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Soilless substrates on vegetable production: A Review

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ABSTRACT

The world's population is growing at a rapid pace, and population growth is making it difficult to provide quality food to this growing population. But at the same time, the world's agricultural land is limited, and the land also faces serious pollution, salinization and drought problems, making it unsuitable for crop production. This need of food security had given birth to soilless cultivation, which further become popular in urban area and became a part of urban farming. (Bhargaw and chauhan.2020). Soilless cultivation refers to the cultivation of plants without using soil as a rooting material, and is divided into hydroponics and substrate cultivation. Among the water culture techniques, float hydroponics is adopted for the cultivation of fresh-cut leafy vegetables and aromatic plants (Tuzel *et al*., 2019). This soilless cultivation has a great prospect in many countries along with high space research to fulfill the lack of arable land where proper cultivable land is not available (Ahngar *et al*., 2020). This kind of agriculture may sound doubtful regarding the plant quality but 100% results are seen (Abinaya *et al*., 2021). A experiment was conducted in *Spinacia oleracea* in that the hydroponic system has a better effect as it makes the plant grow faster and more efficiently (Chakrabart *et al*., 2020). In this review attempts were made to review the research related to various soil-less cultures with different media for the plant growth.

Keywords : Soilless, hydrophonics, cultivation, plant growth, substrate

Introduction :

Soil is usually the most accessible medium for growing plants. It provides support, nutrients, air and water for successful growth of plants. However, the soil sometimes severely limits plant growth. Soil less agriculture is a method of growing plants using mineral nutrient solutions, in water and in other mediums, without soil. Ground plants can only grow with roots in mineral nutrient solutions or in an inert medium such as perlite, gravel, rock wool or coconut husks. According to the United Nations, the world's population is projected to rise from 7.6 billion in 2011 to approximately 8.6 billion in 2030 and 9.8 billion in 2050 (UN 2011).World’s total agricultural land has been increased by 3% in 1958 to 2005 mainly in tropical countries but decrease in 0.19% of agriculture land was recorded between 2005 to 2011 (Foley *et al.* 2011). Extreme population growth is accompanied by ecological destruction, resource scarcity, unequal distribution of food and, in many cases, malnutrition. To feed this growing population at least 6000 tons of food is required which is mostly imported from other sources out of which most of them are non-trusted source in term of quality standers (Dreschel *et al*. 2018) Soil-based agriculture faces several challenges, most notably a drop in per-capital land availability. With rapid urbanization and industrialization and the melting of the iceberg, the area of arable land will shrink further. Reducing agricultural water consumption, while maintaining or improving the economic efficiency of the agricultural sector in arid and semi-arid regions is a major challenge. Soilless techniques such as hydroponics, aerophonics and aquaponics are designed to combat these issues.

Issues in soil based cultivation :

According to United Nation world population is 7.6 billion in 2011 it is expected to reach around 8.6 billion in 2030 and 9.8 billion in 2050 (UN 2011). World's total agricultural land has been increased by 3% in 1958 to 2005 mainly in tropical countries but decrease in 0.19% of agriculture land was recorded between 2005 to 2011 (Foley *et al.* 2011). Extreme rise in population there is degradation of eco- system, resource scarcity, unequal distribution of food, and many cases of malnutrition. To feed this growing population at least 6000 tons of food is required which is mostly imported from other sources out of which most of them are non-trusted source in term of quality standers (Dreschel *et al*. 2018) Soil-based agriculture faces several challenges, most notably a drop in per-capital land availability. Land under cultivation would further decrease due to rapid urbanization and industrialization as well as the melting of icebergs. In arid and semi-arid regions, reducing agricultural water consumption while sustaining or improving the economic efficiency of the agricultural sector is a major challenge. Soilless techniques such as hydroponics, aerophonics and aquaponics are designed to combat these issues.

Classification of soilless culture:

1. Solid media culture
2. Solution culture
3. Aero phonics

Solid media culture:

Soilless media can be in the form of substrates originated from peat moss, bark, coir, compost, rice hulls, vermiculite and perlite. This soilless culture is a mainstream practice in developing countries as normal ground soils are typically discontented in usage for crop production. Hence, the rudimentary characteristics of good soilless media would be easy to acquire, economical, abundant in nature, light weight, possess upright chemical properties and has a satisfactory water retention capabilities. The quality of the growing media must also be greatly maintained to ensure good growth of seedlings. This was because sustainable production of ornamental flower and other crops would need to compensate decent growing media with sufficient water holding capacity and aeration. The most common incorporated soilless media are coir-dust based substrates and sphagnum peat in which it is among the most preferred and commercialized primary media. This was because it is occasionally acknowledged as substrates or growth media with the most prominent crop production mechanisms for containerized or raised beds with restricted volumes and was appropriate for continuous supply of nutrients through fertilization.

Table 1.Yield per hectare and water use efficiency as influenced by different irrigation levels in tomato

Treatment	Yield (tha^{-1})	Cummulative Use of Water, mm	WUE($tha^{-1}cm^{-1}$)
I_1	58.57	5.32	11.01
I_2	44.27	5.437	8.14
I_3	42.123	5.477	7.69
I_4	53.603	5.623	9.53
I_5	50.687	5.67	8.94
I_6	54.297	5.71	9.51
C.D.	0.42	0.026	0.218
SE(m)	0.135	0.009	0.07

Source: Lekhpal *et al*.2020

Lekhpal *et al*.2020 conducted an experiment to determine the irrigation requirement of tomato grown on Coco Peat under Protected Cultivation conditions at Research Farm of Center of Excellence on protected cultivation and precision farming under Polyhouse, College of Agriculture, IGKV, Raipur (C.G), during the Rabi season of 2016-17. The experiment was laid out in a Complete Random Design. The quality and yield response of tomato to drip irrigation was investigated. Six different irrigation levels (I_1 = 0.8 IW:CPE, I_2 = 0.9 IW:CPE, I_3 = 0.1 IW:CPE, I_4 = 1.1 IW:CPE, I_5 =1.2 IW:CPE, I_6 =1.3 IW:CPE). From Table 1, in terms of yield (tha^{-1}), treatment combination I_1 was superior over the rest of the treatment combinations. Water use efficiency (WUE) is the ratio between crop yield (q ha^{-1}) and total depth of water (cm) applied to the crop. It is apparent from the Table 1 that the water use efficiency recorded was significantly influenced by different irrigation levels. Significantly maximum water use efficiency was found under the treatments I_1 (11.01 t/ha/cm) and it was followed by I2 (8.14t/ha/cm), I3 (27.69 t/ha/cm), I4 (9.53 t/ha/cm) and I5 (8.94 t/ha/cm),I6 (9.51 t/ha/cm) respectively.

Vertical Farming:

Vertical farming is one such solution that's been implemented around the world. By Vertical Farming, food crops can be cultivated easily in urban areas by planting in vertically stacked layers in order to save space and use minimal energy and water for irrigation. In India, Vertical Farming is at nascent stages, however, there are few startups and agri-tech companies working to revolutionise the field.

Background and **Concept of Vertical Farming**

In 1915, Gilbert Ellis Bailey coined the term "vertical farming" and wrote a book titled "Vertical Farming". In the early 1930s, William Frederick Gerick pioneered hydroponics at the University of California at Berkley. In the 1980s, Åke Olsson, a Swedish ecological farmer, invented a spiral-shaped rail system for growing plants and suggested vertical farming as a means for producing vegetables in cities.The modern concept of vertical farming was proposed in 1999 by Professor Dickson Despommier. His concept was to grow the food in urban areas itself utilizing less distance and saving the time in bringing the food produced in rural areas to the cities. He intended in growing food within urban environments and thus have fresher foods available faster and at lower costs. Consequently, Vertical farming is conceptualized as cultivating and producing crops/ plants in vertically stacked layers and vertically inclined surfaces. In the physical layout, the plants are vertically stacked in a tower-like structure. This way, the area required to grow plants in minimized. Next, a combination of natural lights and artificial lights is used to maintain a perfect environment for an efficient growth of the plants. The third parameter is the growing medium for the plants. Instead of soil, aeroponic, hydroponic or aquaponic growing mediums are used as the growing medium

Techniques of Vertical Farming:

1. Hydrophonics
2. Aerophonics
3. Aquaphonics

Hydrophonics :

Hydroponics' word has its origin from Greek language where 'hydro' refers to water and 'ponos' refers to labour (Beibel, J.P. 1960).In hydroponic system it is assumed that soil is not necessary for plant growth actually it acts as a source of essential macro and micronutrients that regulate the plant growth and development. Thus, if soil is replaced with a solution having appropriate combination of macro and micro nutrients it is possible to raise a crop to its full maturity.

SWOT analysis of hydroponics system in India :

Swain *et al.*, 2021 has given the SWOT analysis of hydroponics system in India.

Strengths:

- Hydroponics makes any land with water source useful for vegetable production.
- High yields can be obtained from lesser spaces.
- Due to the premium quality, produce can fetch premium prices.
- Less number of labor is required which means it is a less costly venture.
- Integrated pest and disease management can be done in a very effective way.

Weaknesses:

- Till date, there is no association/ tie up with any industries regarding selling of the products or formation of any bodies among hydroponics cultivators.
- High initial cost of investment and capital expenditure (capex).
- It needs more diligence and devotion than conventional farming.
- There are no dedicated standards and laws in India till date.

Opportunities:

- Branding, packaging and selling of the hydroponically grown produce can be done in a clean, healthy and unique way.
- More cash crops such as gingers, saffron, turmeric etc. should be tried to grow hydroponically.
- These crops are gaining good traction in India.
- Hydroponically grown crops can be sold to niche/ urban markets which fetches high return.

Threats:

- There must not be any competition regarding price but on quality in between conventionally and hydroponically grown products.
- There is a wrong perception among some people that hydroponics is unnatural.
- Certain soil grown produce are being marketed vigorously and may be a threat to hydroponic produce as for eg. Calyx-On tomato.
- Inconsistent supply arrangement may also ruin the market intake.

Types of Hydroponics system:

1. Wick system
2. Nutrient film techniques
3. Water culture or deep water culture (DWC)
4. Drip system
5. Ebb and flow systems

Wick system:

This is simplest hydroponic system requiring no electricity, pump and aerators. Plants are placed in an absorbent medium like coco coir, vermiculite, perlite with a nylon wick running from plant roots into a reservoir of nutrient solution. Water or nutrient solution supplied to plants through capillary action. This system works well for small plants, herbs and spice and doesn't work effectively that needs lot of water.

Nutrient Film Technique (NFT) system:

NFT was developed in the mid 1960s in England by Dr. Alen Cooper to overcome the shortcomings of ebb and flow system. In this system, water or a nutrient solution circulates throughout the entire system; and enters the growth tray via a water pump without a time control (Domingues *et al*., 2012). The system is slightly slanted so that nutrient solution runs through roots and down back into a reservoir. Plants are placed in channel or tube with roots dangling in a hydroponic solution. Roots are susceptible to fungal infection because they are constantly immersed in water or nutrient. In this system, many leafy green can easily be grown and commercially most widely used for lettuce production.

Deep water culture system:

In deep water culture, roots of plants is suspended in nutrient rich water and air is provided directly to the roots by an air stone. Hydroponics buckets system is classical example of this system. Plants are placed in net pots and roots are suspended in nutrient solution where they grow quickly in a large mass. It is mandatory to monitor the oxygen and nutrient concentrations, salinity and pH (Domingues *et al*., 2012) as algae and moulds can grow rapidly in the reservoir. This system work well for larger plants that produce fruits especially cucumber and tomato, grow well in this system.

Drip system:

The drip hydroponic system is widely used method among both home and commercial growers. Water or nutrient solution from the reservoir is provided to individual plant roots in appropriate proportion with the help of pump (Rouphael and Colla, 2005). Plants are usually placed in moderately absorbent growing medium so that the nutrient solution drips slowly. Various crops can be grown systematically with more conservation of water.

Ebb and Flow system:

This is first commercial hydroponic system which works on the principle of flood and drain. Nutrient solution and water from reservoir flooded through a water pump to grow bed until it reaches a certain level and stay there for certain period of time so that it provide nutrients and moisture to plants. Besides, it is possible to grow different kinds of crops but the problem of root rot, algae and mould is very common (Nielsen *et al*., 2006) therefore, some modified system with filtration unit is required.

Nutrient solutions

A nutrient solution for hydroponic systems is an aqueous solution containing mainly inorganic ions from soluble salts of essential elements for higher plants. Eventually, some organic compounds such as iron chelates may be present (Steiner, 1968). An essential element has a clear physiological role and its absence prevents the complete plant life cycle (Taiz and Zeiger, 1998). Currently 17 elements are considered essential for most plants, these are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, copper, zinc, manganese, molybdenum, boron, chlorine and nickel (Salisbury and Ross, 1994). With the exception of carbon (C) and oxygen (O), which are supplied from the atmosphere, the essential elements are obtained from the growth medium. Other elements such as sodium, silicon, vanadium, selenium, cobalt, aluminum and iodine among others, are considered beneficial because some of them can stimulate the growth, or can compensate the toxic effects of other elements, or may replace essential nutrients in a less specific role (Trejo-Téllez *et al.*, 2007). The most basic nutrient solutions consider in its composition only nitrogen, phosphorus, potassium, calcium, magnesium and sulphur; and they are supplemented with micronutrients. The nutrient composition determines electrical conductivity and osmotic potential of the solution. Moreover, there are other parameters that define a nutrient solution as discussed below in detail. The nutrient composition determines electrical conductivity and osmotic potential of the solution. Moreover, there are other parameters that define a nutrient solution as discussed below in detail.

Methods of study and use of nutrient solutions:

In 18th and 19th century several researchers including Nicolas-Thédore de Saussure, Jean- Baptiste-Boussingault, Julius von Sachs and Wilhem Knop were interested to study the interrelationship of plant nutrition and their ability to increase productivity. Sach's designed an experimental system to study the minimal nutrient solution required for the growth of plant. The plants were grown, with their roots immersed in aqueous nutrient solution containing inorganic salts. According to Sach's six inorganic salts having nine nutrients (Potassium, Nitrogen, Phosphorus, Calcium, Sulpher, Sodium, Chloride, Magnesium and Iron) are required for the growth of plants. The nutrient media was later modified with incorporation of other essential nutrients. The most commonly used nutrient media has been formulated by D.R. Hogland and is referred to as modified Hoagland's solution.

Table 2.Comparative concentration ranges of macronutrients (mM) in soil and soilless crop

Nutrient	Soil (mM)	Hydroponics (mM)
$N\text{-}NO_3^-$	0.5-10	5-20
$N\text{-}NH_4^+$	0.02-0.05	0.5-2
$P(H_2PO_4^-)$	0.0005-0.05	0.5-2
K^+	0.2-2	5-10
Ca^{2+}	0.5-4	3-6
Mg^{2+}	0.2-2	1-2
$S\ (SO_4^{2-})$	0.1-2	1.5-4

reworked by Epstein 1972; Marschner 1996

Epstein (1972) and Marschner (1996) has give the Comparative concentration ranges of macronutrient (mM) in soil and soilless crop. The main difference between the two systems is represented by the reduced volume of the substrate (and/or nutrient solution) available to each plant, and this justifies the particular management of the nutrient solution in the soil-less system. Also for this reason, one of the most relevant characteristics of the nutrient solutions is the ionic concentration of nutrients, which is usually much greater than that of the circulating solution of the soil, even though this is variable. In order to grow, plants do not require such high nutrient concentrations as those required for soil-less cultivation reported in Table 2. Such high concentrations in soil-less cultivation are used to ensure a good nutrient reserve and to simplify the preparation, the control (e.g. of the electrical conductivity with a conductivity meter) and the reintegration of the nutrient solution.

Table 3.Composition of a modified Hoagland nutrient solution employed in the present study

Compound	Molecular weight	Concentration Of stock solution	Concentration of stock solution	Volume of stock solution per litre of final solution	Elements	Final concentration of element	
	g mol^{-1}	mM	gL^{-1}	mL		µM	ppm
Macronutrients							
KNO_3	101.10	1,000	101.10	6.0	N	16,000	224
$Ca(NO_3).4H_2O$	236.16	1,000	236.16	4.0	K	6,000	235
$NH_4H_2PO_4$	115.08	1,000	115.08	2.0	Ca	4,000	160
$MgSO_4.7H_2O$	246.48	1,000	246.48	1.0	P S Mg	2,000 1,000 1,000	62 32 24
Micronutrient							
KCl	74.55	25	1.864	20	Cl	50	1.77
H_3BO_3	61.83	12.5	0.773		B	25	0.27
$MnSO_4.H_2O$	169.01	1.0	0.169		Mn	2.0	0.11
$ZnSO_4.7H_2O$	287.54	1.0	0.288		Zn	2.0	0.13
$CuSO_4.5H_2O$	249.68	0.25	0.062		Cu	0.5	0.03
H_2MoO_4 (85%MoO_3)	161.97	0.25	0.040		Mo	0.5	0.05
NaFeEDTA (10% Fe)	468.20	64	30.0	0.3-0.1	Fe	16.1-53.7	1.00-3.00

Source: Epstein 1972

Aerophonics:

A plant-cultivation technique in which the roots hang suspended in the air while nutrient solution is delivered to them in the form of a fine mist. Aeroponic systems are a specialized version of hydroponics where the roots of the plant extend only in air and the roots are directly sprayed with a nutrient water mix (the recipe). ... In aeroponics, oxygen is surrounding the roots at all times. Surplus oxygen accelerates nutrient absorption at the root surface. Although Hydroponics manages to grow crops up to 50% faster than in soil, it still has a major drawback. Since, the roots are always submerged in water, only crops that are more tolerant to waterlogging such as cabbages, lettuce and tomatoes are favored for growth. To overcome this demerit, the basic hydroponics setup was modified to use a high-pressure pump to blast freely hanging roots with a fine mist of the nutrient solution at regular intervals. This way the roots didn't face any water logging issues and it turned out that this method ended up in saving more water and nutrients than most hydroponics setups.

Working Principle

Aeroponics is a method of growing plants with their roots suspended in the air in a grow chamber. The chamber contains the water-based solutions that is used to promote healthy growth in the plants. Water is pumped from the reservoir into the mirco-jet nozzles which distribute the nutrient solution to the roots at definite intervals. This is an enclosed system i.e. whatever does not get absorbed by the roots falls back down into the solution chamber and gets cycled through again. The microbes on the plant are in an oxygen-rich environment. This allows the microbes time to digest the nutrients and to make them immediately available for the plant's use. Well-circulating CO_2 in the room also enhances growth.

Table 4.Comparison B/W Soil Less Vs Soil Crops Productivity/Arce

Vegetables	Hydroponics / acres	Traditional /acres
Tomato	180 tons	5-10 tons
Cauliflower	30,000lb	10-1500lb
Lettuce	21,000lb	9,000lb
Cucumber	28,000lb	7,000lb
Cabbage	10-12 tons	6-7 tons
Okra	19,000lb	5-8000lb
Peas	14,000lb	2,000lb

Source: Solanki *et al.* 2017

Table 5.The effect of concentration of the Hoagland solution on the tomato fruit quality parameter

Treatments	T_1 (100%)	T_2 (75%)	T_3 (50%)	CD (P=0.05)
Moisture content (%)	59.220	56.757	50.990	NS
Titrable acidity (%)	0.16	0.16	0.10	0.01
Lycopene(%)	3.0	2.98	2.75	NS
Frimness (KgF)	0.643	0.573	0.557	NS
TSS(°brix)	7.37	6.6	5.2	1.17
Fruit yield(t/ha)	72.57	69.28	50.76	5.75

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Source : Kaur *et al*. (2016)

Kaur *et al.*, 2016 conducted a study in Demonstration Farm of soil and water engineering, PAU, Ludhiana and observed that the Total yield of tomato was higher in T_1 (100%) as compared with T3 (50%) treatments as shown in Table 5. It can be seen from the data that the maximum yield was found with T_1 (100%) followed by T_2 (75%) and T_3 (50%). Higher yield was due to 100% concentration of Hoagland solution. This may be attributed to higher concentration of nutrients or better availability of nutrients which enhances the cell metabolisms resulting in better yield.

Table 6.Comparative cultivation of *Spinacia oleracea* grown in hydroponics and traditional soil system

Planting system	Shoot/root ratio	No. of leaves	Germination rate (%)	Height (cm)
DWC	**3.47**	**36**	**95**	**12.83**
Kratky	**2.67**	**30**	**82.5**	**13.60**
Black cotton soil	2.04	3	15	10.5
Red laterite soil	1.97	3	7.5	13.26

Source : Chakrabati *et al.*,2020

Chakrabati *et al.*, 2020 **c**onducted an experiment in *Spinacia oleracea* grown in hydrophonics (DWC and kratky) system and traditional soil system (black cotton soil and red laterite soil) to investigate the potential of growing spinach. In which hydroponically cultivated crop (table 6) shows best results in Average shoot/root ratio, height, number of leaves, and germination rate.

Table 7.Amount of nutrients applied and saved throughout the production cycle in bell pepper for the three treatments of hydroponic systems used

Treatment	Nutrient applied				Nutrient saved			
	gm^{-2}				gm^{-2}			
	N	P	K	Ca	N	P	K	Ca
OSS	277	77	260	302	0	0	0	0
CSS1	77	77	260	301	16	7	20	36
CSS2	**278**	**78**	**61**	**302**	**18**	**8**	**23**	**30**

Source: Resendiz-melgar *et al.* 2017

OSS: open soilless system
CSS1: closed soilless system controlled by electrical conductivity
CSS2: closed soilless system controlled by the concentration of ions K, Ca, NO_3^- and P

Resendiz-melgar *et al.*, (2017) conducted a experiment in greenhouse of 27 m of width by 40 m of length, type tunnel with skirt and zenithal ventilation located in San Pablo Tepetzingo Tehuacan, Puebla and given that the Amount of nutrients applied and saved throughout the production cycle in bell pepper for the three treatments of hydroponic systems. The amount of nutrient applied for the three treatments was similar because of the way the irrigations were controlled and the reused solutions adjusted. The percentage of nutrients saved was between 6% and 12% individually. Other works with pepper report higher savings with 78% (Ko *et al.*, 2013b) or more than 80% (Giuffrida and Leonardi, 2012). With other crops nutrient savings in closed hydroponic systems are also relevant, in tomatoes, savings of 20-50% of fertilizer (Sánchez-Del Castillo *et al.*, 2014b) and 25% for cucumber have been obtained (Sánchez-Del Castillo, *et al*., 2014). The low nutrient reused may was due to the absorption by the plant and possibly to its being left in the substrate, as has been reported in other studies (Pineda *et al*., 2011).

Conclusion

Soilless farming is considered a newly developed technique for agricultural development, but it is not a simple technique. However, growers and gardeners in many countries lack knowledge of the new technique and require well-trained staff. Also, most of the substrates are international market, so they are expensive. So you're better off looking for good, inexpensive substrates locally. Initially, terrestrial production systems were implemented by imitating traditional methods based on terrestrial production or land based systems. Soilless culture can be the effective tool to increase the crop yield and the water-use efficiency, also reduce the environmental impact of greenhouses and nurseries. Hydroponic cultivation of plants is better than traditional methods of cultivation (table 3). In this method a more efficient use of water could be made and nutrient can be saved (table 6) as well as it also avoid the fertilizers from direct disposal to the environment. By implementing a soilless farming system, better quality of agricultural products can be met to satisfy consumer preferences.

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