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Abstract
Many challenges have come to the limelight in recent years due to a rapid increase in the world population. One of these challenges is the reduction of the per capita land available for soil-based agriculture, leading to other agricultural and environmental problems. Under these critical circumstances, it became necessary to develop advanced technologies and techniques to withstand the current situation. While several studies have been carried out on soil and *in vitro* plant cultivation, few of these are based on soilless crops. Soilless agriculture is a new promising method for improving cultivation of different cash crops. Apart from the reservation and restoration of cultivation land, soilless farming, especially close-loop method, has numerous advantages: it uses recycled fixed quantities of water, saves 85–90% of irrigation water, can be implemented in unfavourable areas for ordinary farming, nearly zero contamination of the atmosphere, better yield than traditional farming. Therefore improved space and water management methods of food production under soilless cultivation have shown some promising results throughout the world.

Keywords: Aeroponics, hydroponics, NFT, pH & EC, soilless culture and water conservation

Introduction
The world's 7.8 billion people today use 1.5 billion ha of land to grow food and raise livestock–an impressive agricultural footprint. By 2050 the world will be equivalent to 10.9 billion people. Because each of us needs a minimum of 1,600 calories per day, civilization would have to expand another 2.1 billion acres if agriculture continues to be practiced as it is today. There simply is no such thing as so much fresh, arable earth.

Agriculture often uses 70 per cent of the world's freshwater available for irrigation, making it unusable to drink due to pollution with fertilizers, pesticides, herbicides and silt. If current trends continue, healthy drinking water in certain heavily populated regions would be impossible. The resulting emissions of greenhouse gases are of course a major concern, but so is the price of food as it becomes related to the price of fuel, a process that essentially doubled the cost of eating in most places around the world. With a number of reports predicting that farmers would find it hard to feed the extra 3 billion people swelling across the world by 2050.

With growing population / urbanization and squeezing of land resources, alternative means of cultivation need to be created, so that the limited space available can be used in the best possible way. Hydroponic / soil less cultivation is considered a promising technology which also respects the nutritional value of the products and the protection of the environment (Butler and Oebker, 2006) [3]. Even now the idea of vertical agriculture is gaining ground to solve the issue of horizontal farming.

The term hydroponics refers to plant cultivation in nutrient solutions without the use of soil as the medium. This method of plant cultivation can be traced back to ancient times, also referred to as soil less agriculture, aquaculture, solution culture or nutrition. All plant varieties can be grown using this method which enables more control of external plant growth factors, such as nutrient availability, as a closed system. This simplifies crop predictability and management, and is generally more effective than traditional methods of soil cultivation. Most hydroponic systems regulate the amount of water, nutrients and photoperiod automatically, based on the requirements of different plants (Resh, 2013) [18].

Background
The hydroponic process rising in our oceans goes back to the time the earth was formed. Hydroponic growing preceded soil growing. But as a farming method, many believe it began

with the famous hanging gardens in the ancient city of Babylon, which are classified as one of the Seven Wonders of the Ancient World, and was possibly one of the first successful attempts to hydroponically grow plants.

It was during the 1860s, according to modern science, that the German plant physiologist Julius von Sachs (1832-1897) experimented with growing plants in water-nutrient solutions, naming them *nutriculture.* In 1929, Professor William Frederick Gericke of the University of California at Berkeley first suggested the use of a solution culture for agricultural crops. He first named it aquaculture, but later found aquaculture already being applied to aquatic organism cultivation. Gericke recorded that in his backyard, tomatoes and other plants growing to a remarkable size (25 feet) in solutions of mineral nutrients rather than soil. In 1937 Gericke introduced the term hydroponics for the plant cultivation in water (although he asserts that the term was suggested by Dr. W. A. Setchell, of the University of California). American forces deployed on non-arable islands in the Pacific Ocean during the 1940's used hydroponics successfully. Fresh produce has also been practiced in arid countries, such as Saudi Arabia. Sholto Douglas worked on what he dubbed the hydroponic system of Bengal. He tried to simplify hydroponic methods and equipment, so that it could be provided as a partial solution to food shortages in India and other developing countries. Hydroponics, widely introduced in some cases, will remain in limited use as long as conventional methods of farming in natural soil can sustain the world's population.

Hydroponics-the soilless growth of plants

Nutrients are supplied to the plant in an aqueous solution, as opposed to those obtained from the soil by the plant. Extends the versatility of the gardening; allows a wider variety of plants to thrive in a wider variety of climates.

Benefits

A hydroponic acre can yield up to ten thousand plants, while an acre of soil can yield up just one million. Hydroponics saves a-enormous amount of water; it requires as little as 1/20 of the amount of food as a normal plant. Water and fertilizers are retained, since they can be reused. There is no leaching of minerals and water leakage. Crop rotation is unnecessary because nutrients are not lost, and there is no issue with soil sickness. Very useful for areas where stress on the environment (cold, heat, dessert etc) is a big problem (Polycarpou *et al*., 2005) [17]. Growing isn't regulated by the seasonal changes. Hydroponics allows for continuous year-round development (Manzocco *et al.*, 2011) [13]. Cloning / cutting of already-in-bearing plants will cut short vegetative growth to quickly flower. Regulated systems present little or no risk of weeds or parasites and reduce labor charge (Jovicich *et al.*, 2003) [10]. People will make productive use of their time on the rooftop and increase the output of oxygen in a choked environment. By the root growth, plants can use their flowering and fruiting resources with higher productivity. Furthermore, hydroponics allows for greater plant monitoring to produce more consistent performance.

Disadvantages

Initial cost of capital, operating costs are high. It requires specialized knowledge and equipments (Resh, 2013) [18]. It is a method which is more complex and involved than traditional farming. Plant in a hydroponics system is sharing the exact same nutrient and water borne diseases can easily spread from one plant to another (Ikeda *et al.*, 2002) [9]. Hot weather and limited oxygenation can limit production and may result in crop loss. Hot weather and limited oxygenation can restrict production which may lead to crop loss. Maintenance of pH, EC and proper concentration of the nutrient solution is of prime importance. Finally, light and energy supply is required to run the system under protected structure.

Types of systems

There are different types of systems available for cultivation under hydroponics. However the factors like space and other available resources, expected productivity, availability of suitable growing medium and expected quality of the produce – color, appearance, free from pesticides, etc are to be considered in selection of system. Plants grown in solution culture have their roots suspended directly in a nutrient solution. It can be further classified into

i) Circulating methods (Active or Closed system)/ Continuous flow solution culture

a) Nutrient film technique (NFT) b) Deep flow technique (DFT) c) Ebb and Flow technique

ii) Non-circulating method (Passive or open systems)/ Static solution culture

a) Root dipping technique b) Floating technique c) Wick technique

i) Circulating methods

The excess nutrient solution that runs off is collected back in the reservoir for reuse in a circulating method. It uses a little more effectively the nutrient solution as the excess fluid is reused; this often enables the use of a cheaper timer since a circulating method does not require precise monitoring of the watering cycles. This system can have significant changes in the levels of pH and nutrient intensity that involve periodic checks and adjustments.

a. Nutrient Film technique

N.F.T. systems have a constant flow of nutrient solution so no timer required for operation of the submersible pump. The nutrient solution is pumped into the growing tray (usually a tube) and flows over the plant's roots, then drains back into the tank (Domingues *et al.,* 2012) [5]. There is typically no growing medium used other than air, which saves the cost of replacing the growing medium with the roots in the nutrient solution for every small plastic container. N.F.T. systems are very susceptible to power outages and pump failures. When the flow of nutrient solution is disturbed the roots dry out very easily.

b. The Deep flow technique

It is the simplest of all active hydroponic systems. The frame holding the plants normally consists of Styrofoam and floats directly on the nutrient solution. An air pump provides air to the air stone which bubbles the nutrient solution and supplies the plant roots with oxygen. It is the method of choice for growing leaf lettuce which is fast growing water-loving plants, making them an ideal option for this form of hydroponic system. In this type of system very few plants other than lettuce can do well (Domingues *et al.*, 2012) [5]. This form of system's main downside is that it doesn't work well with large plants or with long-term plants.

c. The Ebb and Flow technique

It is also called as flood and drain. This method works by flooding the rising tray with nutrient solution temporarily, and then draining the solution back into the reservoir (Nielsen *et al*., 2006) [15]. Typically this operation is performed with a submerged pump which is attached to a timer. When the timer turns the pump on the solution of nutrients is pumped into the rising tray. When the timer shuts off the pump the nutrient solution flows back into the tank. Depending on the size and variety of plants, temperature and humidity, and the variety of growing medium used, this collection comes on several times a day. The Ebb and Flow method is flexible, and can be used with a variety of media. The whole container can be filled with rocks, gravel or granular rockwool. Many people prefer to use individual pots filled with growing medium, which makes it easier to move or even move plants inside or out of the system.

The key drawback of this kind of device is that there is a susceptibility to power outages as well as pump and timer failures with certain forms of growing medium (Gravel, Growrocks, Perlite). The roots will dry out quickly at interruption of the watering cycles. This problem can be somewhat relieved by using could media which retains more water (Rockwool, Vermiculite, coconut fiber or a good soiless mix like Pro-mix or Faffard's).

ii) Non-circulating method

The Non- circulating method does not collect the run off. It should also have a more accurate timer, so that watering cycles can be modified to ensure that plants obtain enough nutrient solution and that the runoff is held to a minimum (Awad, *et al*., 2017) [2]. This method needs less maintenance since the excess nutrient solution isn't pumped back into the reservoir, so the reservoir's nutrient intensity and pH won't adjust. That means you can fill the reservoir with pH-adjusted nutrient solution and then forget it until you have to add more.

a) Root dipping technique

The plants are grown in this technique in small pots filled with little growing medium. The pots are placed in such a way that lower 2 – 3 cm of the pots is submerged in the nutrient solution. Some roots are dipped in the solution while others hang in the air above the solution for nutrient and air absorption, respectively. This technique is simple, and can be established using materials that are easily accessible. This increasing method of 'low tech' is inexpensive to create, and requires little maintenance. Importantly, this technique doesn't need costly things like power, water pump, channels, etc. However an inert medium must be used for root crops (beet, raddish, etc.).

b) Floating technique

This is similar to box approach but can be used in shallow containers (10 cm deep). Plants established in small pots are fixed to a Styrofoam sheet or any other light plate and allowed to float on the nutrient solution filled in the container and solution is artificially aerated (Singh and Singh, 2012.) [20]

c) The wick system technique

It is the simplest hydroponic system type, by far. This is a passive device, meaning that there are no movable pieces. The nutrient solution is drawn from the reservoir by a wick into the rising medium. There are free plans for a basic wick-system. In this system can use a variety of growing medium like Perlite, Vermiculite, Pro-Mix and Coconut Fiber. This system's greatest downside is that plants that are large or require large quantities of water can absorb the nutrient solution quicker than the wick(s) can produce it.

1. Drip System

Drip systems may be system of active recovery or non-recovery type. The hydroponic system category most used in the world. It is easy to operate; the timer controls a submerged pump. The timer turns the pump on, and a short drip line drips nutrient solution onto each plant's foundation (Rouphael and Colla, 2005) [19]. Main drawbacks of the systems are more suited to larger gardens, pH and nutrient fluctuations.

2. Aeroponic System

It is probably the most high-tech method of hydroponic gardening as above the increasing medium the N.F.T. device is mainly air (Maboko *et al*., 2011) [12]. The roots remain in the air and are misted with a solution of nutrients. Normally the misting are performed every few minutes. Since the roots are exposed to the air like the N.F.T. method, if the misting cycles are disrupted, the roots can dry out quickly. A timer controls the nutrient pump in much the same way as other forms of hydroponic systems, but the aeroponic system needs a short cycle timer running the pump every few minutes for a few seconds.

The Nutrient Solution

Managing plant nutrition is essential to success in increasing hydroponics. That is achieved by properly managing the nutrient solution. This solution contains different combinations of nutrients explicitly formulated to imitate and/or improve the combinations of nutrients present in soil (Mwazi *et al*., 2010) [14]. Chemicals contained within the nutrient solution are the following

- **Nitrogen-** Influential in the production of leaves and the growth of the stem. ·
- **Phosphorus-**Vital in flowers, fruits, leaves and stems growth. Also encourages healthy root growth.
- **Potassium-** Used by the cells of a plant during assimilation of energy produced by photosynthesis.
- **Calcium-** Spurs root growth. Also facilitates a plant's absorption of potassium.
- **Magnesium-** A component of chlorophyll. Also active in the process of distributing phosphorus throughout the plant.
- **Sulphur-** Joins with phosphorus to heighten the effectiveness of that element. Also used in the production of energy.
- **Iron-** Essential in chlorophyll production within a plant.
- **Manganese-** Aids a nitrogen-absorbing vine.
- **Zinc-**_Essential component of the process of energy transfer in a plant.
- **Boron-** Although boron is necessary in minute quantities, it is not known exactly how boron is used.
- **Copper-** Required chlorophyll production.

pH and Electrical Conductivity (EC) Management

In hydroponics, plant nutrients are dissolved in water and are primarily in inorganic and ionic forms. All 17 basic elements for plant growth are provided using various chemical combinations. *Hoagland's* solution is used as most common nutrient solutions for hydroponic systems. Variables such as temperature, light, evaporation, processing of the tap water and the amount of nutrients can also influence the pH level. Checking these variables, periodically the pH level of the solution is vital to maintain a healthy environment for the growth of the plant

For a general hydroponic solution the recommended pH level is between pH 6-6.5. (Kirimura and Inden, 2005) [11].

If the solution is too acidic the pH level of the nutrient solution can change through adding one tablespoon of baking soda to three gallons of solution. Adding of one tablespoon of white vinegar per four gallons of solution can alter the pH level if it is too acidic.

Table 1: Optimum range of EC and pH values for hydroponic crops (Nisha Sharma *et al.*, 2018) [16]

Crops	EC (dSm^{-1})	pH
Asparagus	1.4 to 1.8	6.0 to 6.8
African Violet	1.2 to 1.5	6.0 to 7.0
Basil	1.0 to 1.6	5.5 to 6.0
Bean	2.0 to 4.0	6.0
Banana	1.8 to 2.2	5.5 to 6.5
Broccoli	2.8 to 3.5	6.0 to 6.8
Cabbage	2.5 to 3.0	6.5 to 7.0
Celery	1.8 to 2.4	6.5
Carnation	2.0 to 3.5	6.0
Courgettes	1.8 to 2.4	6.0
Cucumber	1.7 to 2.0	5.0 to 5.5
Egg plant	2.5 to 3.5	6.0
Ficus	1.6 to 2.4	5.5 to 6.0
Leek	1.4 to 1.8	6.5 to 7.0
Lettuce	1.2 to 1.8	6.0 to 7.0
Pak Choi	1.5 to 2.0	7.0
Peppers	0.8 to 1.8	5.5 to 6.0
Parsley	1.8 to 2.2	6.0 to 6.5
Rhubarb	1.6 to 2.0	5.5 to 6.0
Rose	1.5 to 2.5	5.5 to 6.0
Spinach	1.8 to 2.3	6.0 to 7.0
Strawberry	1.8 to 2.2	6.0
Sage	1.0 to 1.6	5.5 to 6.5
Tomato	2.0 to 4.0	6.0 to 6.5

Table 1 indicates the optimal range of EC and pH values for the various hydroponic crops. Ideal EC range for hydroponics for most of the crops is between 1.5 and 2.5 dSm^{-1}. Higher EC will prevent nutrient absorption due to osmotic pressure and lower level severely affects plant health and yield. Appropriate EC management in hydroponics technology can therefore provide an effective tool to improve vegetable yield and quality (Gruda, 2009) [8].

Suitable crop grown under Hydroponics

Hydroponics system may produce a large number of plants and crops or vegetables. The consistency of the end products' stock, taste and nutritional value is usually higher than the cultivation based on natural soil. Various experimental findings outlines that leafy greens (lettuce, spinach, parsley celery and atriplex etc) can be successfully and easily grown in hydroponic systems. Lettuce and spinach are the most promising species to develop in integrated hydroponic and aquaculture systems due to its higher growth and capacity to absorb nutrients.

Table 2: Various species of plants grown under soil less hydroponic system

Types of crops	Name of the crops
Cereals	Rice, Maize
Fruits	Strawberry
Vegetables	Tomato, Chilli, Brinjal, Green been, Beet, Winged bean, Bell Pepper, Cucumbers, Melons, Green onion
Leafy vegetables	Lettuce, Spinach, Celery, Swiss chard, Atriplex
Condiments	Coriander leaves, Methi, Parsely, Mint, Sweet basil, Oregano
Flower/Ornamental crops	Marigold, Roses, Carnations, Chrysanthemum
Medicinal crops	Indian Aloe, Coleus
Fodder crops	Sorghum, Alfa alfa, Bermuda grass. Carpet grass

Table 3: Hydroponic averages compared with conventional soil yields (Fallovo, *et al*., 2009) [6]

Name of crop	Hydroponic equivalent per acre	Agricultural average per acre
Wheat	5,000 lb.	600 lb.
Oats	3,000 lb.	850 lb.
Rice	12,000 lb.	750-900 lb.
Maize	8,000 lb.	1,500 lb.
Soybean	1,500 lb.	600 lb.
Potato	70 tons	8 tons lb.
Beet root	20,000 lb.	9,000 lb.
Cabbage	18,000 lb.	13,000 lb.

Peas	14,000 lb.	2,000 lb.
Tomato	180 tonnes	5-10 tonnes
Cauliflower	30,000 lb.	10-15,000 lb.
French bean	42,000 lb. of pods for eating	-
Lettuce	21,000 lb.	9,000 lb.
Lady's finger	19,000 lb.	5-8,000 lb.
Cucumber	28,000 lb.	7,000 lb.

Table 4: Vegetable production under soil-less culture in India (Frezza *et al.*, 2005) [7]

Vegetables	Production ($g/m^2/day$)
Carrot	56.5
Cucumber	226
Garlic	57
Ginger	57
Leek	57
Green Bean	113
Lettuce	226
Onion	56.5
Peapod	113
Potato	56.5
Salad greens	226
Tomato	113
Greens	113

Under hydroponics method the application of pesticides is usually avoided. With reduced pest problems and continuous nutrient feeding to the roots, hydroponic productivity is high, despite restricted plant growth due to low or minimal atmospheric carbon dioxide levels (Singh and Singh, 2012) [20]. Some sealed greenhouses inject carbon-di-oxide into their atmosphere to further increase yield (CO_2 enrichment), or add lights to prolong the day, control vegetative growth etc.

Growing Medium

Growing medium is used to support the roots and plants while retaining ample air volume (oxygen) in contact with the roots. In different types of hydroponic systems a variety of increasing medium is used for their individual qualities. Some popular examples of growing medium are: sand, brick shards, vermiculite, perlite, gravel, rockwool, sawdust, and polyethylene sheeting.

For each medium there are two major variations: sub-irrigation and top-irrigation. However, it is classified as follows: 1. Hanging bag technique, 2. Grow bag technique, 3. Trench or trough technique and 4. Pot technique

Sand

- **Advantages:** Abundance; Cost is low.
- **Disadvantages:** Poor drainage; Wasteful of nutrients; Salt buildup; Clogs roots easily; Must be sterilized between the uses.

Brick Shards

- **Advantage:** Shows adaptability of the hydroponic method, good use of used/recycled materials.
- **Disadvantages:** Hard to work with; must be scrubbed in between uses; can adjust pH.

Vermiculite/Perlite

- **Advantages:** Easy to work with; Lightweight (6 to 10 lbs/ ft^3).
- **Disadvantages:** (Perlite) Retains water yet is poorly permeated by minerals; (Vermiculite) can become waterlogged very rapidly.

Gravel

- **Advantages:** Inexpensive; quick to keep clean; incapable of waterlogging.
- **Disadvantages:** Heavy; dries out quickly.

Rockwool (Sterile, porous, non-degradable material made from volcanic materials)

- **Advantages:** Lightweight; simple to mold; standardized application of nutrients to plants; individual feed for each plant.
- **Disadvantages:** Relatively expensive; hard to work with but humid; easily grows algae.

Sawdust

- **Advantages:** High water retention; Common; Lightweight; Adaptable to fertilizer.
- **Disadvantages:** Tendency to clot; water compact; need to be chemically cleaned; susceptible to biological breakdown (mold) due to its organic nature; cannot use unique woods (walnut) containing acids that can destroy the plants.

Polyethylene Sheeting

- **Advantages:** Used primarily for NFT systems; Inexpensive; Easy to work with.
- **Disadvantage:** Very little root support.

Recent Hydroponics

Recent plastics advances have cut hydroponic device costs that have made hydroponics financially feasible to more people. The pump architecture has allowed hydroponic systems to evolve into fully automatic systems. Advances are currently being made in developing highly engineered hydroponic crops for use in any area.

Water conservation in hydroponic

As water becomes scarce and valuable as a resource, it is now possible to use hydroponics and other water-saving technologies for crop production, and is ready to popularise in time. Hydroponics uses even less water compared with soil cultivation. In soil cultivation, most of the water we supply to the plants is leached deep into the soil and is unavailable to the roots of the plants, whereas in hydroponics, plant roots are either submerged in water or a film of nutrients mixed in water constantly encompasses the root zone, keeping it hydrated and fed. Water is not wasted in this process, as it gets recovered, filtered, replenished and recycled. Waste nutrient solution can be used as an alternate water resource for crop cultivation under hydroponic system (Choi *et al.*, 2012) [4]. Table 3 shows savings in irrigation water, fertiliser, and increased productivity of vegetables and water under the hydroponic system as compared with conventional farming. By recycling run-off water, NFT-based hydroponics can reduce irrigation water use by 70 per cent to 90 per cent.

It is possible to effectively grow high value, good quality vegetables under controlled hydroponic conditions using 85 to 90% less water than traditional soil based production. Water sources from groundwater or dam/river water commonly contain factors that can influence plant yield and affect plant condition, including salinity, dissolved solids and pathogens. While some of these factors can be beneficial to crops, others need to be minimized.

Table 5: Percentage of water and fertilizer consumption, vegetables yield percentage and the percentage of water productivity for different hydroponic systems as compared with conventional farming system (AlShrouf, 2017) [1]

Parameters	Hydroponic system			
	Media soilless system		Nutrient solution system	
	Open	Closed	Open	Closed
% Irrigation water saving	80	85	85	90
% Fertilizer saving	55	80	68	85
% Productivity increases	100	150	200	250
% Water productivity	1000	1600	2000	3500

The Future of Hydroponics

Hydroponics is a relatively modern technology which has developed rapidly since its creation 70 years ago. Hydroponics has found many new uses from its roots in academic research to its use in industry and government. It is a flexible technology, suitable for both emerging and high-tech space stations. Hydroponic technology can produce food crops efficiently from barren desert sand and desalinated ocean waters, in mountainous areas too steep for planting, on town rooftops and concrete schoolyards and in Arctic communities. Hydroponics can provide locally grown, high-value specialty crops such as fresh salad greens, herbs and cut flowers in densely populated tourist areas where high land prices have forced out conventional agriculture.

Further production of solar heating technology in hydroponic greenhouses would reduce the hydroponics cost and economic impact. Plans are currently being drawn up for the use of soilless culture techniques in space stations, and maybe one day on surfaces of other celestial bodies (planets, asteroids, etc.) that do not have soil. Developing countries will be able to feed more people in the future, along with all other nations, using less land than the existing farming techniques. Advances in lighting technology can lead to hydroponics being used more commonly in areas with insufficient seasonal sunlight. In the future, more use will be made of the application of hydroponics in providing food in areas with large areas of non-arable land, such as deserts and mountainous terrain.

Conclusion

In India, the capacity for growing vegetables such as tomato, capsicum, lettuce, cabbage, cauliflower, herbs other than cut flowers and medicinal andaromatic plants is enormous. Some organizations such as the Institute of Simplified Hydroponics have emerged at international level where India is also benefiting from growing soilless vegetables (hydroponics) under a program with very meager resources to eradicate hunger in southern states.

Demand for increased production of vegetables is growing rapidly across the world. In many parts of India, however, production of solanaceous vegetables (tomato, capsicum, and brinjal) has remained remarkably poor. The key constraints are: heavy rainfall (often even hailing), problem soils, bacterial wilderness during fruiting, water management and lack of appropriate technology to resolve these constraints. Soil cultivation / hydroponic cultivation is a valuable means of growing fresh vegetables not only in countries with limited arable land, but also in countries that are very limited in the region and have a large population. This could be especially useful in some smaller countries where tourism is the main industry. On the remaining non-arable land, soil less cultivation / hydroponics could be used to provide enough fresh vegetables for both the indigenous population and the visitors. The hydroponic culture can be practiced also in urban areas in polyhouses / on roof tops and backyards / garages.

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