a flagship program that encompasses various initiatives, including Per Drop More Crop (PDMC), Watershed development, Micro Irrigation, and Crop Insurance Scheme, which indirectly support soilless farming.
11. **Vertical Farming Scheme under Kerala State Horticulture Mission:** This scheme provides subsidies to promote vertical farming practices, including soilless techniques, in Kerala.
12. **Collective Farming Scheme:** This scheme encourages collective farming approaches, including soilless farming, to enhance productivity and income of small and marginal farmers.
13. **Rainfed Area Development (RAD):** RAD focuses on enhancing productivity in rainfed areas through various interventions, including soilless farming, to ensure sustainable agriculture.
14. **Tamil Nadu Irrigated Agriculture Modernization Project (TNIAMP) - IAMWARM:** TNIAMP aims to improve irrigation practices and modernize agriculture, which can indirectly support the adoption of soilless farming techniques.

15. **Pradhan Mantri Fasal Bima Yojana:** This scheme provides crop insurance coverage to farmers, including those practicing soilless farming, to safeguard against crop losses.
16. **Rashtriya Krishi Vikas Yojana (RKVY):** RKVY supports agriculture and allied sector rejuvenation, including the adoption of innovative approaches like soilless farming under the scheme's Remunerative Approaches for Agriculture and Allied sector Rejuvenation (RAFTAAR) component.
17. **CHAMAN Project:** This project aims to assess and manage horticulture practices and provides support for the development and adoption of advanced farming techniques, including soilless farming.
18. **Sub-Mission on Agricultural Mechanisation (SMAM**): SMAM focuses on promoting agricultural mechanization, which can indirectly support soilless farming practices.
19. **National Committee on Plasticulture Applications in Horticulture (NCPAH):** NCPAH works towards promoting the use of plasticulture applications, including the use of plastic mulch in soilless farming, to enhance productivity and resource efficiency in horticulture.
20. **Agricultural Universities and Research Institutions:** Agricultural universities and research institutions in India conduct research, develop technologies, and provide expertise in the field of soilless farming. They contribute to the knowledge base, conduct training programs, and disseminate information on soilless culture practices to farmers and stakeholders.

These organizations and schemes collectively contribute to the promotion and adoption of soilless farming in India by providing support, funding, knowledge-sharing platforms, and technical assistance to farmers, researchers, and entrepreneurs in the horticulture sector.

Conclusion

As the world's population grows, more food will be needed in the next four decades than in the previous 10,000 years. As the world's population grows and the amount of arable land accessible for food production decreases, new crop production alternatives must be explored. The traditional soil-based farming technique will not be sufficient to meet the world's expanding food need. As a result, establishing a new farming approach is essential to avoid future food crises. Soilless culture's technologies and procedures can be referred to as next-generation agricultural science because they open the possibility to establishing a new civilization in space. In a world where clean water and a sufficient quantity of nutritious food are major concerns, Soilless farming is becoming more popular around the world, and such systems provide growers and consumers with a plethora of new chances to produce high-quality vegetables rich in bioactive compounds by displacing traditional farming. Hydroponic culture is the most intensive form of crop production in today's agriculture business, and it is mostly employed in industrialized and developing countries to produce food in small spaces. Aeroponics proved to be a very viable approach for producing aerial and root raw materials for the herbal dietary supplement and pharmaceutical industries. Aquaponics is a sort of soilless culture that uses a circulating aquaculture and hydroponics system to provide a double harvest of fish and vegetables in a symbiotic environment. It can also improve people's lives and boost a country's economic growth by encouraging inventive businesses to engage in hydroponic farming. The world needs to embrace the soilless culture as a vital solution to the growing demand for food. Its potential to produce high-quality crops in limited spaces, its resource efficiency, and its ability to adapt to different environmental conditions make it a promising avenue for sustainable agriculture. By incorporating soilless farming techniques into our agricultural systems, we can meet future food challenges and pave the way for a more resilient and productive food production system.

Future scope

Soilless culture is the fastest-growing area of agriculture, and it has the potential to become the primary source of food production in the future. People will turn to innovative technologies like hydroponics, aeroponics, and aquaponics to generate extra channels of crop production as the population grows and arable land shrinks owing to bad land management. We simply need to look at some of the early adopters of hydroponics to get a sense of the future of this science. Hydroponics has also shown to be successful in Israel's dry and arid climate. Using hydroponic systems, a business called "Organitech" has been growing crops in 40 feet (12.19-meter) long shipping containers. They're growing a lot of berries, citrus fruits, and bananas, which would ordinarily be impossible to cultivate in Israel's environment. The output produced by hydroponics techniques is 1,000 times larger than what a similar-sized plot of land could generate in a year. Best of all, the procedure is fully automated, with robots operating on an assembly line-style system similar to those used in manufacturing factories. Following that, the shipping containers are moved across the country (Butler and Oebker, 2006). The future scope of soil-less culture techniques in horticulture crops is bright and promising. With its ability to address challenges such as disease control, resource efficiency, year-round cultivation, and integration with technology, soil-less culture has the potential to revolutionize agriculture. By embracing this technique, farmers can enhance productivity, ensure food security, and contribute to sustainable and efficient agricultural practices in the years to come.

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