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CONTENTS

Foreword

Providing quality nutritive food to more than 1.6 billion people by the Year 2025 would be a major challenge for the country. Increasing population, decreasing land and water holding, urbanization, industrialization, global warming are some of the major impediments for the country. Various biotic and abiotic stress factors are threatening the open field agricultural production systems throughout the world in varying degrees. The soil fertility status has attained almost the saturation level in most parts of the country as the productivity is not rising pro rata with the amount of inputs. More than 6 million ha area has been affected by salinity and alkalinity apart from other factors continually degrading the soil health. Under these circumstances, it would become increasing by difficult to provide quality nutritive food for the burgeoning population in the near future. The demand for fresh and green horticultural produce, mainly vegetables, fruits and flowers, is rising sharply particularly in peri-urban and urban areas. Under such scenario, hydroponics system is emerging as potentially alternate technology for growing quality vegetables and flowers in various soil-less media under limited space throughout the year. Although the technology is in fledgling stage in the country it is about time that seeds of initiatives are planted for timely technological adoption and its agro-ecological refinement vis-a-vis our crops and climate, so that the pace of development is in tune with the needs of the nation, economic viability of production systems, health and safety of the consumers. The Government of India has been providing technical and financial support to the commercial initiatives related to hydroponics through National Horticultural Board (NHB) and National Horticultural Mission (NHM). Our institute is mandated to spearhead technological innovations in agricultural production system besides their outreach to all the stakeholders. I am happy that the team of scientists from CPCT, IARI have taken a lead for timely developing a popular literature on hydroponics technology for its wide spread not only for technological but also its commercial adoption at large. I congratulate the authors for their efforts in developing this technological bulletin and would indeed exert for continual refinement in work and development of literature on these lines.

New Delhi

Date : 14th March 2018

Director

IARI, New Delhi

Preface

Hydroponics cultivation is being actively practised by many farmers, entrepreneurs, professionals mainly in peri-urban and urban areas for growing green vegetables, flowers, seedlings and herbs in many parts of the world. It has become one of the most popular agricultural technologies related to precision farming and protected cultivation. The major advantage of hydroponics cultivation is round the year availability of green, healthy and safe horticultural produce. Its technological advantages are encouraging growers and professionals to start the cultivation with their own initiatives, innovations and investment in kitchen garden, rooftop, balcony and farms. Lately it is fast catching up with not only among progressive growers but also urban and peri-urban households. However, lack of technical knowhow, systematic protocols and procedures, input management and plant protection are some of the major impediments in the expansion and popularization of hydroponics technology. The major problems being faced by the growers are non-availability of indigenous hydroponics models and fertigation scheduling charts in the form of user friendly packages. ICAR-IARI has been actively promoting protected cultivation and precision farming technology through its dedicated Centre for Protected Cultivation Technology and Water Technology Centre. The Centre has been actively working on different aspects of protected cultivation and hydroponics technology. The Centre has standardized various indigenous soil-less cultivation models, water and nutrient budgeting and fertigation scheduling related to hydroponics cultivation. User friendly fertigation scheduling charts have been developed to prepare indigenous fertigation solutions with local and commonly available water soluble fertilizers in the most economic way. The bulletin deals with the suitable designs of structures, production and protection technologies, fertigation scheduling, GAP & IPM, Government initiatives and addresses of fabricators and suppliers, related to hydroponics.

The publication shall be very useful for the wide range of stakeholders including farmers, growers, professionals, entrepreneurs, policy makers, extension officials, students and most importantly the common households for actively growing green horticultural crops through hydroponics cultivation as very few user friendly literature is available particularly on hydroponics cultivation. The authors would like to acknowledge the Director IARI, publication unit, all the collaborators and co-workers for co-operation and suggestion.

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Hydroponics Technology for Horticultural Crops under Protected Cultivation

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 even in adverse climatic conditions. Protected cultivation technology offers several advantages to produce vegetables, flowers, hybrid seeds of high quality with minimum risks due to uncertainty of weather and also ensuring efficient management of resources. This becomes relevant to farmers having small land holding who would be benefitted by a technology, which helps them to produce more crops each year from their land, particularly during off season when prices are higher. This kind of crop production system could be adopted as a profitable agro-enterprise, especially in peri-urban areas. Greenhouse is an inflated structure made with G.I or steel pipes covered with plastics and nets, which can be used for crop production under controlled environment conditions. Micro climate inside greenhouse is created and maintained for high quality crop production mainly of vegetables and flowers for round the year.

Protected cultivation offers several advantages to produce horticultural crops and their planting material of high quality and yields, through efficient resource utilization. Fruits, vegetable and flower crops normally accrue 4 to 8 times higher profits than other crops. This margin of profit can increase manifolds if some of these high value crops are grown under protected conditions, like greenhouses, net houses, tunnels etc. Such an agricultural production system could provide a more profitable source of income and employment in rural sector. The amount of post harvest losses in vegetables and cut flowers is very high (20-30%), which can be significantly reduced and productivity can be increased 5-10 through protected cultivation technologies by taking the crops round the year. Protected cultivation has very high entrepreneurial value and profit maximization leading to local employment, social empowerment and respectability of the growers. Environmentally safe methodologies involving IPM tactics reduce the hazards lacing the high value products. Fertigation has been found to be one of the most important production technology for hi-tech horticulture and protected cultivation. It helps in achieving higher productivity and enhancing the quality of horticultural produce. Precision application of water and nutrients is possible through drip fertigation to attain very high crop water and nutrient use efficiency mainly in protected cultivation.

Hydroponics refers to cultivation of plants without soil, either in water or based on various soil-less media. Utilizing this technology, the roots absorb balanced nutrients dissolved in water that meet all the developmental requirements of plants. The word hydroponics was derived from the Greek words, HYDRO (water), and PONOS (labor), literally "water working".

Hydroponics system is scientifically possible because in the photosynthetic process, soil is not mentioned. Photosynthesis process: (Carbon Dioxide + Water ? Glucose + Oxygen)

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$$

Table 1: Important Characteristics of Different Hydroponics System

Types of Hydroponics	Relevance	Crops Grown	Initial Investment	Operating Cost
Soil-less Grow Bag System	High	Vegetables & Flowers	Low/Moderate	Low/Moderate
Soil-less Pot System	High	Vegetables & Flowers Pot Plants	High	Moderate/High
Pure Hydroponics NFT System	Low	Leafy Vegetables	High	Moderate
Pure Hydroponics Floating System	High	flowers Leafy Vegetables & Bulbous	Low	Low
Aeroponics	Low	Vegetables	Very High	Very High

Hydroponics (or soil-less culture) is a broad term that includes all the techniques for growing plants in solid media other than soil (substrate culture) or in aerated nutrient solution (water culture). Soil-less cultivation refers to growing wide range of horticultural crops in different growing media or substrates contained inside grow bags, pots, conduits, pipes and trays. Soil is usually the most common growing media used for growing plants throughout the world as it provides adequate support, nutrition, air and water required for optimum growth of the plants. However, soil poses some serious limitations mainly in sustainable growing of crops in protected cultivation due to presence of soil-borne diseases, nematodes, drainage and other factors. Hydroponics or soil less culture provides optimal conditions for plant growth and therefore, higher and better quality yields can be obtained compared to soil grown in protected and open field cultivation. Soil borne diseases and nematodes are two most devastating problems being faced by farmers and growers in protected cultivation. They are adopting costly soil sterilization and soil amelioration and risky chemical treatments for tangible in come protected cultivation. In such a scenario, hydroponics provides cost effective and environment friendly option for protected cultivation. The basic requirements of any hydroponics system are optimum EC and pH, optimum aeration and temperature, buffer action of water and nutrient solution on the growing media and supply of all micro and macro nutrients to the plants through the growing media.

Hydroponics or soil-less 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. Kindly see Table 1 for important characteristics of different hydroponics systems.

Apart from this the important physical properties of common soil-less media are explained in Table 2.

Table 2: Bulk Density and Porosity of Important Soil-less Media

Soil-less Media	Bulk density (kg/m^3)	Total porosity (%v/v)
Coco-Peat	80-100	90-95
Perlite	80-120	85-90
Vermiculite	90-150	90-95
Rockwool	80-90	95-97
Expanded Clay	600-900	85-90

Classification of Hydroponics cultivation depends upon type of substrate and container, nutrient delivery system to the plant and drainage.

1. Solution culture or Liquid hydroponics

-Circulating methods (closed system)

- Nutrient film technique (NFT)
- Deep flow technique (DFT)

-Non-circulating method (open systems)

- Root dipping technique
- Floating technique
- Capillary action technique

2. Solid media culture (Aggregate systems) –

-Hanging bag technique

-Grow bag technique

-Trench or trough technique

-Pot technique

3. Aeroponics

-Root mist technique

-Fog feed technique

Major advantages of hydroponics cultivation are as follows:

- Soil-borne pathogens and diseases avoidance
- Soil disinfection and treatment avoidance
- Cultivate gre enhouse crops in poor quality soil
- Precision nutrition control in inert media
- Optimum control of environmental parameters
- High yield and better quality of products
- High water and nutrient use efficiency
- Round the year production

Major disadvantages/limitation of hydroponics cultivation are as follows:

- High initial investment
- Highly technical
- Precision surveillance

Fig 1. Hydroponics Cultivation in Bag Type and Pot Type Soil-less Media

Solution culture or liquid hydroponics refers to growing plant in fully liquid medium contained in pipe or suitable container. In Circulating closed system nutrient solution circulates around the plant root system and it can be collected, replenished and reused as per the plant need.

Nutrient Film Technique (NFT) is a hydroponics system, where the plant roots are directly exposed to the thin film of (thickness 0.5mm) nutrient solution flowing through the channel. The channel is made of flexible PVC or plastic sheet on the top of which seedlings with growing media inside tailor made pots are anchored properly. The growing media absorbs the nutrient solution though the porous root system of the plant. The length of channel varies from 5-10 meter kept at the slope of 1in50 to 1in70. The flow rate of nutrient solution is 2-3 liters per minute and its salt concentration is monitored at regular interval through the important indices like EC, pH and TDS.

Deep Flow technique (DFT) is a hydroponics system in which 2-3 cm deep nutrient solution flows through PVC pipes. The plants are inside plastic pots fitted with the PVC pipe at regular or desired interval. The main and sub-main pipes are fixed over the raised platform made inside the protected structure. Pump, tanks, valves, timers and other accessories including nutrient monitoring system are placed over the floor of the protected structure. PVC pipes are arranged in single horizontal plain or in multiple zig-zag vertical plain.

Non-Circulating Open system is the system in which nutrient solution is not circulated but used only once for a longer duration depending upon the EC and pH of the nutrient solution.

Root Dipping Technique: Plants are grown in small pots filled with growing media. The bottom 2-3 cm of the pots is submerged in the nutrient solution. Roots are hanged in air and also submerged in the nutrient solution. This technique is very simple, cheap and can be constructed easily.

Floating Technique: It uses shallow containers (10 cm deep) and is similar to box method. In this technique plants are established in small pots and fixed to Styrofoam sheet or other similar light plate and allowed to float on the nutrient solution filled in the container. Artificial aeration is required for the solution.

Capillary Action Technique: In this technique planting pots of different shapes and sizes are used. Pots are filled with highly porous material like old coil dust filled with sand or gravel. Nutrient solution rises to the pots filled with porous material by capillary action. This technique is suitable for indoor plants and ornamental flowers. Artificial aeration is required for the solution.

Solid media culture (Aggregate systems): Solid media with high porosity, better aeration, high water and air holding capacity and efficient drainage are used in sterilized form for growing plants. The most common examples are coco-peat, perlite, vermiculite, vermi-compost, gravel, tur, rockwool, saw dust, coconut fibre and peat moss.

Hanging bag Technique: In this technique thick UV stabilized polyethylene bags filled with cocopeat or coconut fibre in cylindrical shape one meter high are used to grow plants. The bags are suspended vertically and supported overhead and collecting channel is placed below for the nutrient solution. Micro sprinklers are attached inside the hanging bag for supply of nutrient and water to the plants attached to the holes inserted in the bag. It is suitable for growing lettuce, leafy vegetables, strawberry and small flower plants.

Grow Bag Technique: In this technique grow bags made with UV stabilized polyethylene sheets of 1 meter length, 15-20 cm width and 8-10 cm height are used for growing plants. Single or paired rows can be used with the plant spacing kept at 30-60 cm depending on the type of crops. Fertigation is done with special stake drippers fitted with poly tubes and lateral pipes. It is very common, cheap and easy technique. The entire floor is covered with white UV resistant polythene before placing the grow bags for efficient sunlight supply, lowering of relative humidity and fungal diseases incident.

Trench or trough technique: In this technique plants are grown in trenches or trough made with UV stabilized PVC/HDPE sheet, bricks, concrete or other local material. Trench or trough is filled with inert organic, inorganic or mixture of materials like coco-peat, sand, perlite, vermiculite with the depth ranging from 30-60 cm depending on the type of crops. Fertigation is done with special stake drippers fitted with poly tubes and lateral pipes. Drainage is very important, which can be provided with holes or separate drainage pipe.

Pot technique: In this technique readymade pots made of plastic in the range of 4 inch to 12 inch diameter are used for growing plants. Pots are filled with inert organic, inorganic or mixture of materials like coco-peat, sand, perlite, vermiculite etc. The volume of the container and growing media depends on type of crops and it varies from 01-10 litres. Fertigation is done with special single/multiple outlet stake drippers fitted with poly tubes and lateral pipes.

Aeroponics technique: It is a technique of growing plants in suspended air in Styrofoam panels with the roots hanging inside dark chamber created to promote growth. Plants are supported by tailor made holes in Styrofoam panels. The nutrient solution is sprayed in fine mist form to the suspended roots in calculated cyclic form for few seconds in every 2-3 minutes. Roots are kept properly hydrated and aerated as per the need of the plant. Aeroponics is practised inside protected structures and is found to be suitable for leafy vegetables like spinach, lettuce etc. It is found to be very efficient technique for space utilization inside protected structures as in some cases almost double no of plants can be grown in aeroponics system. Fertigation nutrient solution conc. for mini tuber potato in aeroponics in Table 3.

Table 3 : Fertigation Nutrient Solution Conc. for Mini Tuber Potato in Aeroponics

Element	0-35 Days	After 35 Days
Potassium K	200 ppm	250 ppm
Nitrogen N	190 ppm	150 ppm
Calcium Ca	150 ppm	150 ppm
Sulphur S	70 ppm	90 ppm
Magnesium Mg	45 ppm	45 ppm
Phosphorous P	35 ppm	35 ppm
Iron Fe	1.0 ppm	1.0 ppm
Manganese Mn	0.5 ppm	0.5 ppm
Boron B	0.50 ppm	0.50 ppm
Zinc Zn	0.15 ppm	0.15 ppm
Copper Cu	0.10 ppm	0.10 ppm

Soil-less culture helps in intensive production of crops in greenhouse. It guarantees flexibility and intensification of crop production system in areas with adverse growing conditions. The main advantages of soil-less culture are the precise control over the supply of water and nutrients, pH and root temperature, elimination of soil-borne diseases, reduction of labour requirement, more crops per year etc. Soil-less culture is becoming very popular technology as it has become the substitute for the places where the soil health is very poor and there are abundant and frequent soil borne diseases. The most effective fumigant presently being used for treatment of soil throughout the world is Methyl Bromide. It has been proved through research that methyl bromide is damaging the vital ozone layer of the atmosphere. Therefore, most of the countries have either banned or in the process of banning the use of methyl bromide for soil treatment. Moreover, the continuous crop production inside greenhouse results in build up of salts, damaging soil structure, increasing pH and EC of soil. In these circumstances, soil less production system has its own advantages. Therefore it is necessary to develop a sound fertigation strategy for growing horticultural crops in soil-less media.

Protected structures for Hydroponics Cultivation Technology

Vegetable and flower production is significantly influenced by the seasonality and weather conditions. The extent of their production causes considerable fluctuations in the prices and quality of vegetables. Striking a balance between all-season availability of vegetables and flowers with minimum environmental impact, and still to remain competitive, is a major challenge for the implementation of modern technology of crop production.

The crop productivity is influenced by the genetic characteristics of the cultivar, growing environment and management practices. The plant's environment can be specified by five basic factors, namely, light, temperature, relative humidity, carbon dioxide and nutrients. The main purpose of protected cultivation is to create a favourable environment for the sustained growth of plant so as to realize its maximum potential even in adverse climatic conditions. various type of protected structures, as per location, crop and in treatment are available. Therefore, we need to develop hydroponics system accordingly.

Protected Structures for Hydroponics Technology:

Most of the traditionally used protected structures like greenhouse, nethouse, walking tunnel etc with little modifications can be used for hydroponics system. Hydroponics system normally requires specialized structures and micro-climate, which can be cosntroled inside protected structures. Specialized structures required for hydroponics like stand, piping system, grow bags, troughs, containers, pot stands, chambers etc can be made or constructed inside protected structures with additional investment ranging from 10-30% of the overall cost of the structure. Micro-climate required for hydroponics in the form of temperature, humidity and sunlight intensity can be provided by installing additional system inside protected structures. Exhaust fan, cooling pad, chillers, dehumidifier, foggers, heaters etc. are required for protected structures suitable for specialized hydroponics system. Simple hydroponics system can be installed in very primitive and traditional protected structures with little investment, though it may be difficult to maintain them infection and pest free.

Protective Structures / Methods

The kinds of protective structures for crop production range from simple provisions such as rain shelters, shade houses, mulches, row covers, low tunnels, cloches to greenhouse structures with passive or active climate control. Salient points of various structures are as under;

Greenhouses

A greenhouse is quasi-permanent structure, covered with a transparent or transluscent material, ranging from simple home made designs to sophisticated pre-fabricated structures, wherein the environment could be suitably modified for the propagation or cultivation of plants. Materials used to construct a greenhouse frame may be wood, bamboo, and steel or even aluminum. Coverings can be glass or various rigid or flexible plastic materials.

Plant Environment and Greenhouse Climate

A plant grows best when exposed to an ideal environment for that particular plant species. The aerial environment for the plant growth can be specified by the following factors:

- Heat or temperature
- Light
- Relative humidity
- Carbon dioxide

Materials of Greenhouses

As mentioned earlier, the purpose of a greenhouse covering is to amply allow sunlight sufficient for photosynthesis yet separate and protect the crop inside from outside factors. Glass was the main covering material in the early greenhouses. Apart from the plastic materials, there are now several alternatives available for greenhouse coverings like glass, acrylic, polyethylene film, polycarbonate sheet etc. for different objectives.

Types and Designs of Greenhouses:

The greenhouse design and cost range from a simple plastic walk-in tunnel costing about Rs.200/m2 to a climate-controlled, saw-tooth greenhouse with automatic heating, ventilation and cooling, costing more than Rs.3000/m2. The selection of the greenhouse design should be determined by the grower's expectations, need, experience, and above all its cost-effectiveness in relation to the available market for the produce. Obviously, cost of greenhouse is very important and may outweigh all other considerations. Greenhouses are classified in different shapes, which also determine their cost, climate control and use in terms of crop production. Commonly used structural designs suitable for hydroponics greenhouse are gable, gambrel, skillion, raised arch and saw tooth.

Naturally Ventilated Greenhouse:

It is the most common and most popular greenhouse type for Indian farmers. It is a zero energy model greenhouse with natural ventilation from sides and top. Saw tooth type greenhouse design has the maximum ventilation and is most effective and suitable for crop production. This type of greenhouse can be used for crop production ranging from 9-12 months depending upon the location and climatic factors. It is found to be suitable for hydroponics cultivation only in limited areas having mild climate.

Semi- Climate and Climate Controlled Greenhouse Design:

Apart from the basic specifications required for the naturally ventilated greenhouses as mentioned above, the following design specifications are required for the semi-climate and climate controlled greenhouse. It is found to be highly suitable for hydroponics cultivation.

- Exhaust Fans for removal of hot air inside greenhouse

Fig 2. Climatic Controlled Greenhouse for Hydroponics Cultivation

Drip Irrigation and Fertigation System for Hydroponics Cultivation Technology

Drip irrigation is the best available technology for the judicious use of water for growing vegetable in large scale on sustainable basis. Drip irrigation is a low labor intensive and highly efficient system of irrigation, which is also amenable to use in difficult situations and problematic soils, even with poor quality water. Irrigation water savings ranging from 30-80% can be affected by adopting a suitable Drip irrigation system. Drip irrigation or low volume irrigation is designed to supply filtered water directly to the root zone of the plant so as to maintain the suitable moisture near to field capacity level for most of the time. Water and fertilizer saving around 25 and 30 percent respectively through drip fertigation system over traditional irrigation system was reported for various fruit crops for Delhi region. The field capacity of moisture level is found to be ideal for efficient growing of vegetable plants. This is due to the fact that at this level the plant gets ideal mixture of water and air for its development. The device that delivers the water to the plant is called dripper. Water is frequently applied to the soil through emitter placed along a water delivery lateral line placed near the plant row. The principle of drip irrigation is to irrigate the root zone of the plant rather than the suitable and getting minimal wetted surface. This is the reason for getting very high water application efficiency (90-95%) through drip irrigation. The area between the crop row is not irrigated therefore more area of land can be irrigated with the same amount of water. Thus water saving and production per unit of water is very high in drip irrigation. Also the important characteristics of irrigation water suitable for hydroponics have to meet specific standards in terms of its chemical properties and quality parameters as seen in Table 4.

Table 4: Characteristics of Irrigation Water Suitable for Hydroponics

Parameters	Unit	Optimum Value
EC	dS m^{-1}	0.5-2.0
pH	-	6.8-7.5
Bicarbonates	mol m^{-3}	2-6
Nitrates	mol m^{-3}	0.5-2
Ammonium	mol m^{-3}	0.1-1.0
Phosphorous	mol m^{-3}	0.3-1.0
Potassium	mol m^{-3}	0.5-2.5
Calcium	mol m^{-3}	1.5-5.0
Magnesium	mol m^{-3}	0.75-2.0
Sodium	mol m^{-3}	3-10
Chlorides	mol m^{-3}	3-10
Sulphates	mol m^{-3}	2-4
Iron	mol m^{-3}	<90
Boron	mol m^{-3}	30-100
Copper	mol m^{-3}	<15
Zinc	mol m^{-3}	<30
Manganese	mol m^{-3}	<10

Drip irrigation and fertigation system is the best available technology for the timely supply of water and nutrients in judicious manner to the crops grown in soil-less media inside grow bags or tailor made containers. In-line and stake drippers are specially suitable for soil-less media. Low volume high frequency irrigation concept is popularly used for different horticultural crops grown in soil-less media. Irrigation and fertigation scheduling are very sensitive to different soil-less media and therefore appropriate fertigation management is required for it.

Table 5 shows important characteristics of greenhouse soil-less media from fertigation point of view.

Table 5: Important Characteristics of Greenhouse Soil-less Media

Parameters	Unit	Optimum Value
EC	dS m^{-1}	<1.50
pH	-	5.5-6.0
Nitrates	mg L^{-1}	50-70
Ammonium	mg L^{-1}	3-6
Phosphorous	mg L^{-1}	3-5
Potassium	mg L^{-1}	50-100
Calcium	mg L^{-1}	50-80
Magnesium	mg L^{-1}	20-30
Sodium	mg L^{-1}	<90
Chlorides	mg L^{-1}	<90
Sulphates	mg L^{-1}	40-90
Iron	mg L^{-1}	0.5-1.0
Boron	mg L^{-1}	0.2-0.4
Copper	mg L^{-1}	0.05-0.1
Zinc	mg L^{-1}	0.1-0.2
Manganese	mg L^{-1}	0.2-0.4

Fertigation Accessories for Hydroponics System:

- Pressure gauge for optimum pressure (2-6 bar)
- Filters (120-200 micron)
- PVC Tanks (200-1000 liter)
- Venturi/Reciprocating Pump/Mixing tank for fertilizer injection
- EC and pH measuring device
- Controllers/valves for automation

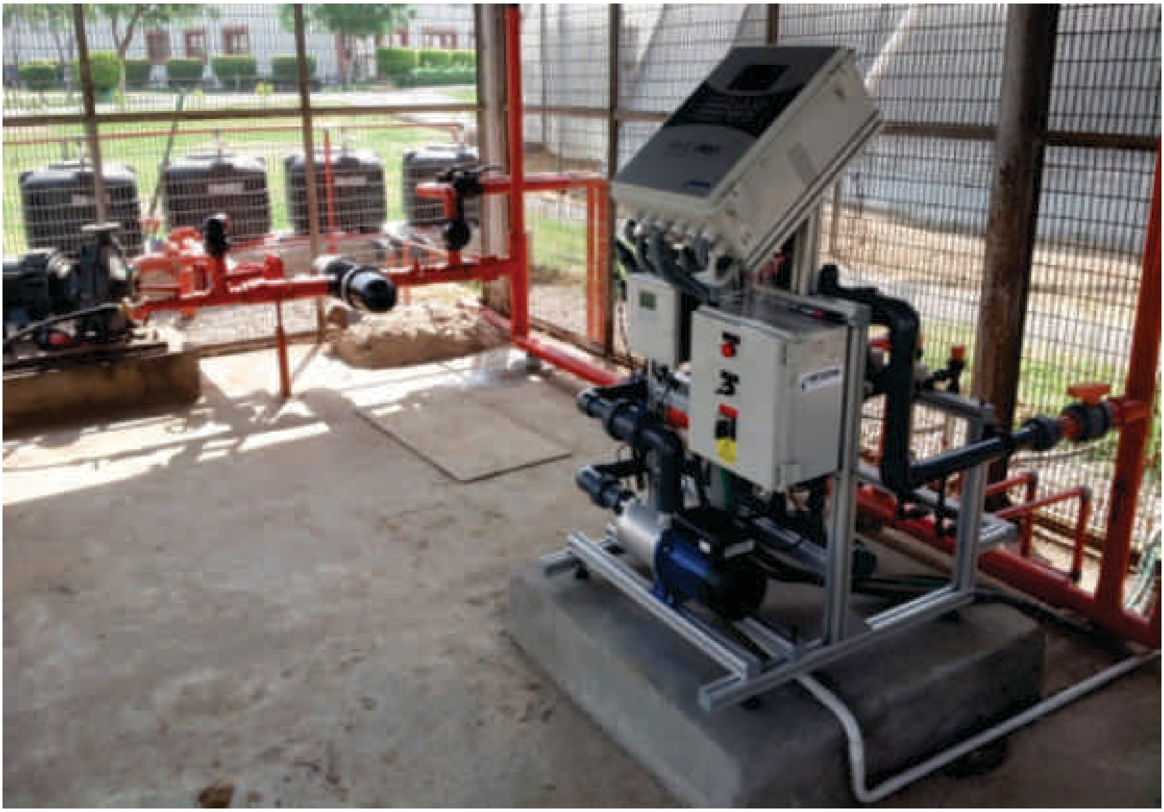

Fig 3 Fertigation system for Hydroponics Cultivation

Fertigation Management in Greenhouse Hydroponics crops

Table 6: Standard Major Nutrient Solution for Fertigation in Hydroponics

Major Nutrient	Conc. (mmol/L)	Conc. (ppm)
Nitrate	14	196
Dihydrogen Phosphate	1	97
Sulphate	2	192
Potassium	6	240
Ammonium	1	14
Calcium	4	160
Magnesium	2	48

The growth of vegetables and flowers in greenhouses built on sandy dunes and with inert substrates requires a special and precise control of the fertigation because the CEC of these growing media are very low and therefore they do not provide nutrients. The only source of nutrients is fertigation. Growing plants in containers allows the collection of the leaching water and its comparison with irrigation water. The measurement of EC, pH and nutrients concentration of the leached solution indicates if fertilizers are being applied in excess or in deficient and therefore allows the consecutive correction of the fertigation regime. It is recommended to collect the leached solution from the containers and the solution from the drippers, and to compare both solutions on a daily basis. A higher value of EC in the leached solution than in the applied solution indicates that the plant absorbs more nutrients than water, therefore we must apply greater amount of water to the plant. On the other hand, if the difference between the EC of the leached solution and the incoming solution is less than 0.4-0.5 dS/m, we must apply a leaching irrigation to wash the excess salt. The optimal pH value of the irrigation solution must be around 6 and the pH of the leaching solution should not exceed 8.5. A more alkaline pH in the leaching solution indicates that pH in the root zone reaches a value that causes phosphorus precipitation and decreases micronutrient availability. When pH in the leachate is higher than that of irrigation water we must adjust NH_4/NO_3 ratio of the irrigation solution by increasing the NH_4 proportion. When pH in the irrigation solution is higher than 6, we must add acid to the solution to lower the pH. The chloride accumulation in the root zone can be removed by applying irrigation without fertilizer. Standard major and micro-nutrient solution for fertigation in hydroponics are given in Table 6 and 7, respectively.

Table 7: Standard Micro Nutrient Solution for Fertigation in Hydroponics

Micro Nutrient	Conc. (µmMol/L)	Conc. (ppm)
Iron	25	1.4
Manganese	9	0.50
Zinc	0.75	0.05
Copper	0.3	0.02
Boron	46.3	0.50
Molybdenum	0.1	0.006

Fertigation Strategy for Soil-less Cultivation:

Due to compatibility issue among different water soluble fertilizers, it is recommended to use at least two tanks for stock solution. Tank A should contain Calcium and Magnesium related fertilizers and tank B should contain Phosphorous and sulphur related fertilizers. Nitrogen and potassium fertilizers can be used in both tanks, while chelated micronutrients should be a part of tank B.

Table 8: Chemicals needed to prepare 1000 L of nutrient solution for hydroponics fertigation (Dr Alan Cooper Formula)

Nutrient	Weight in g
Pot. dihydrogen phosphate	263
Pot. Nitrate	583
Calcium Nitrate	1003
Mag. Sulphate	513
EDTA Iron	79
Manganese Sulphate	6.1
Boric Acid	1.7
Copper Sulphate	0.39
Ammonium Molybdate	0.37
Zinc Sulphate	0.44

Table 9: Chemicals needed to prepare 1000 L of nutrient solution for hydroponics fertigation (Albert Mixture)

Nutrient	Weight in g
Potassium Nitrate	38
Calcium Nitrate	952
Mag. Sulphate	308
EDTA Iron	8
Zinc Sulphate	0.15
Boric Acid	0.20
Manganese Sulphate	1.15
Copper Sulphate	0.10
Mono Pot. phosphate	269
Potassium sulphate	423
Ammonium Molybdate	0.03

EC and pH should be regularly monitored. Proper striation of the solution is also required for effective fertigation. The solution temperature should be kept in desirable level as per the climatic condition. The concept of ppm for nutrient concentration is found to be very effective for hydroponics cultivation. The necessary calculation as per the crop stage should be done in advance and then the fertigation should be done accordingly. Stock solutions are taken from both the tanks and mixed with irrigation water for effective dilution normally in the range of 1-3 Liter concentrated solution with 1000 liter of normal irrigation water. Ec and pH should be monitored finally before final delivery to the crop.

Fig 4. Water and Nutrient Balance study for Hydroponics cultivation

Fig 5. Monitoring of EC, pH and moisture for Hydroponics Cultivation

Plug Tray Nursery Raising Technology under Hydroponics Cultivation

The plug-tray nursery raising technology is aimed to produce disease-free, vigorous and season-independent seedlings using protected environment. Depending on the objective, different types of protected structures, like greenhouse, net-house and poly-tunnels are used to take care of biotic and abiotic stresses during seedling raising period. In order to raise high density seedlings without root-borne diseases, plastic pro trays and sterilized soil-less growing media are used. The type and ingredients of soil-less media used for nursery raising have been standardized as also the size and volume of the cells of pro-trays for different vegetable crops. Irrigation and fertigation schedules have also been standardized for raising of seedlings of different vegetables in different seasons. The root development under this system of nursery raising is so vigorous that no mortality occurs during transplanting period.

This technology has a very high potential of adopting as an agro-enterprise supporting production of most horticultural crops. A suitable protected structure, depending on the local climate and scale of operation, is constructed. All the required ingredients of the process, like plastic trays, growing media, nutrients, seeds etc are commercially available. The technology provides a package of processes required to raise healthy nursery in a given time frame. The highlights of the technology are summarized below:

i. It is an excellent proposition to grow high-density seedlings and propagate any suitable plant material required for higher productivity of horticultural crops.

ii. It is possible to raise disease-free nursery independent of season.

iii. Nursery of cucurbits during off-season can be raised to get higher returns from the crop.

iv. It can be adopted as self-employed enterprise by agri.-graduates or progressive farmers for enhancing incomes.

Fig 6. Greenhouse Hydroponics Cultivation for Plug Tray Nursery Raising

Production Technology of Vegetables Grown under Hydroponics Cultivation

The most common vegetables grown under greenhouse soil-less cultivation are Tomato, capsicum, cucumber and melon. The brief production technology of above vegetables is discussed as below.

Capsicum: Sweet pepper or capsicum is a very important greenhouse crop. It can tolerate day temp greater than 30°C as long as night temp is in the range of 21-24°C. It can be best grown in well drained loam or sandy loam soil with pH 5.5-7.0. Sweet peppers are mostly available in green, red and yellow color with the market preference for four lobbed square shaped fruit. 30 days old seedlings are transplanted inside the greenhouse at a planting distance of 30x60cm. Three seedlings can be transplanted in one meter long soil-less grow bag filled with cocopeat, perlite, vermiculite, tuff or mixture of above. About 5000 seedlings are transplanted inside 1000 m² greenhouse. Drip irrigation requirement varies from 2-7 m³/day/1000m². The fertigation requirement varies from N 80-100 ppm, P 50-80 ppm and K 100-150 ppm for the major nutrient applies for different growth stages of the crop. The average yield varies from 60-70 t and 100-120 ha, respectively, for coloured and green capsicum. Capsicum is found to be sensitive to the salinity of irrigation/fertigation and growing media. It is highly sensitive to calcium deficiency resulting in BER symptom. Efficient flowering and fruiting requires optimal night temperature (18-20°C) and day temperature (25-28°C) respectively. Relative humidity in the range of 60-75 % is ideal for efficient plant growth. Flowers are self pollinators but bumble bees are recommended for efficient fruit setting. The major pests found to effect capsicum crops are spider mite, thrip, aphid, caterpillar and white fly. Capsicum can be grown in walking tunnel, net house and greenhouse with soilless media. Drip irrigation and fertigation scheduling details for soil-less grow bags grown capsicum are shown in Table 10 and 11, respectively.

Table 10: Drip Irrigation Scheduling Details for Soilless Grow Bag System for Capsicum

Item/Month	Nov	Dec	Jan	Feb	Mar
CWR* per plant	250 ml	300 ml	400 ml	600 ml	800 ml
CWR for 200 sqm Greenhouse	125 L	150 L	200 L	300 L	400 L
No of Irrigation	4	5	5	6	8
Irrigation Duration	15 min	20 min	25 min	35 min	50 min
Irrigation Interval	6 days	5 days	5 days	4 days	3 days

* CWR: Crop water requirement

Table 11: Fertigation Scheduling Details for Soilless Grow Bag System for Capsicum

Stages/Macro Nutrient (ppm)	N	P	K	Ca	Mg	S
Vegetative	100-120	40-60	100-120	100-150	40-45	50-55
Flowering-Fruiting	120-140	60-80	150-180	150-180	45-50	55-60
Harvesting	140-180	80	180-200	160-200	50-60	60-70

Cucumber: It is the most popular greenhouse vegetable crop. It can be grown round the year inside greenhouse, with the possibility of taking up to four crops. It requires temp ranging from 15-22°C for better and maximum fruit development. Well drained loam or sandy loam soil having pH in the range of 5.5-6.8 is best suitable for it. 25-30 days old seedlings are transplanted inside the greenhouse at a planting distance of 30x60cm. About 4000 seedlings are transplanted inside 1000 m² greenhouse. Different gynoecious/parthenocarpic varieties are grown inside greenhouse with the average yield ranges from 120-150 tonnes per hectare. Drip irrigation requirement varies from 3-8 m³/day/1000m². The fertigation requirement varies from N 80-100 ppm, P 60-80 ppm and K 100-140 ppm for the major nutrient applies for different growth stages of the crop.

Table 12: Drip Irrigation Scheduling Details for Soilless Grow Bag System for Cucumber

Item/Month	July	Aug	Sept	Oct
CWR* per plant	300 ml	400 ml	600 ml	900 ml
CWR for 200 sqm Greenhouse	150 L	200 L	300 L	450 L
No of Irrigation	6	8	9	10
Irrigation Duration	20 min	25 min	35 min	55 min
Irrigation Interval	5 days	4 days	3 days	3 days

Table 13: Fertigation Scheduling Details for Soilless Grow Bag System for Cucumber

Stages/Macro Nutrient (PPM)	Nitrogen	Phosphorous	Potassium	Calcium	Magnesium	Sulfur
Vegetative	100-140	60-80	120-150	100-140	40-45	50-55
Flowering-Fruiting	140-150	80-100	150-180	150-180	45-50	55-60
Harvesting	150	80	180-200	160-200	50-60	60-70

Tomato: It is a very popular greenhouse soil-less vegetable crop, which can be grown round the year inside greenhouse. 4he night temperature range 16-22°C is the most critical factor for the tomato fruit setting. The ideal temperature range is 16-25°C for better fruit development. Slicing and cluster types are two major tomato varieties transplanted in the month of August-September for Indian condition. 28-30 days old seedlings are transplanted at the spacing of 60x50cm, with planting density of about 2000 plants for 1000 m² drip fertigated greenhouse. Three seedlings can be transplanted in one meter long soil-less grow bag filled with cocopeat, perlite, vermiculite, tuff or mixture of above. Greenhouse grown tomatoes needs regular trellising, training and pruning of plants. One single main stem is retained by removing all side shoots or suckers that develop between leaf petioles and the stems. Greenhouse grown tomato requires pollination inside greenhouse, which is usually provided either by Bumble bees or by vibrators. Drip irrigation requirement varies from 2-8 m³/day/1000m². The fertigation requirement varies from N 80-150 ppm, P 50-60 ppm and K 100-180 ppm for the major nutrient applies for different growth stages of the crop. Greenhouse tomato yield varied from 150-200 t and 200-300 t/ha, respectively for cherry tomato and slicing type big tomato. It tolerates saline water up to 3 dS/m (mmhos/cm) and fertigation pH in the range of (5.5-5.8) is found to be ideal. It is found to be highly sensitive to calcium deficiency resulting in Blossom End Rot (BER). Proper Zn and Mn nutrition result in alleviation of stress under saline condition. Common nutrient deficiency under soilless condition: K deficiency affecting fruit quality mainly colour and blotch ripening, Ca deficiency causing BER, Mg deficiency in acidic condition and B, Fe and Mn deficiency in alkaline condition.

Table 14: Fertigation Nutrient Concentration (ppm) for Greenhouse Tomato in Soil -less Cultivation

Growth Stage	N	P	K	Ca	Mg	S
Vegetative	100-120	40-50	100-120	100-150	40-50	50-55
Flowering-Fruiting	120-140	50-60	140-180	150-180	40-50	55-60
Harvesting	140-180	60	180-200	160-200	50-60	60-70

Fig 7. Greenhouse Vegetables in Hydroponics Cultivation

Production Technology of Flowers Grown under Hydroponics Cultivation

The most common flowers grown under greenhouse soil-less cultivation are rose, gerbera, chrysanthemum, lilium and melon. The brief production technology of above flowers is discussed as below.

Rose: Greenhouse rose is the most important cut flower grown round the year. It requires day and night temperature in the range of 24-26°C and 16-20°C respectively, relative humidity (50-60%) for optimum

Table 15: Fertigation stock solution for Rose in soilless cultivation

Tank A (1000L)	Tank B (1000L)
Calcium Nitrate: 75 Kg	Potassium Nitrate: 25 Kg
Potassium Nitrate: 8 Kg	Mono Pot. Phosphate MPP: 18 Kg
Iron EDTA: 3500 g	Mag. Sulphate: 40 Kg
Magnesium EDTA: 300 g	Mono Ammon. Phosphate MAP: 3 Kg
Zinc EDTA: 150 g	Borax: 300 g
Copper EDTA: 50 g	Sodium Molybdate: 25 g

growth and better yield. It requires light texture soil with pH 6.0-6.5 and Ec up to 1.5 dS/m. Roses are planted at the spacing of 20 cm Plant to plant and 40 cm row to row, with two rows per bed width of 1.2 m. Planting density varies from 70,000 to 1,40,000 plants per hectare depending upon different varieties. Bending, pruning, pinching, disbudding, de-shooting are regular operations. It can be grown very well in soil-less growing media such as sand, rockwool, coco-peat and perlite within pot or grow bag. The important propagation methods are cutting, T budding and micro propagation. Common diseases found in greenhouse rose are die back, black spot, powdery and downey mildew, rust and wilt. The main insect pests found to effect greenhouse rose are mites, aphids, thrips, ants and bugs. The average yield of greenhouse rose varies from150-300 stems/m²/year depending upon climate, varieties and management.

Carnation: It is a very popular greenhouse cut flower due to extended vase life, lighter weight and availability in vast range of colors. Standard, spray, micro and mini are the four major types of florist carnation.It requires day and night temperature in the range of 18-23°C and 10-15°C respectively, relative humidity (50-60%) for optimum growth and better yield. The important propagation methods are terminal stem cutting and micro propagation. The planting time varies between Sept-Oct in the plains and Oct-March in the hills. The planting density varies from 25-40/m² within the spacing of 20*20 cm and 30*30 cm respectively for standards and spray types. Pinching, de-shooting, staking, disbudding and weeding are regular operations. The three common grades in India are A(>45cm), B(30-45cm) and C (<30cm). Common diseases found in greenhouse carnation are wilt, foot rot, stem rot, rust and blight. The main insect pests found to effect greenhouse carnation are mites, aphids, thrips and caterpillars. The average yield varies from 200-300 stems/m²/year depending upon climate, varieties and management.

Table 16 : Fertigation stock solution for Carnation in soilless cultivation

Tank A (1000 L)	Tank B (1000 L)
Calcium Nitrate: 80 Kg	Potassium Nitrate: 42 Kg
Potassium Nitrate: 6 Kg	Potassium Sulphate: 4 Kg
Iron EDTA: 2300 gm	Mono Potassium Phosphate: 14 Kg
Magnesium EDTA: 430 g	Mag. Sulphate: 25 Kg
Zinc EDTA: 180 g	Mono Ammon. Phosphate: 3 Kg
Copper EDTA: 30 g	Borax: 300 g Sod. Molybdate: 12 g

Chrysanthemum: It is a very popular greenhouse cut flower due to extended vase life, varieties of colors and light flower weight. It is a short day plant variety. It requires day and night temperature in the range of 18-21°C and 10-16°C respectively, relative humidity (50-60%) and light intensity (1.2-1.6 MJ/m²/day) for optimum growth and better yield. The important propagation methods are terminal stem cutting (June-July) and Suckers (Feb to April). The planting density varies from 40-54/m²for greenhouse cut flowers and 20-25/m2 for loose flowers. The spacing varies from 20*20 cm and 30*30 cm respectively for standards and spray types. Pinching, de-shooting, staking and disbudding are regular operations. Common diseases found in greenhouse carnation are wilt, foot rot, stem rot, bacterial rot, powdery mildew and blight. The main insect pests found to effect greenhouse carnation are mites, aphids, thrips and caterpillars. The average yield varies from 150-250 system/m²/year depending upon climate, varieties and management.

Table 17: Fertigation stock solution for Chrysanthemum in soilless cultivation

Tank A (1000 L)	Tank B (1000 L)
Calcium Nitrate: 75 Kg	Potassium Nitrate: 40 Kg
Potassium Nitrate: 6 Kg	Potassium Sulphate: 5 Kg
Iron EDTA: 2200 g	Mono Potassium Phosphate: 14 Kg
Magnesium EDTA: 400 g	Magnesium Sulphate: 25 Kg
Zinc EDTA: 180 g	Mono Ammon. Phosphate: 3 Kg
Copper EDTA: 30 g	Borax: 300 g Sod. Molybdate: 10 g

Table 18: Fertigation st ock solution for Gerbera in soilless cultivation

Tank A (1000 L)	Tank B (1000 L)
Calcium Nitrate: 54 Kg	Potassium Nitrate: 32 Kg
Potassium Nitrate:16 Kg	Potassium Sulphate: 4 Kg
Iron EDTA: 3200 g	Mono Potassium Phosphate: 3 Kg
Magnesium EDTA: 210 g	Mag. Sulphate: 25 Kg
Zinc EDTA: 180 g	Mono Ammon. Phosphate: 12 Kg
Copper EDTA: 30 g	Borax: 300 g Sod. Molybdate: 12 g

powdery mildew and blight. The main insect pests found to effect greenhouse gerbera are white fly, mites, aphids, thrips, nematodes and caterpillars. The average yield varies from 200-250 flowers/m²/year depending upon climate, varieties and management.

Lilium: It is a popular greenhouse cut flower widely grown by farmers in soil-less cultivation. Oriental and Asiatic are two main distinct Lily groups. Oriental lily is late flowering, having white and pink fragrant flowers and large bulbs 16-22 cm. Asiatic Lily is having extended flowering period, wide range of colours from orange, red, yellow etc, odourless flowers and small bulbs 10-16 cm. It requires day and night temperature in the range of 18-25°C and 12-18°C respectively, partial shade (40-50%) and proper ventilation for optimum growth and better yield. Bulbs, bulblets, scales and bulbils are the important propagation methods. Optimum planting time is Oct-Nov in Plains and Feb-March in hills. Planting density and spacing depends upon group of Lilium, bulb size and place of cultivation. Planting density varies from 25-50 and 40-90 bulbs/m² for Oriental and Asiatic Lily, respectively, depending upon bulb size mainly. Common diseases found in greenhouse lilium are gray mould, soft bulb rot, fusarium bulb rot, brown scale, root rot, bacterial rot and viral diseases. The main insect pests found to effect greenhouse lilium are white fly, mites, aphids and thrips. The average yield varies from 150-200 flowers/m²/year depending upon climate, varieties and management.

Fig 8. Greenhouse Flowers in Hydroponics Cultivation

Table 19: Range of Climatic parameters for Crops grown in Hydroponics cultivation

Crops	Optimal Day Temp. (^{0}C)	Optimal Night Temp. (^{0}C)	RH (%)
Capsicum	25-30	21-24	60-75
Cucumber	25-30	15-20	50-70
Tomato	18-25	16-22	50-65
Rose	24-26	16-20	50-60
Carnation	18-23	10-15	50-60
Gerbera	16-22	12-15	50-70
Chrysanthemum	18-21	10-16	50-60
Lilium	18-25	12-18	40-60

The range of climatic parameters for crops grown in hydroponic cultivation is summarized in Table 19.

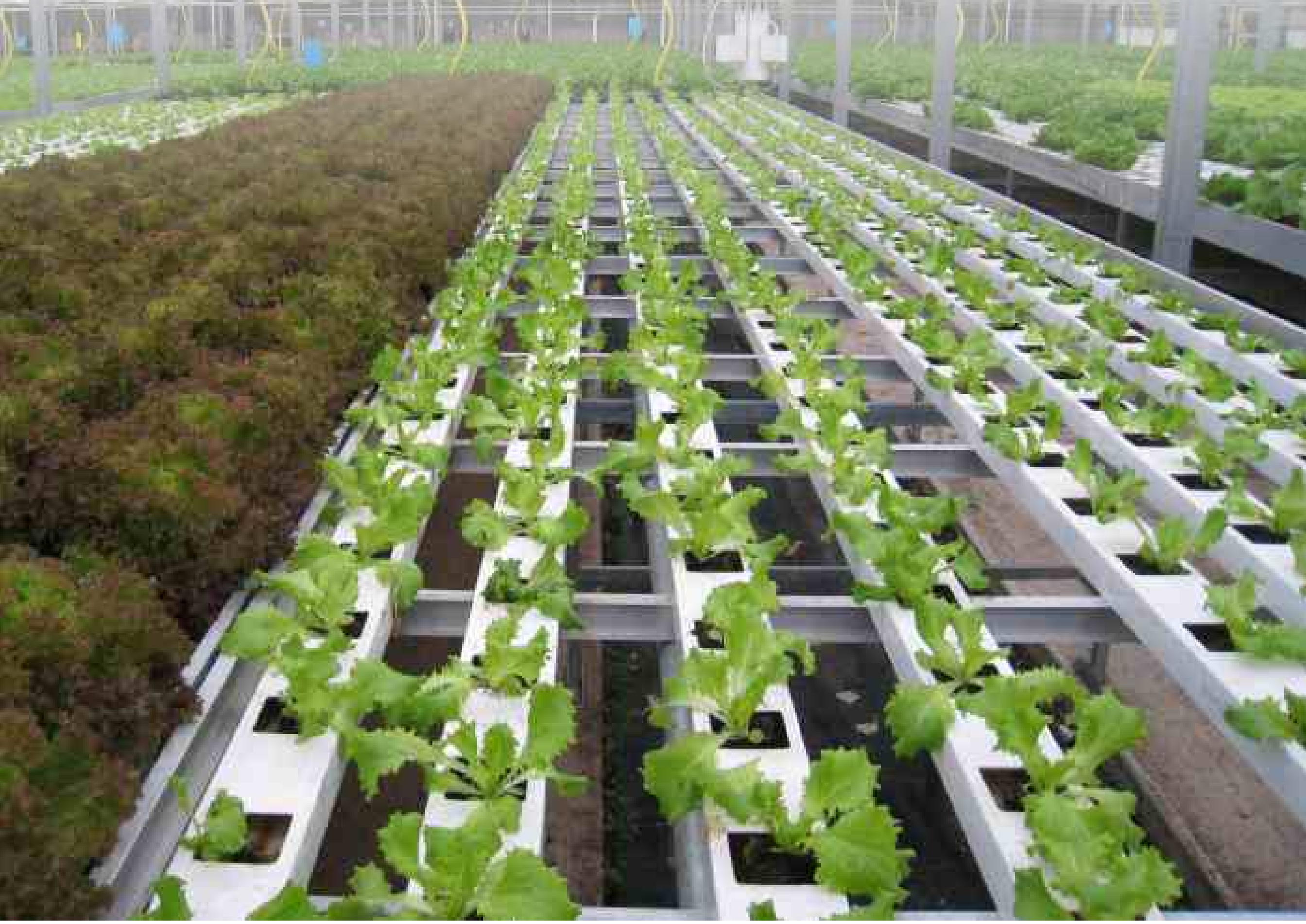

Fig. 9 Hydroponic System in Liquid Media

Fig. 10 Aeroponic System

Good Agricultural Practices (GAP) and IPM for Hydroponics Cultivation

GAP and Hydroponics Cultivation

Protected Hydroponics cultivation technology including greenhouse production systems require adherence to GAP protocols because intensive cultivation in greenhouses often involves excessive use of chemicals since the stakes are high due to intensive inputs and high expectations on quality front. Therefore, perennial production leads to the build up of severe pest related problems. Older greenhouses often suffer still severe pest situations and hence maintaining economic profitability of farms is difficult without high chemical inputs as pest multiplication is much faster - compelling growers to resort to excessive chemical use. Therefore, greenhouse production systems require even stricter adherence to GAP protocols. In soilless cultivation GAP protocol adherence is equally important because the quality expectations from such production systems are much higher.

Standards and Record Keeping for Export Oriented Greenhouse Hydroponics Production and Processing Units

- Land used, adjacent land use records, animal and wildlife activities, landfills, hazards including industrial effluent/dumping/disposal sites besides animal intrusion records and exclusion arrangements should be documented, for in and around the production facility.
- Farm production units should be allotted/assigned designation plot series and displayed on site maps and history.
- Record keeping of any production /processing unit actually mirrors the evidence of facilities, infra-structure and operating conditions, indeed the entire work culture as well. Adherence to man and machine, procedure and operating conditions, environmental assessment, employee hygiene, health of employees (for symptoms of fever, diarrhoea, dysentery, vomiting and other infectious/contagious diseases, besides open wounds, sores, burns, boils etc should be regularly supervised near harvest and processing facilities) and their training water usage, pest control, inputs and their labels must be produced within reasonable time limits.
- Record of all sources of inputs used including - seed, planting material, fertilizers, pesticides, bioagents, pollinators, post-harvest paraphernalia and procedures.
- Water used - quality standards/tests conducted/irrigations followed and crop protection sprays undertaken, besides microbial analysis including record of any contramination history, treatment, recycle and alternative sources of water. Cold water immersion is not advised. Washing water may be treated with hypochlorite/ozonated/peroxyacetic acid/aqueous chlorine dioxide, registered disinfectants against *Salmonella* and *E. coli* etc.
- Hygienic practices followed - written policies and employee training records with self-audit. Toilet practices around premises and facilities for workers and waste disposal records. Canteen, eating facilities including drinking water facilities. Jewellery restrictions, hair restraints, nails restraint, plastic aprons. Use of gloves during harvesting/processing (single use disposable ones/reusable ones with full standards of manufacturing quality etc.). Routine sanitation procedures, time-lines, actual practice records. All containers/stores should be assorted and labelled. Cleanliness/sanitation standards followed and their written records of compliance. Records of visitors should also be maintained and visitors should follow hygiene products.
- Employee list, service and training records, health check-ups and vaccination records, child-labour policy, food safety policy guidelines and company commitment to such standards should be displayed and also records should be maintained.
- Microbial, chemical, radiations, history of epidemics/natural calamities like floods / runoffs and other hazard analyses on and near production site including any mitigation plan may be recorded.
- Crop protection records including use of chemicals, their date of purchase, cycle of use, disposal, safety clothing, equipment use etc. Apart from this records of manures, composts, biosolids, etc. including trainings for their use and disposal. Chemicals used must be as per legal guidelines and permitted by competent authorities
- Processing facilities/storage facilities should be well-guarded, supervised

- Canteen facilities for workers are available
- Debris/waste disposal standard followed records.
- All records of traceability from land/site, input used/procedure/process/manpower be kept and be produced within reasonable time limit.
- Traceable records of transportation should be maintained.

Therefore, traceability, labelling and record keeping are body and spirit of good agricultural practices for greenhouse production, protection and processing.

Major Steps for GAP and IPM in Hydroponics Cultivation

1. **Water management/Irrigation/Fertigation/ Conservation:** Ensure clean uncontaminated water from safe source and it has to be maintained infection free for storage, sprays, properly filtered and asepticised, with proper maintenance of pH, electrical conductivity, TDS, etc.
2. **Greenhouse Structure and Maintenance:** Construction/fabrication of greenhouse has to take care of GAP standards of area sterilisation and fabrication has to be such that maintenance of pest free ambience and surroundings is easier to implement. The insect proof screen, healthy nursery, entry points need to be given particular attention for keeping the areas pest and infection free.
3. **Fertilizer Application:** Fertilizer application in soilless systems is highly precise, controlled, monitored and has to be maintained pest and disease-free all the time. Immature organic supplements and heavy metals have to be avoided as per GAP standards being adopted. All the fertigation schedules have to be recorded with doses.
4. **Crop Protection/IPM:** Asepticisation/sterilisation has to be done for media and implements properly. Use of clean polythenes/trays/pipes/media/ etc. Healthy planting materials and treated seeds as per GAP standards, use of resistant cultivars/grafted nursery is recommended. Besides this monitoring tools like yellow, blue or silver sticky traps for sucking pest have to be used at entry points and inside structures. Use of soft or biorational compounds as per GAP standards including neem, horticultural mineral oil, green molecules is suggested. IPM modules agreed as per GAP standards have to be adopted depending upon the crop and pests dominant in the area. Damaged paraphernalia like pipes, tanks etc should be replaced immediately. Safety gear for the workers, display of guidelines, observation of protocols and record of all the chemicals or inputs used, must be maintained. For plant protection it is always advisable to use Integrated Pest Management (IPM) schedules which indeed are very specific to crops and environment. In keeping with the environmental sustainability parameters, the chemicals or pesticides used have to comply with the CIBRC guidelines and MRLs for pesticide residues and avoiding banned pesticides or chemicals but also the guidelines or GAP protocols as per buyer agreements. As far as possible, the use of pesticides has to be avoided.
5. **Farm Health:** GAP deals with farm health issues comprehensively hence clean handling and processing of products and processes at all check points and control points need strict monitoring for which display of GAP protocols including attendance, responsibility rosters, procedures/protocols all are duly recorded including all inputs and outputs. All records and certifications have to be duly attested and recorded including storage and waste disposal.
6. **Harvest and On-farm Processing and storage:** Ensuring product quality by implementation of acceptable protocols for harvesting, storage, and processing of farm products by maintaining processing standards of temperature, humidity, light, quality and processing parameters including clean and safe handling for on-farm processing of products and their transport from the farm in clean and appropriate containers. Other than this other post harvest mechanisms such as use of only permitted and registered chemicals/waxes/oils, maintenance of records of harvest including location/area/name of grower/date of harvest along with treatment details (including dosage/frequency/dates of application) of all batches of harvests separately, types of treatments used before and after harvest (gassing, spraying, drenching, dusting etc), trade names of all the products and dosage and frequency of their use and names of operators and record of incidences of pests/diseases intercepted/treated.

Advantages of Adopting GAP

- GAP ensures sustainable agricultural through resource optimization - land, water, human capital and enhances information sharing, thereby increasing agricultural productivity, lowers production costs and reduces overall losses to the growers and processing units
- Improvement in the environment as well as soil/substrate fertility
- Development of basic infrastructure at the field level
- Traceability through complete integration of food chain i.e. from farm to fork, the produce must be traceable for its origin including all inputs
- Worker safety and welfare from production to processing
- GAP supports long term thinking and assists evolving strategies on agricultural practices to be in tune with latest developments, technologies and trade practices
- Reputation in the international market as a producer
- Build up the culture of following good agricultural practices by the farmers/growers/producers
- Good quality and safe produce
- Removal of Technical Barriers to Trade (TBTs) faced by exporters of agro products - in simpler terms the local growers can become eligible to export their products as GAP certified products and hence the growers can increase in their income considerably. The GAP protocols would vary from country to country and possibly from buyer to buyer.

General IPM for Soilless Cultivation

Integrated pest management (IPM) is a philosophy of integration of all suitable protection measures to keep the key pests below economic threshold levels in such a mannel that economic viability of the producer, health and safety of produce and the workers and sustainability of the environment are ensured to the best of possibilities. However, in soilless cultivation the level of tolerance to pest presence is nearly zero as the system of soilless cultivation is highly cost intensive and very precise in input management.

1. Construction and Maintenance of greenhouses

a. The site selection of greenhouse should be preferably disease and pest free particularly for soilless type of cultivation. It should be away from existing agriculture production areas to reduce pest incidence while still amenable to easy transport of inputs/produce

b. Fabrication of the green house should be proper with double doors, provision of insect-proof screens, maintaining strict hygiene and restricting the entry of unwanted visitors

2. Preventive Measures

- Fumigation of the site before the construction of greenhouse
- Sanitation and asepticisation of the entire greenhouse area, media and the paraphernalia including drip irrigation system, water storage facility, trays, pipes, equipment for spray etc.
- Augment bioagents (such as *Trichoderma harzianum* culture (c.f.u. 2×10^{9} spores/g or ml of culture or solution) and/or *Pseudomonas fluorescens* (c.f.u. 2×10^{12} spores/ml) with the media.
- Implement GAP protocols as discussed in the manuscript especially

  - Use of clean, uncontaminated water for irrigation from safe source
  - Only need-based pesticide application
  - Maintenance of worker hygiene
  - Proper disposing of polythenes by burying

Key Components of IPM for Common Pests of Greenhouses (Kindly adhere to CIBRC guidelines on use of pesticides and their doses)

Mites	• Good hygiene before transplantation and general sanitation during crop • Regular monitoring of the crop and strict watch on population build-ups • Mites tend to be around hot areas first; if any hotspot of higher population is localized, tie a coloured tag so as to locate it for revisiting such spots for regular and repeated monitoring and spot sprays • Misting of crop (without droplet formations) • Spray of biorationals/botanicals -agrospray/horticultural oils/azadirachtin or neem oil/garlic extract based botanicals; alternatively, bifenazate (floramite) can also be used • If need be spray dicofol, omite, spiromesifen, abamectin, etoxazole etc. • Release of predatory mites such as Phytoseiulus persimilis (with only specific and safe chemicals)
Thrips	• Use of insect proof net • Regular monitoring with blue sticky traps • Botanicals or biorationals like azadirachtin or neem oil, paraffin oil, insecticidal soaps • Spray fenpropathrin 30EC @ 100 -120 ml/ac in 200 -250 L wate r or pyriproxyfen 10EC @ 200 ml or spinosad 45SC @ 75 g/ac in 200 lit water or fipronil 5SC @ 400 ml/ac in 200 L water. Other chemicals such as chlorfenapyr are good for thrips management • Release of predatory bug, *Orius laevigatus* is helpful in keeping th rip (*Frankliniella occidentalis*) population under control (not against *Scirtothrips dorsalis)* (with only specific and safe chemicals)
Whiteflies	• Good hygiene before transplantation and general sanitation during crop • Keep the greenhouse doors closed; vent ilators and all other openings should be secured with quality insect-proof net • Monitoring and on-the-spot spray on noticing infestation • Spray of biorationals like agricultural oils/horticultural oils and soap including neem oil, help repel this seriously dangerous pest • Spray insecticides like imidacloprid, acetamiprid, acephate, growth regulators like buprofezin, green chemicals like abamectin/milbectin etc. • Release of beneficial insects/mites like *Amblyseius swirskii*, *Encarsia formosa* etc. (with only specific and safe chemicals)
Leaf miner	• Ensure clean cultivation and no transmission of leaf miner infested leaves in and around greenhouse • Spray of biorationals/botanicals like agrospray/horticultural oils/azadirachtin or neem oil/garlic extract based botanicals • Application of systemic insecticides • Release of Entomopathogenic nematode *Steinernema feltiae* • Release of parasitic wasps such as *Diglyphus isaea*
Fusarium wilt	• Complete asepticisation of the medium and paraphernalia before the crop • Application of *Trichoderma harzianum* in the media • Application of systemic fungicides such as metalaxyl 1.0 g/L only if permitted under GAP protocols

	• Grow resistant cultivars, if available • Spray sulphur 52SC @ 800 ml/ac in 200 L water or sulphur 80WP @ 1.25
Damping-off/Root rot	• Disinfectation of water and nutrient storage • Use of chlorine, chlorine dioxide, copper, hydrogen peroxide, electrochemical, soaps (wetting agents) etc. to clean water, drips and other items • Avoid over-irrigation which increases risk of plant mortality • Filtration of storage water • Use of FYM enriched with *Trichoderma harzianum, Gliocladium* sp. etc. • Use of Mycostop (*Streptomyces*) • Application of Carbendazim (0.1%) + Captan (0.2%) in the nursery medium (before or at the time of transplantation)
Soil-borne pathogens	• Complete asepticisation of the medium and paraphernalia before the crop • Drenching with Metalaxyl / copper-oxychloride / mancozeb @ 1g/Lfor fungal pathogens • Use of resistant/ tolerant varieties or rootstock or grafting with resistant rootstock for nematodes and other soil borne pests

Management of some other Diseases

Early Blight of Tomato - Mancozeb 35SC 5 g/L, Mancozeb 75WG 2 g/L, Zineb 75WP 2 g/L, Ziram 80WP 2 g/L, Iprodione 50WP 3g/L, Famoxadone 16.6%

+ Cymoxanil 22.1SC 1 g/L (Equation Pro) Metalaxyl M 3.3% + Chlorothalonil 33.1SC 2 g/L, Azoxystrobin 23SC 1 ml/L water

Late Blight of Tomato - Mancozeb 35EC 5 g/L or Mancozeb 75WG 2 g/L, Famoxadone 16.6% + Cymoxanil 22.1SC (Equation Pro) 1 g/L, Cymoxanil 8%

+ Mancozeb 64WP (Moximate) 3 g/L, Famoxadone 16.6% + Cymoxanil 22.1SC (Equation Pro) 1 ml/L, Metalaxyl M 3.3% + Chlorothalonil 33.1SC (Folio

Gold) 2 g/L, Azoxystrobin 23SC 1 ml/L water

Downy Mildew of Cucumber - Cymoxanil 8% + Mancozeb 64WP (Moximate) 3 g/L or Azoxystrobin 23SC 1 ml/L water

Viral Diseases –Currently no chemical control measures available. Crop rotation, crop hygiene, vector control, destruction of infected plants and safe disposal are the only methods other than a few resistant cultivars

Use neem products and horticultural oil in combination with canopy and environmental control measures for the management of control sucking pests may be adopted

Disclaimer: Kindly ensure label claims and registration (as per CIBRC guidelines & regulations) for spray of chemicals mentioned above. These guidelines are largely indicative of types of chemicals to be used. Also ensure expert guidance on compatibility/bio-safety of crops/bio-agents with concomitant chemical use as well as the waiting period before harvest. Compilation is only suggestive and losses arising out of any use/misuse shall not be liable on authors.

Monitoring is done to take timely action against pests

Government of India (GOI) initiatives for Hydroponics cultivation

Hydroponics cultivation has great prospects for Indian agriculture. It is one of the potential technologies for doubling farmers income. In the changing scenario of food habits and growing fad for green vegetables, herbs and fruits, hydroponics technology is going to play a major role for sustainable and round the year production in urban and peri-urban areas. As this technology is capital intensive and requires technical knowhow, GOI has launched many schemes to promote this technology through different agencies.

Some of the major agencies to promote Hydroponics Cultivation are as follows.

1. National Horticultural Board (NHB)
2. National Horticultural Mission (NHM)
3. Horticulture Mission for North East & Himalayan States

Credit linked projects relating to establishment of Commercial production units in protected conditions for Hydroponics cultivation are supported financially by National Horticultural Board NHB. The details of the schemes are available through the link (www.nhb.gov.in). National Horticultural Mission (NHM) and Horticulture Mission for North East & Himalayan States also indirectly support Hydroponics related projects through the protected cultivation initiatives. Farmers and entrepreneurs can avail these schemes as per the eligibility and suitability.

Addresses of Firms Dealing with Hydroponics Cultivation Technology

1. Future Farms
   4/640, 12th Link III Cross Street
   I main Road, Nehru Nagar, Kottivakkam
   Chennai-600041
   www.futurfarms.in
   M-09884009110

2. Pet Bharo
   99 Bendre Nagar, Dharwad
   Karnataka 580008
   www.petbharoproject.co.in
   M-8137848383/9743219388

3. Green Pot Organic
   House No 216, Sec-29
   Faridabad, Haryana-121008
   Greenpotorganic33@gmail.com
   M-9212027880, 9729207044

4. Rajdeep Agri Products (P) Ltd.,
   3229/1, Ranjeet Nagar
   New Delhi: 110 008.
   Ph.25748881

5. M/S Netafim Irrigation Pvt Ltd
   S1 and S10, plot no 16
   Pankaj Arcade, 2nd floor
   Dwarka sector5 New Delhi 75
   M-9582596703

6. M/s Classic Agricon
   SCO No.394, 1st Floor,
   Cabin No. 12, Sector- 20,
   Panchkula (Haryana) - 134112
   — 09876427998

7. SAVEER BIOTECH LIMITED
   1442, Wazir Nagar,
   New Delhi - 110003, INDIA
   Phone No: +91-11- 24622889, 24602074
   Fax: +91-11-24620211
   Email: business@saveer.com

8. Agriplast Tech India Pvt. Ltd.
   Survey No. 426/3B-1B, Nallur Village
   Opp Nallur Government High School,
   Hosur Panchayat Union & Taluk, Krishnagiri Dist - 635 103 Tamil Nadu
   M-8141446666, www.agriplast.co.in

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3. Anon. (2009). Hydroponics. Soil-less Culture Book. Department of Agriculture. Ministry of Agriculture. Pp 1-45

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