WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
SJIF Impact Factor 7.523
Volume 6, Issue 7, 722-739. Review Article ISSN 2277–7105

SOILLESS CULTIVATION, ITS VARIOUS TYPES AND APPLICATIONS IN AGRICULTURAL AND PHARMACEUTICAL SECTOR

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Article Received on
08 May 2017,

Revised on 29 May 2017,
Accepted on 19 June 2017

DOI: 10.20959/wjpr20177-8825

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ABSTRACT

Soil a natural resource, has been facing the burnt of human civilization. Due to rapid explosion of human population, the agricultural land has shrank and the per capita land availability for agricultural purposes have decreased. Less rainfall due to change in climatic conditions and over utilization of under-ground water has further escalated this problem. Soil also poses serious limitations in plant growth as many nematodes, disease causing organisms, poor drainage and degradation due to erosion reduces the crop productivity. Therefore, soilless cultivation of plants seems to be a good alternative to overcome these challenges. To meet the demands of growing population, soilless cultivation is being considered to be the major thrust area in agriculture sciences. Growing of medicinal plants in soilless culture system will allow growers to market very high quality products (high purity and bioactivity), year around, in a pesticide free environment thereby paving the way for pharmaceutical industry. Looking at the initial cost for setting up soilless culture system, under developed countries are not able to harness the benefits of this technique. Moreover the skilled manpower is also lacking due to poor dissemination of knowledge. There is a lot of scope to project soilless culture system at world level by conducting workshops, seminars and training to the farmers and gardeners.

KEYWORDS: Soilless culture system, Hydroponics, Aeroponics, Agriculture, Floriculture, Medicinal plants.

INTRODUCTION

In simple term, soilless culture means growing of plants without soil. Although soil is known to be an important medium for crop cultivation, its mere function is to retain water and nutrients, exchange of gases and to provide physical support to plant's root system. However soil do hamper crop production due to soil borne pests and diseases, soil salinity, soil alkalinity, non-fertile soil etc.[1] Apart from above mentioned problems associated with soil, soilless culture also overcomes the weed problem and increases the efficiency of water usage. Mineral nutrients present in the soil when dissolved in water are absorbed by the roots of the plants. If these mineral nutrients dissolved in water and artificially given to plants, there won't be any need for soil for the survival of plants. Use of 3-indole acetic acid (IAA), a growth regulator, has been recommended for rooting in hydroponic system.[2] In an another study, application of growth hormone, IBA, by fertigation increased total marketable yield of greenhouse-grown pepper, and reduced ion emission.[3]

Soilless culture also circumvents the problems associated with retention of water and nutrients. Soil with low retention quality can be substituted with the sphagnum peat, vermiculite, or bark chips. Apart from these soilless mixes, rice straw/hulls[4], bagasse (sugarcane refuse), sedge peat, and sawdust can also be used. Protected soilless culture system can control the growing environment by managing nutrient composition and concentration, weather and humidity. This helps in improving the quality of horticultural crops grown through soilless culture compared to conventional soil culture.[5-7] Adoption of hydroponics in early years of its inception failed due to lack of knowledge of nutrient management and role of oxygen, systematic design approaches, and disease management. Thereafter with open source innovation and extension activities funded by government, knowledge system regarding hydroponics was improved and projects were taken to dissemination this knowledge to the farmers and end users. Due to the inclination of researchers towards water culture, many automated and computerized hydroponics farms were established around the world during 1980s. Scientist at NASA are also doing extensive hydroponic research for their Controlled Ecological Life Support System or CELSS. Researches are also being conducted for the automation in soilless culture system for nutrient managemen[8], for pH control[9], replenishment of recycled greenhouse effluents.[10] Mathematical models are being worked upon that might be useful in designing and managing the soilless culture system. The model is based on the crop potential needs for water and

nutrients, and of water quality.[11] Iron-oxide nanoparticles are also being looked upon to increase the growth rate and productivity of spinach grown hydroponically.[12]

To achieve a goal to improve the quality and quantity of product, there has been a radically change the way farmers grow the crops. The farmers eye on the larger profit margin by growing off-season agricultural products and sell them in a very competitive world market. In today's world, these aspects are quite relevant for horticultural commodities. Decrease in per capita land availability due to urbanization and industrialization has also posed serious concerns in soil based agriculture. It has been predicted that by 2050, 70% of the population will be living in urban areas. Certainly the demand for agricultural products will not be enough to meet the great needs of these urban areas. Moreover by then, the land available for agriculture will also get reduced to a large extent due to population explosion. Agriculture in the cities will also have significant benefits for food security, along with rural regions. To overcome the scarcity of land, water and other related programs such as biological and abiotic stress, resources and the high cost of labor, hydroponics or soil less cultivation will plays an important role in the agriculture of the future and are of great value to ecological systems. Worldwide, crops grown in greenhouses are mainly using soil as a solid support, however in developed countries, such as in Europe, North America and Australasia, hydroponic systems predominates the culture system. In developed countries, there was a move away from soil-grown greenhouse crops in the early 1960s, which, combined with improvements in the control of the greenhouse environment, resulted in considerable increases in productivity compared with soil-based systems. Majority of population living in cities can use soilless culture system like growing vegetables in window or hanging boxes. This technology is suited for growing vegetables like tomato, sweet pepper, brinjal, cucumber, melon, french bean, radish, cabbage, cauliflower, lettuce, spinach, potato, spring onion, etc.

Over the years, soilless culture especially hydroponics have been widely used around globe as a commercial means of growing food crops, horticulture plants[13] medicinal and ornamental plants,[14,15] However in recent times, it is also being used as a standard methodology for plant biological researches in different disciplines.[16] To illustrate the physiological and biochemical responses of *Salvia miltiorrhiza* to salt stress, Gengmao et al.[17] used hydroponic system to evaluate the feasibility of cultivating it in saline coastal soil. To evaluate the physiological and biochemical changes occurring in soybean plant due to

water stress, Tripathi et al.[18] used hydroponic system. However, growing plants in hydroponic system is questionable to some researchers, as it does not represent an actual field condition. But hydroponic system has an advantage as every input given to the plants can be controlled, whether it be nutrients, temperature, humidity, gaseous exchange.

Although soilless cultivation techniques provide the best growing conditions for plants to achieve good yield, however stress due to temperature, nutrient supply, pathogens, light, oxygen or carbon dioxide do exist but of differing magnitude.[19] Drop in rhizosphere oxygen levels due to high root density and relative confinement of the growing medium in soilless culture, oxyfertigation technique has been developed to improve rhizosphere oxygen availability. It consists of supplying dissolved oxygen in the irrigation water at oversaturated concentrations using fertigation equipment.[20] Introduction of beneficial microorganisms (BMO) into the soilless culture have shown to reduce the above stated stress conditions. Woitke and Schitzler[21] introduced plant growth promoting rhizobacteria (PGPRs) and reported the efficacy in soilless culture system. Their introduction in soilless culture system, also improves the efficiency and prolonged activity of BMO due to the lack of competition occurring in soil. Dual microbial inoculation of *Acacia mangium* grown in aeroponic culture with *Bradyrhizobium* sp. and *Glomus intraradices* stimulated the growth of plant without affecting plant development or establishment of *Bradyrhizobium* symbiosis.[22]

TYPES OF SOILLESS CULTURE SYSTEM

Soilless culture system can be broadly categorized into.

1. Substrate culture/Solid support system/ aggregate system (Gravel, agricultural perlite)
2. Solution culture/Water culture/system (Hydroponic system)
3. Aeroponic system.

SOLID SUPPORT SYSTEM

Plants can grow in a mineral solution only or in an inert medium, such as washed sand, gravel, perlite, etc.[23, 24] Solid support system is something different from pure solution culture as it uses gravel or some solid support to provide plant support and retain mineral nutrient and water. Culture system that uses solid medium other than soil for anchorage, and nutrient solution for plant growth, is known as aggregate system. It also comes under soilless culture. It involves cultivation of crops in a solid, inert or non-inert medium instead of soil. Selection of solid support depends on the plant being grown, its water and air holding capacity and how easily it can be drained. In addition, it should be free from toxic substances,

pests, disease causing microorganisms, nematodes, etc. The medium used must be thoroughly sterilized before use. Several substrates have been tried looking at their unique properties for holding moisture, aeration, leaching or capillary action, and reuse potentiality.[25, 26]

The solid support may be organic substrates like sawdust, coco peat, woodchips, wood fibres[27], peat moss, fleece, bark[28] etc. whereas, inorganic substrate like perlite, vermiculite, zeolite, gravel, rockwool, glass wool, volcanic tuff and lastly the synthetically produced substrates such as hydrogel, foam mates (polyurethane)[29], oasis (plastic foam), fytocell etc.[30]

Figure 1: Use of pertile in soilless culture system.

Perlite

Perlite granules are known to originate from a silicone mineral that forms in volcanoes. These are light weighed and its use in growing medium increases the drainage and aeration in the soil. Perlite is less expensive and is being used around the world for successful production of vegetables, fruits, and cut flowers in the greenhouse.[31]

Figure 2: Various types of coconut coirs used soilless culture system.

Coconut Coir

It is organic in nature as it is made from shredded coconut husks. Coconut coir are finely shredded and steam sterilized that helps in protection against root diseases and fungus. It is being used as a substitute for rockwool in the greenhouse vegetable industry. It is known by various trade names like Ultrapeat, Cocopeat and Coco-tek and offers an ideal rooting medium for plants.

Figure 3: Use of vermiculite in soilless culture system.

Vermiculite

It holds a lot of water and nearly absorbs 200% - 300% moisture by weight and aids in drainage and aeration of the soil, it contains both potassium and magnesium. Vermiculite is a very popular medium type for drip hydroponic systems and is also inexpensive like perlite.

Figure 4: Use of peat moss in soilless culture system.

Peat Moss

Tropical plants require extra moisture and warmth to grow and flourish. Use of peat moss in soilless culture helps in retaining more moisture in growing mediums.

Figure 5: Use of fytocell in soilless culture system.

Fytocell

Fytocell, is an organic synthetic hydrophilic foam (aminoplast-foam) with additional specific physical characteristics. It provides optimum capillarity, homogenously throughout the whole substrate and promotes strong and uniform rooting. This solid support is biodegradable and can be composted with other organic materials such as plant waste and can be used as soil improver thereby reducing the problem of waste disposal.

SOLUTION CULTURE SYSTEM

It includes hydroponic systems and is further categorized as open (i.e., once the nutrient solution is delivered to the plant roots, it is not reused) or closed (i.e., surplus solution is recovered, replenished and recycled). Of the various hydroponic systems, NFT (nutrient film technique) is the most popular one. It is a closed system in which nutrients are circulated constantly. The roots growing in the nutrient solution are feeding directly from the solution. This system needs a close supervision as many test done for pH and nutrients and adjustments are needed constantly. In their study, Bentes et al.[32] found vertical bag system of hydroponics culture for out of season strawberry production to be promising and beneficial to use in protected cultivation.

HYDROPONICS SYSTEM

Traditional soil culture system is challenged by globally declining resources due to climate change and growing population. Alternative methods such as hydroponics have a great potential to generate high yield per unit area using limited land, water, and no soil.

Hydroponics or hydroponic farming is a method of growing plants using mineral nutrient solutions instead of agricultural land. Hydroponics, the water culture system of plants is used in various research and commercial areas since 18th century. The word 'Hydroponics' was coined by Dr. W.F. Gericke in 1936 to describe the cultivation of edible and ornamental plants grown in a solution of water and dissolved nutrients. Gerick cultivated tomato vines twenty-five feet high in mineral nutrient solutions rather than soil. It literally means working water; 'hydro' meaning 'water' and 'ponos' meaning 'labour/work'. As already mentioned, soil being the most available growing medium for plants, provides nutrient for the plant growth, however it also provide serious limitations for plant growth such as crop loss due to nematodes and disease causing organisms residing in the rhizosphere, poor drainage and degradation due to erosion.

In hydroponic technique the roots receive a balanced nutrient solution dissolved in water with all the chemical elements essential for the development of plants that can grow in a mineral solution only.

Hydroponics can also be used as a domestic cultivation alternative, to prevent the loss of genetically diverse pure lines of medicinal plants and use of controlled environments that can overcome the cultivation difficulties and can also be used to manipulate phenotypic variation in bioactive compounds. Due to the property of uptake of nutrients from the nutrient solution, toxic organic and inorganic compounds of waste water can be removed.

In today's scenario, peoples prefer organic food, so the question arises "Is hydroponics organic?". In hydroponics, plant roots are dipped in nutrient solutions (water with dissolved fertilizers) rather than soil. However, hydroponic production is not mentioned in the Organic Foods Production Act (OFPA) of 1990. Till 1995, National Organic Standard Board (NOSB) did not consider the concept of growing organic crops without soil and defined organic agriculture as "an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain, and enhance ecological harmony". In 2002, the National Organic Program (NOP) redefined organic production in the Code of Federal Regulations as "a production system that respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biological diversity" and this definition does not require that organic systems be soil-based, but it does require that organic methods include

the use of biological practices that foster the cycling of resources. The current administration of the National Organic Program continues to allow the certification of hydroponic operations despite the recommendation from the NOSB that clearly states it is not compatible with organic production. United States is one of the few countries that allows hydroponics to be organic. Mexico, Canada, Japan, New Zealand, and 24 European countries (including Holland, England, Germany, Italy, France, and Spain) all prohibit hydroponic vegetable production to be sold as organic in their own countries. This means "organic" hydroponic producers in other countries are often growing exclusively for a U.S. market.

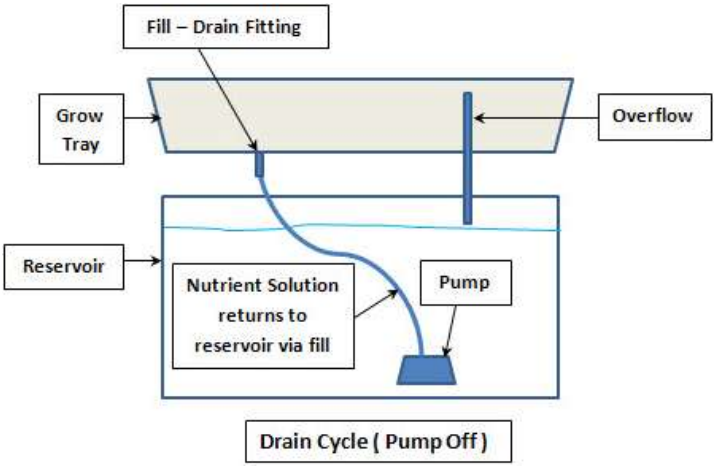

Figure 6: Set up basic hydroponic system Source: http://www.minnie-online.co.za/blog/gardening/hydroponics-diy/

SETTING UP OF A HYDROPONIC SYSTEM

In hydroponic system, plants are grown with their roots immersed in nutrient solution of water with all the chemical elements essential for the development of plants. Before building a hydroponic system, it's important to first consider the type of plants you want to grow in it and the required space for it. Along with that we need to make sure to design the system to be able to accommodate the plant's needs (plant size, root size, oxygen to the roots, water consumption, etc.). While one type of hydroponic system may be well suited for growing some types of plants, it may not be the best choice for growing others. In general hydroponic system need few basic parts to build.

Growing Chamber

In this chamber, plant roots will be growing that would provide plant support, as well as access to nutrient solution. It also protects the roots from light, heat, and pests. It's important to keep the root zone cool and light proof as prolonged light will damage the roots and high

temperature will cause heat stress. This in turn will affect the growth of plant and there would be increase in drop of fruits and flowers.

Nutrient Reservoir

Nutrient reservoir stores a solution that consists of plant nutrients (salts, minerals, hormones) dissolved in water. Depending on the type of hydroponic system, the nutrient solution can be pumped from the reservoir up to the growing chamber (root zone) in cycles using a timer, as well as continually without a timer, or the roots can even hang down into the reservoir 24*7, making the reservoir the growing chamber also. Reservoir need to be light proof to discourage the growth of algae and micro-organisms that begin to grow in even low light levels.

Submersible Pump

It is used to pump nutrient solution from the reservoir to the growing chamber. These are of wide variety of sizes depending upon the size (length and breadth) of overall hydroponic system. To avoid any contamination, it should be taken all apart on regular basis and cleaned thoroughly, both the pump and filter.

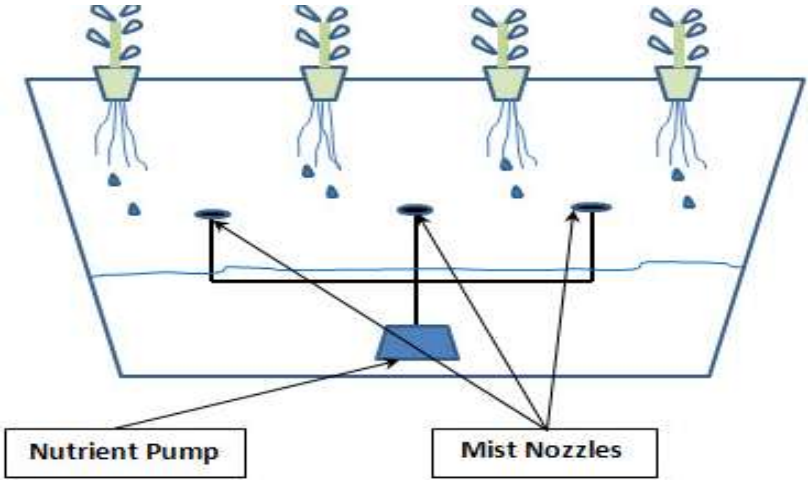

Figure 7: Set up basic aeroponic system Source: http://www.minnie-online.co.za/blog/ gardening/ hydroponics-diy.

AEROPONIC SYSTEM

Aeroponics is an advanced version of hydroponic system. It is the most innovative and new technologies which consist of growing system that sprays the nutrient solution at the root level in a fog form. In aeroponic culture method, plants are anchored in holes in Styrofoam panels and their roots are suspended in air beneath the panel. The panels compose a sealed

box and nutrient solution is sprayed in fine mist form to the roots. On the basis of requirement, misting is done for a few seconds every 2-3 minutes as that much is sufficient to keep roots moist and nutrient solution aerated. Nutrient solution forms a film around the root system from where the plants obtain nutrient and water.[33] Aeroponic culture is found to be suitable for low leafy vegetables like lettuce[34], spinach, production of potato seeds[35] etc. Agri-research is also being carried out using aeroponics in potato, where low temperature of nutrient solution and nitrogen removal during tuberization produced large number of potato mini-tubers.[36] Use of aeroponics with image analysis has enabled high-throughput quantitative assessment of root growth and development. The data generated from this combination is a prerequisite for exploiting the large amount of genomic data available in root research.[37] Lobet et al[38], developed a novel and semi-automated image analysis software that streamlines the quantitative analysis of root growth and architecture of complex root systems. Major advantage of aeroponics is the maximum utilization of space and production of plants free of soil particles. Aeroponics is somewhat similar and high-tech type of hydroponic culture. Special care should be taken to avoid drying of roots, as roots may dry out rapidly if we miss the misting cycles.

APPLICATION OF SOILLESS CULTURE

Theoretically, all plants can be grown in soilless culture. However, it has been used mainly to cultivate vegetables, medicinal plants, ornamental plants and in horticulture. A soilless culture termed as aquaponics is also an upcoming system which is a combination of hydroponics (plant cultivation) and aquaculture (fish and marine farming). Aquaponics perform dual function, plants utilize the nutrients present in water with the fish faeces and gives back clean water to fishes dwelling in the fish tank, thereby benefitting both systems. A study by Saha et al.[39] at the Georgia Southern University, Statesboro, GA, USA during the period August to November, 2015 showed that the use of crayfish (*Procambarus* spp.) as the aquatic species in soilless culture resulted in greater growth and yield of basil (*Ocimum basilicum* L.). It was assumed that crayfish waste (excreta and unconsumed feed) might have supplied additional nutrients required for the growth of basil.

Soilless culture system is extremely useful to overcome the scarcity of agricultural land, water and other related problems such as biotic and abiotic stress, resources and the high cost of labour, problems of drought etc. It helps to face the challenges of climate change and also helps in production system management for efficient utilization of natural resources and

mitigating malnutrition. Laboratory of Defence Institute of Bio-Energy Research (DIBER), a DRDO (Defence Research Development Organization) institute in India has developed nutrient solutions for cultivation of tomato under hydroponic system. It is very useful in snow bound hilly and high altitude areas and metropolitans where enough land mass is not available besides rocky, desert and other non-productive areas. The laboratory also developed greenhouse technology where off season vegetable can be cultivated and using this technique Indian troops are provided with fresh vegetables during winter months even in Kargil, Drass, Mana and Malari areas (9,000-16000 ft altitude). Both of these technologies have been successfully demonstrated at South Pole during IX, X, XI, XV and XVI Indian Antarctic Expeditions.[40]

Soilless culture utilizes all the resources efficiently for maximizing yield of crops and thus being used for commercial production of greenhouse vegetables[41-43] and medicinal plants.[44] Aeroponic system have been used by Johnson et al.[45] for evaluation of biomass production using algae (*T. chuii* and *P. kessleri*). They evaluated novel aeroponic system and reported an increase in biomass production without affecting the fatty acid composition. This technique has reduced the energy inputs and increased the financial returns. It has great potential to produce biofuel, nutraceuticals and feed for fisheries and various other applications.

Medicinal plants due to its active ingredient are being increasingly cultivated on commercial scale to meet the large demand for natural remedies. Open field cultivation of these plants results in large variability year wise both in biomass production and content of active principles. Hydroponic culture system on the other hand produce high-standard plant material all year-round by controlling the growing conditions and by stimulating secondary metabolite production by appropriate manipulation of mineral nutrition. A series of experiments by Maggini[46], at the University of Pisa on greenhouse hydroponic cultivation of echinacea (*Echinacea angustifolia*) and basil (*Ocimum basilicum* L.), revealed that both the species grew rapidly and healthy. And in two to four months they accumulated large biomass with minimal contamination. The plants are typically cultivated for their distinctive caffeic acid derivatives (CADs), specifically echinacoside in echinacea and rosmarinic acid in basil.

In recent years, due to its bioactive chemicals, Barbados aloe (*Aloe vera* (L.)Burm.F.) is attracting the global market. Traditionally it has been used for healing in natural medicine. Bioactive extracts from the leaves are used in industrial preparations for pharmaceutical, cosmetic, and food products. Cristiano et al.[47] discussed various propagation techniques for

its cultivation. One of the main constraints in hydroponic cultivation is to obtain a suitable nutrient solution with the highest yield and quality. Saliqehdar et al.[48, 49] developed a nutrient solution which produced the highest vegetative growth without negative effects on qualitative indices including aloin, total phenol, and total anti-oxidative activity. Comparison of biomass of soilless culture vs. field grown production of various medicinal crops like *Arctium lappa*, *Urtica dioica and Anemopsis californica* showed that hydroponic or aeroponic systems produce very clean, high-quality herb, root crops and can be used for natural products industry.[50]

There has been a paradigm shift towards use of medicinal plants for therapeutic purpose. This industry has grown up significantly as demand for some plant species largely exceeds the offer and supply for good quality products. Medicinal plants studied (*Achillea millefolium*, *Artemisia vulgaris*, *Inula helenium*, *Stellaria media*, *Taraxacum officinalis*, and *Valeriana officinalis*) by Dorais et al.[51] were found to be well adapted to the floating raft system. Their shoot and root dry weight was many times higher when compared to field growing plants. Accumulation of Rosmarinic acid (RA), a caffeic acid derivatives increased in hydroponically cultured sweet basil (*Ocimum basilicum* L.). Content of RA ranged approximately from 4 to 63 mg/g DW from the roots of hydroponically-grown seedlings at full bloom.[52] An additional advantage of hydroponic system was the possibility to harvest the root system of basil, which contained higher levels of rosmarinic acid compared to the leaves.

Soilless culture can be used for more efficient production of medicinal and aromatic plant as suggested by Azarmi et al.[53] They assessed the growth potential and essential oil production of valerian (*Valeriana officinalis*) and lemon verbena (*Lipia citriodora*) in soil and various soilless production system and found the later one promising. Simeunovic[54], optimized the concentrations and ratios of nutrient solutions required for higher production of secondary metabolite in two medicinally important plants, *Hypericum perforatum* and *Tanacetum parthenium*. Use of soilless culture has also been used for floriculture. Plants such as rose are in demand round the year for interior and external market during all season. Ioana et al.[55] emphasized on the knowledge of modern technologies of soilless cultures and the rose variety that suits best this kind of culture.

To conclude with, it can be ascertained that soilless culture is rapidly gaining momentum and popular among farmers, gardeners and florists. Due to lesser availability of land for

agricultural practices and commercial production of vegetables during off season, it is being accepted by the countrymen. Seeing towards the prospects, it can be said that soilless culture would dominate food production in years to come. There is a need to popularize soilless culture, by providing scientific proven technology of soilless culture to gardeners and create mass awareness in potential areas at national level.

REFERENCES

1. Gullino ML, Garibaldi A. Influence of soilless cultivation on soilborne diseases. Acta Hort, 1994; 361: 341-353.
2. Hassanein AMA. Comparison of plant propagation efficiency under hydroponic/soilless culture and traditional/soil culture systems. Journal of Agricultural and Veterinary Sciences, 2015; 8(2): 201-212.
3. Lopez-Elias J, Salas MC, Urrestarazu M. Application of indole-3-butyric acid by fertigation on pepper plants in soilless culture grown in a greenhouse. Acta Hort, 2005; 697: 475-479.
4. El- Sayed SF, Hassan HA, Mahmoud SO. Effect of some soilless culture techniques on sweet pepper growth, production, leaves chemical contents and water consumption under greenhouse conditions. Middle East J. Agric. Res, 2015; 4(4): 682-691.
5. Xu HL, Gauthier L, Gosselin A. Effects of fertigation management on growth and photosynthesis of tomato plants grown in peat, rockwool and NFT. Scientia Horticulturae, 1995; 6(1-2): 11-20.
6. Massantini F, Favilli R, Magnani G, Oggiano N. Soilless culture-biotechnology for high quality vegetables. Soilless Culture, 1988; 4(2): 27-40.
7. Gruda N. Do soilless culture systems have an influence on product quality of vegetables? Journal of Applied Botany and Food Quality, 2009; 82: 141-147.
8. Stradiot, P. Nutrient management in protected cropping: the need for automated control. Acta Hort, 2005; 697: 223-230.
9. Domingues DS, Takahashi HW, Camara CAP, Nixdor SL Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. Computers and Electronics in Agriculture, 2012; 84: 53-61.
10. Savvas D. Automated Replenishment of Recycled Greenhouse Effluents with Individual Nutrients in Hydroponics by Means of Two Alternative Models. Biosystems Engineering, 2002; 83(2): 225-236.

11. Ben-Asher J, Silberbush M, Eprath, J. Uptake rates of NO_3 and K by lettuce on soilless culture: a mathematical model and experimental results. Acta Hort., 2005; 697: 307-312.
12. Jeyasubramanian K, Thoppey UUG, Hikku GS, Selvakumar N, Subramaniab A, Krishnamoorthy K. Enhancement in growth rate and productivity of spinach grown in hydroponics with iron oxide nanoparticles RSC Adv, 2016; 6: 15451–15459.
13. Di Lorenzo R, Pisciotta A, Santamaria P, Scariot V. From soil to soilless in horticulture: quality and typicity. Italian Journal of Agronomy. 2013; 8(4)
14. Hassanpouraghdam MB, Tabatabaei SJ, Aazami MA, Shekari F. Soilless culture production of alecost [*Chrysanthemum balsamita* (l.) baill.]: a preliminary study. Romanian Biotechnological Letters, 2010; 15(5): 5530-5536.
15. Giurgiu RM, Morar GA, Dumitras A, Boanca P, Duda BM, Moldovan C. Study regarding the suitability of cultivating medicinal plants in hydroponic systems in controlled environment Research Journal of Agricultural Science, 2014; 46(2): 84-92.
16. Palee J, Dheeranupattana S, Jatisatienr A, Wangkarn S, Mungkornasawakul P, Pyne S, Ung A, Sastraruji T. Influence of plantlet age and different soilless culture on acclimatization of *Stemona curtisii* Hook.f.. Asian Journal of Plant Sciences, 2012; 11(6): 294-299.
17. Gengmao Z, Quanmei S, Yu H, Shihui L, Changhai W. The physiological and biochemical responses of a medicinal plant (*Salvia miltiorrhiza* l.) to stress caused by various concentrations of NaCl. PLoS ONE, 2014; 9(2): e89624.
18. Tripathi P, Rabara RC, Shulaev V, Shen QJ, Rushton PJ. Understanding water-stress responses in soybean using hydroponics system-a systems biology perspective. Front. Plant Sci., 2015; 6: 1145.
19. Leonart S, Pednealt K, Gossellin A, Angers P, Papadopoulos AP, Dorais M. Diversification of greenhouse crop production under supplemental lighting by the use of new culture with high economic potential. Acta Hort, 2002; 580: 249-254
20. Marfa O, Caceres R, Guri S. Oxyfertigation: a new technique for soilless culture under mediterranean conditions. Acta Hort, 2005; 697: 65-72.
21. Woitke M, Schitzler WH Biotic stress relief on plants in hydroponic systems. Acta Hort, 2005; 697: 557-565.
22. Weber J, Ducousso M, Tham FY, Nourissier-Mountou S, Galiana A, Prin Y, Lee SK. Co-inoculation of *Acacia mangium* with *Glomus intraradices* and *Bradyrhizobium* sp. in aeroponic culture. Biol Fertil Soils, 2005; 41: 233–239.

23. Cantliffe DJ, Funes J, Jovicich E, Paranjpe A, Rodriguez J, Shaw N. Media and containers for greenhouse soilless grown cucumbers, melons, peppers, and strawberries. Acta Hort, 2003; 614: 199-203.
24. Olle M, Nagouajio M, Simos A. Vegetable quality and productivity as influenced by growing medium: A Review. Zemdirbyste Agriculture, 2012; 99(4): 399-408.
25. Bilderback TE, Warren SL, Owen Jr. JS, Albano JP. Healthy substrates need physicals. Hort Technology 2005; 15: 747-751.
26. Mastouri F, Hassandokht MR, Padasht Dehkaei MN. The effect of application of agricultural waste compost on growing media and greenhouse lettuce yield. Acta Hort, 2005; 697: 153-158
27. Muro J, Irigoyen I, Samitier P, Mazuela P, Salas MC, Soler J, Urrestarazu M. Wood fiber as growing medium in hydroponic crop. Acta Hort, 2005; 697: 179-185.
28. Khalighi A, Padasht Dehkaei MN. The effect of media produced by tree bark, tea waste, rice hull and azolla as a substitute for peat, on growth and flowering marigold (*Tagetes patulta* L. Golden Boy). Iranian Journal of Agricultural Science, 2000; 31(3): 557-565.
29. Huber JJ, Zheng Y, Dixon MA. Hydroponic cucumber production using urethane foam as a growth substrate. Acta Hort, 2005; 697: 139-145.
30. Welleman, JCC. Fytocell, an increasingly popular substrate. Acta Hort, 2005; 697: 195-198.
31. Grillas S, Lucas M, Bardopoulou E, Sarafopoulos S, Voulgari M. Perlite based soilless culture systems: Current commercial applications and prospects. Acta Horti, 2001; 548: 105-114.
32. Bentes M, Mattas K, Paroussi G, Tzouramani I. Employing soilless culture systems in strawberry production. Medit, 1996; 7(2): 4-8.
33. Weathers PJ, Giles KL. Regeneration of plants using nutrient mist culture. In Vitro Cellular and Developmental Biology, 1988; 24: 727- 732.
34. Demsar J, Osvald J, Vodnik D. The effect of light-dependent application of nitrate on the growth of aeroponically grown lettuce. J. Amer. Soc. Hort. Sci, 2004; 129(4): 570-575.
35. Chiipanthenga M, Maliro M, Demo P, Njoloma J. Potential of aeroponics system in the production of quality potato (*Solanum tuberosum* l.) seed in developing countries. African Journal of Biotechnology, 2012; 11(17): 3993-3999.
36. Oraby H, Lachance A, Desjardins Y. A Low Nutrient Solution Temperature and the Application of Stress Treatments Increase Potato Mini-tubers Production in an Aeroponic System. Am. J. Potato Res, 2015; 92(3): 387-397.

37. De Dorlodot S, Bertin P, Baret P, Draye X. Scaling up quantitative phenotyping of root system architecture using a combination of aeroponics and image analysis. Aspects of Applied Biology, 2005; 73: 41-54.
38. Lobet G, Pages L, Draye X. A novel image analysis toolbox enabling quantitative analysis of root system architecture. Plant Physiology, 2011; 19: 111.179895.
39. Saha S, Monroe A, Day MR. Growth, yield, plant quality and nutrition of basil (*Ocimum basilicum* L.) under soilless agricultural systems. Annals of Agricultural Science, 2016; 61: 181–186.
40. Defence Institute of Bio-Energy Research, Defence Research Development Organization, https://www.drdo.gov.in/drdo/labs1/DIBER/English/indexnew.jsp?pg=achieve.jsp.
41. Schroder FG. Alternative vegetables grown in hydroponic systems. Acta Hort, 1999; 481: 213-220.
42. Dorais M, Papadopoulos AP, Gosselin A. Greenhouse tomato fruit quality. Horticultural Reviews, 2001a; 26: 239-319.
43. Frezza D, Leon A, Logegaray V, Chiesa A. Soilless Culture Technology for High Quality Lettuce. Acta Hort, 2005; 697: 43-48.
44. Dorais M, Papadopoulos AP, Leonhart S, Gosselin A, Gaudreau L. Soilless greenhouse production of medicinal plants in north eastern Canada. Acta Hort, 2001b; 554: 297-303.
45. Johnson M, Villani TS, Azmat A, Simon JE, Both AJ. Evaluation of algal biomass production on vertical aeroponic substrates. Algal Research, 2015; 10: 240–248.
46. Maggini R, Kiferle C, Guidi L, Pardossi A, Raffaelli A. Growing medicinal plants in hydroponic culture. Acta Hort, 2012; 952: 697-704.
47. Cristiano G, Murillo-Amador B, De Lucia B. Propagation techniques and agronomic requirements for the cultivation of Barbados Aloe (*Aloe vera* (L.) Burm. F.) – A review. Front. Plant Sci, 2016; 7: 1410.
48. Saliqehdar F, Sedaghathoor SS, Olfati, J. Effects of four nutrient solutions on vegetative traits of *Aloe vera* L.cv. Austin at six harvest periods. J. Sci. Tech. Greenhouse Cult, 2013; 4: 15-27.
49. Saliqehdar F,Sedaghathoor S, Olfati JA. Nutrient solution on aloin, content and other quality characteristics of *Aloe vera*. J. Med. Plants By Prod, 2014; 3: 59–62.
50. Hayden AL. Aeroponic and hydroponic systems for medicinal herb, rhizome, and root crops. Hortscience, 2006; 41(3): 16-18.

51. Dorais M, Papadopoulos AP, Luo X, Leonhart S, Gosselin A, Pedneault K, Angers P, Gaudreau, L. Soilless greenhouse production of medicinal plants in north eastern Canada. Acta Hort, 2001; 554: 297-304.
52. Kiferle C, Lucchesini M, Mensuali-Sodi A, Maggini R, Raffaelli A, Pardossi A. Rosmarinic acid content in basil plants grown in vitro and in hydroponics. Central European Journal of Biology, 2011; 6(6): 946–957.
53. Azarmi F, Tabatabaie SJ, Nazemieh H, Dadpour MR. Greenhouse production of lemon verbena and valerian using different soilless and soil production systems. J. Basic. Appl. Sci. Res, 2012; 2(8): 8192-8195.
54. Simeunovic D. Cultivation of medicinal plants in greenhouse hydroponics. Electronic Theses and Dissertations, 2002; 1594.
55. Ioana C, Cantor M, Buta E, Husti A. Soilless Culture of Roses in Greenhouses, a New Alternative. ProEnvironment, 2013; 6: 422 – 426.