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Nutrients for Hydroponic Systems in Fruit Crops

Pramod Kumar and Simran Saini

Abstract

Hydroponic systems for crop production are nowadays essential to maximize yields. Sometimes, the benefits of hydroponics have been questioned by the researchers as compared to growing of crops in other soilless culture. The growers raised the crops through hydroponics system get yields more compared to conventional practices as hydroponically grown plants dip their roots directly into nutrient-rich solutions. Therefore, the aim of the current chapter is to provide accurate and updated information about their different nutrients and their composition used hydroponically compared to conventional production mode. This chapter will be divided as the following sections: (1) rationale, (2) nutrient solution technique, and (3) work done on fruit crops. With this chapter, we hope to present an updated information, comparing hydroponic versus conventional technique.

Keywords: soilless culture, hydroponics, conventional production, nutrients, recycling

1. Rationale

Hydroponics is the emerging sector of horticulture that deals with growing of plants in a soilless nutrient solution. This term refers to the use of nutrient and water solution for growing plants without soil. Since the ancient time, this technique is being used from thousands of years that traced from the hanging gardens of Babylon and the floating gardens of China. With the decline in arable land, there is a need of alternative to meet the demand of increasing population, and in this regard, hydroponics serves as an additional channel for crop production. In this technique, the crop plant growth is influenced by certain substances in the water. The German botanists, Julius Von Sachs and Wilhelm Knop developed the first standard formula for the nutrient solutions in 1860–61 where the nutrient solutions contained macronutrients the especially nitrogen, phosphorus, potassium, sulfur, magnesium, and calcium varied concentration depending upon crop. Since 100 years back, William Frederick Gericke popularized the idea that plants could be grown in a solution of nutrients and water. He contributed toward hydroponic culture by producing an effective nutrient solution. In the early 1930s, he did an experiment on production of agricultural crops through nutrient culture and termed it as aquaculture. The term so used was dropped due to culturing of aquatic organisms as aquaculture. During 1930s refinement work on hydroponics was expanded toward Europe, Japan, and North America worked England, Africa, Britain, France, Italy, Spain, and Sweden. In 1937, W.A. Setchell introduced the term “hydroponics.” The hydroponic nutrient solution includes minerals in the raw

water and nutrients added with fertilizers. The right fertilizer, right dose, and right concentration in the hydroponic nutrient solution greatly depend on the quality of the raw water to be used. This technique has advantages over other methods such as high water use efficiency, improved growth rate, and disease control and also offers more controlled environmental conditions for plants growth and development.

2. Nutrient solution technique

Hydroponics is a technology in which nutrient uptake occurs through plant roots dipped in the nutrient culture. Prior to use of hydroponic culturing, the crop physiological functioning system must be clear. For optimum crop growth and functioning, mixture of sunlight, carbon dioxide, water, and nutrient elements for photosynthetic efficiency is needed. Besides, the minerals are either found naturally in the soil or supplied through the fertilizers to the soil. Thus, it is evident that plant needs mineral derived from the soil for its growth, not the soil which becomes a basic idea behind the development of hydroponics. Moreover, the roots also need an optimum supply of oxygen for uptake and transport of metabolites to the whole plant. In hydroponic system, the roots of plants are in direct contact with the nutrient solution only *vis-a-vis* the absorption of nutrients occurs more easily than soil grown plants. This system also performed the crop plants with faster growth and higher yields and in turn saves energy for extensive root system development and thus, more of energy can be diverted toward leaf and stem growth. Besides, it also offers significant advantages over traditional farming, producing greater yields, faster growth, and possibly year-round crop production. This system further allows recycling of nutrient solution without wastage of water. The amount and composition of the nutrients to which plants have access can be monitored precisely by the grower. It also allows the grower to control the pH level of the solution and protects plants from pests and diseases. However, the literature is still scanty with respect to production of hydroponic fruits [1, 2]. Seedlings of fruit crops can also be grown hydroponically in earlier stages of growth and then transplanted to the field. Different fruit crops namely, grapes, raspberry, blackberry, blueberry, and strawberry can be grown hydroponically. Strawberries and blueberries perform best under hydroponics system because of acidic soil requirement are best suited to blueberries and be grown under hydroponic system as pH level and nutrient content are easily controlled and maintained in hydroponics.

2.1 Hydroponics technique

There are different types of hydroponics technique being employed for growing of plants. There are mainly three types of hydroponic systems.

2.1.1 Nutrient film technique

It is a system in which the nutrient solution is passed through the roots of plants placed in a channel. The plants are placed on channels made up of wood, rigid to flexible tubes or plastic and the nutrient rich solution is either pumped through it or passed under gravitation reaching the root system effectively. This technique is effective only for the plants with large root system. The nutrient film technique (NFT) was developed during the late 1960s by Dr. Allan Cooper at the Glasshouse Crops Research Institute in the U.K. NFT is the growing of plants, bare-rooted in long, waterproof channels, down which flows a very shallow stream of re-circulating water, into which are dissolved all the minerals required to grow healthy plants.

NFT is a hydroponic technique wherein a very shallow stream of water containing all the dissolved nutrients required for plant growth is re-circulated past the roots of plants in a watertight gully, also known as channels. According to the pre-requisite to achieve a nutrient film situation more effectively is described as (i) ensuring the gradient down where water flows is uniform and not subject to localized depressions, (ii) rapid inlet flow rate that a considerable depth of water flows down to the gradient, (iii) adequate width of the channels to avoid any damming up of the nutrients, and (iv) flat channel base but not curved due to which otherwise will be a considerable depth of liquid along the center of a channel with a curved base. N.F.T. system is fairly a simple design. However, this is not best suited for smaller quick growing plants.

2.1.2 Deep film technique

It is a technique in which the plants are grown with roots submerged in floating nutrient solutions (10–20 cm deep) on a flat table. This method is effective for growing plants with short root system and is relatively cheaper.

2.1.3 Substrate method

In this method, the plant growth is supported by using materials such as stones, vermiculite, perlite, etc. in structures such as tubes and pots. This system results in affective utilization of nutrients and reusing of the nutrient solution as the drained solution is re-circulated in the system. This system is commonly utilized in Asia, Europe, and Israel for strawberry cultivation by using several trough systems.

Among the three systems, NFT and DFT are the most commonly used methods. The basic idea behind the working of NFT is the recycling of the nutrient solution. This technique offers major advantages over other systems like low cost of installation, easy operation and management as well as conservation of nutrients and water. In this system, nutrient solution enriched with material like sand, vermiculite or rock wool is passed and re-circulated through a slope consisting of plants placed in a plastic trough. It provides the optimum amount of nutrients to the plant through its root system. It is best suited for short period crops like lettuce, strawberry, and raspberries. Nutrient film technique has been termed as a promising tool in the areas with limited land resources.

Various materials that can be used for hydroponics in fruit crops include that of mineral origin and organic origin. Vermiculite is one of the mineral substances utilized in pears, peach, and tangerine seedlings as it is free of pathogens attack and have high water retention capacity. In case of grapevine, sand because of its easy acquisition is used as it results in the increased absorption of macro-nutrients. Rice hulls have been found to be effective organic source in growing strawberry plants under hydroponics. For strawberry, perlite or vermiculite is the best growing medium. Materials like coconut coir or peat moss should be avoided as they absorb too much of nutrient solution and cause condition of suffocation to the plants.

For growing strawberries through hydroponics, two systems viz., “closed” and “open” are employed. Among these two, recirculation of nutrient solution occurs in the closed system with plants grown in channels or pipes. The closed system can have continuous nutrient supply or the supply can be at irregular intervals when the plants are grown in pots. In case of pot grown plants, different substrates having high water retention power help in supplying nutrients to the plant system. Whereas in case of open system, there is no recirculation of nutrient solution and is applied to the plants with the help of drippers.

In strawberries, NFT is the most commercially practiced method. In this method, the runners of strawberry are placed in net pots in which the roots are covered with clay medium in the root zone, which help in increasing the strength of plant. They can also be placed with plugs into the net pots which are framed in the NFT channels. It must be placed such that there is continuous contact with the flow of nutrient solution in the initial weeks of root development. The optimum amount of oxygen must also be maintained during the operation of system with 14–16 hours of daylight. The nutrient discharge should be 1–2 liters/minute with circulation pump running all the time. In NFT, it must be grown in low humidity conditions and care should be taken as it is susceptible to root rot.

3. Nutrient solution

Nutrients are the basic elements for hydroponics, and nutrient solution is the liquid fertilizer solution prepared in definite composition to support plant growth. The plants need is fulfilled through the ionic form of nutrients with proper oxygen supply and temperature. Environmental factors and nutrient solution are the two important factors to be considered for productivity in hydroponics. Supply of nutrient elements depends upon the requirement of crop, and the frequency of application is based upon the type and age of crop, the type of material used in media and the prevailing environmental conditions.

The kind of nutrient solution varies according to crop species, their growth stage, environment, and other related factors as there is no ideal nutrient solution available to meet the needs of all the crops. Among fruit crops, a lot of research have been done regarding the nutrient solutions. In grapevine, macronutrient absorption based on nutrient culture of was studied. It was reported that higher accumulation of nutrients resulted in increased vigor of rootstocks Jales, Tropical and Campinas. Solution was also used in pineapple cv. Perola produced through micropropagation in hydroponics system. Long Ashton nutrient solution was used in grapevine under hydroponics [3]. The nutrient solutions for some fruit crops such as peach and pear have not been disclosed.

3.1 Composition

The composition of various nutrients in the nutrient solution plays a major role, as the uptake of these nutrients in optimum amounts affects the functioning of plants, thereby affecting its growth. Testing of water must be done before using it in hydroponics for nutrient solution to get the accurate details about the properties of water. In strawberry for a closed type of NFT, the nutrient solution with the following composition can be used:

Nutrient elements	Quantity (ppm)
Nitrogen (nitrate form)	160.0
Nitrogen (ammonium form)	15.0
Phosphorus (PO ₄)	50.0
Potassium	210.0
Calcium	190.0
Magnesium	50.0
Iron	6.0

Nutrient elements	Quantity (ppm)
Boron	0.50
Manganese	0.50
Copper	0.10
Zinc	0.08
Molybdenum	0.05

There are different nutrient solutions being standardized containing different concentrations of nutrient elements. Hoagland and Arnon nutrient solution has been used for the production of seedlings of guava and pineapple. Furlani et al. nutrient solution was used in production of guava seedlings. Yamazaki solution can be used for strawberry which includes N(NO₃:5; NH₄:0.5); P:1.5; K:3; Ca:2; Mg:1; S:1; Fe:3; B:0.5; Mn:0.5; Zn:0.05; Cu:0.02; Mo:0.01 in meq/L [4].

Nutrient elements	Hoagland and Arnon (1938)	Furlani et al. (1999)	Hewitt [3]	Cooper [5]
	mg/L			
N	210	202	168	200–236
P	31	31	41	60
K	234	193	156	300
Ca	160	142	160	170–185
Mg	34	39	36	50
S	64	52	48	68
Fe	2.5	0.26	2.8	12
Cu	0.02	0.04	0.064	0.1
Zn	0.05	1.8	0.065	0.1
Mn	0.5	0.37	0.54	2.0
B	0.5	0.06	0.54	0.3
Mo	0.01	0.11	0.04	0.2

3.2 Nutrient preparation

The nutrient solution for hydroponics can be either bought premixed or can be prepared by self. Plants require same macro and micronutrients but in different ratios. So, the nutrients supplying fertilizers must be bought based on the plants' need as each nutrient has distinct function in different plants. For the preparation of nutrient solution, the nutrient fertilizers are mixed with water which breaks down to release nutrients. The selection of fertilizers should be such that the amount of water and nutrients present in the solution are equal to the amount of water and nutrients taken up by the plants. The nutrient solution preparation requires water of good quality which is contamination free for which chemical analysis is important. The formulations must be based upon the targeted crop and must supply all the essential nutrients. The nutrient solution preparation also requires maintaining optimum levels of pH and EC. For the proper growth of strawberry plants, the pH of nutrient solution used must be between 5.5 and 6 and the ideal EC range is 1.8–2.0 dS/m during growth period and 1.8–2.5 dS/m during

fruiting stage. The pH of the solution can be maintained through potassium hydroxide used to increase pH or through phosphoric acid to lower down the pH. At EC higher than 1.2 dS/m to prevent the damage to strawberry plant root area of plants can be flushed with clean water for the removal of accumulated salts.

4. Recycling of nutrient solution

To meet the requirement of plant without any loss of nutrients, the closed system of hydroponics offers a huge benefit for recycling of nutrients reducing economic as well as environmental costs. In a closed system, the water and nutrient supply is equal to their quantity taken up by the plants [6]. This system provides controlled nutrient supply with minimal leaching losses and reduced environmental contamination. There is a continuous supply of nutrient solution touching the roots of the plant which after passing down is recirculated and is again available for the use of the plants. Among the added fertilizers, only 50% is utilized by the plant and 70% of the added water is utilized by the plant for its proper growth and transpiration [7]. Recycling of nutrients through closed system of hydroponics and nutrient film techniques is very efficient as it uses only 10% of the water and 25% of fertilizer to that of conventional systems. The mineral content of the added fertilizers may be reduced due to the uptake by plants which may be replenished from time to time. The recycling and reusing of nutrients and water having huge advantages also poses some issues. There is increase in EC of the nutrient solution if water uptake is greater than the nutrients and reduced EC due to greater nutrient uptakes which as a result disrupt the recycling mechanism of the system. There may be problem of increased concentration of salts, toxic ions, and pathogens in the nutrient solution where recycling of pathogens occurs along with the solution in the system resulting in their build up. The problems being faced in the closed system can be removed by using ultraviolet treatment, heat treatment, and slow sand filtration. It has been proved that among the previously mentioned, slow sand filtration is best as it is chemical free, easy to maintain, and energy efficient with adaptability in components [8]. Bio sand filter is used in the system against pathogens of *Pythium* spp. and *Phytophthora* spp. In case of open system, the nutrient solution is not recirculated but released into the environment after the crop cultivation. It has been proposed that the nutrient solution released to environment can be recycled to be used as irrigation water without by reducing further pollution chances [9].

5. Frequency of application

For growing strawberry hydroponically, the plants must be fed with nutrient solution daily and best time being 6:00 am–8:00 am. The application must be such that conditions like overwatering and drying not occur. For the early stages of plant growth when the plant is small, less amount of nutrients are required. In actively growing period and during summers, large amount of water is consumed by the plants due to increased transpiration rate. The water requirement also varies depending upon the environmental conditions maintained. The amount of nutrients to be added to the system must be based upon the crop usage. The quantity of water and nutrients taken up by the plants can be known by measuring the EC daily. Lower amount of EC indicates more nutrient uptake, and higher level indicates increased water uptake. Based upon the EC levels, the water must be added to avoid buildup of salts. The reservoir must be filled with water once it is lower than the required volume and must be checked for EC and pH. If the EC and pH of the

solution is not stable as per the requirement, it must be adjusted accordingly. The refilling of reservoir from time to time may result in imbalance of nutrients in the nutrient solution. So, it must be dumped after a period of time to avoid any interruption in the growth of plant. If the reservoir is small, the solution must be dumped after every 10–15 days while in case of large reservoirs once a month.

6. Nutrient need through hydroponics

In soil grown plants, the fertilizers are added into the soil or applied through foliar application, but in hydroponics, a solution of ionic compounds helps in delivering nutrients into the plant system. Hydroponics is better in meeting plants nutrient need as under the manipulated set of conditions nutrients are directly supplied to the roots by coming in contact with them. Hydroponics, due to their better control over the environmental conditions, has been proved to be superior and sustainable for growing of different crops. Particularly in case of berry crops like strawberry, it has turned to be a very effective method producing fruits of superior quality with high yielding potential. Hydroponically, grown strawberries have been found to produce fruits with higher amount of vitamin C, vitamin E, and total polyphenols. By following different systems in hydroponics and different substrates, the nutrient demand of the plant can be met more efficiently. The supply of optimum amount of nutrients and water must be ensured depending upon the crop need so that the plant continues to grow without any lack or excess of both nutrients and water. With several discussed advantages, hydroponics is better choice over conventional methods to produce fruits with reduced water and fertilizer use.

7. Work done

Maximized growth and yield with mixture of perlite (60–80%) and peat (20–40%) in strawberry [10]. Maximum yield was recorded in strawberry grown in perlite mixed with coco coir or vermiculite in vertical hydroponic system [11]. Takeda [12] suggested that transplant plug plants were superior in increasing yield to fresh plants for hydroponic production of strawberry cv. Sweet Charlie and Camarosa. Costa et al. [13] concluded that the carbonized rice husk substrate produced more than one crop (off-season) in soilless culture in strawberry cv. Albion frigo. Treftz et al. [14] reported combined benefits of environment and better sensory attributes, and it is desirable to grow strawberry hydroponically. Treftz and Omaye [15] noted that growing strawberries in hydroponic systems are more sustainable and superior to soil grown systems. Ramirez-Gomez et al. [16] reported maximum yield with vertical hydroponic pots system; the maximum number of fruits with vertical four pipes system and inferior quality fruit were produced with vertical three pipes system in strawberry.

Ramirez-Arias et al. [17] reported maximum yield with vertical hydroponics system and the lowest was found in three level horizontal systems in strawberry cv. Festival. Peralbo et al. [18] concluded that maximum yield was produced by peat as compared to cork compost in both open and closed hydroponics system in strawberry. Miranda et al. [19] found that closed hydroponic system of gutters and grow bags was superior than the open system in saving water and fertilizer in strawberry. Roosta and Afsharipour [20] concluded that dry weight, leaf area, number of runners, Leaf N, P, K, Fe, Mg, and yield was significantly higher in hydroponics as compared to aquaponics except for soil perlite. Portela et al. [21] noted higher yield through nutrient solution between EC ranges of 1.2–1.5 dS/m in NFT hydroponics

system in strawberry cv. Camarosa. Vikas et al. [22] reported maximum plant height and maximum number of fruits with sewage sludge and cocopeat (20:80), whereas the maximum number of leaves and yield was observed with sewage sludge and cocopeat (30:70) in strawberry under hydroponics. Choi et al. [23] concluded that FAI technique for coir substrate was best in hydroponics due to sustainable use of water and fertilizers in strawberry. Albaho et al. [24] concluded that continuous sub irrigation capillary system is the best among hydroponics in strawberry. Jun et al. [4] reported that nutrient solution with EC ranges between 0.8 and 1.2 dS/m during low temperature season in hydroponically grown strawberry cv. Maehyang.

Lee et al. [25] noted that nutrient solution with EC of 1.0 dS/m is best for hydroponically produced strawberry cv. Albion and Goha. Andriolo et al. [26] reported maximum fruit yield with EC 0.9 dS/m under closed soilless growing system in strawberry. El-Sayed et al. [27] noted significant improvement in vegetative growth characters, leaf chemical content, and yield in perlite: peat moss substrate under hydroponics in strawberry cv. Festival. Ebrahimi et al. [28] reported maximum number of fruits and yield with cocopeat + perlite substrate and improved quality with peat + sand + perlite substrate in strawberry cv. Camarosa and Selva. Marinou et al. [29] concluded that sawdust was best substrate medium under hydroponics in strawberry. Caruso et al. [30] reported improved fruit quality through nutrient solution with EC 1.3 dS/cm in spring season and through 2.2 mS/cm in winters under NFT in strawberry cv. Alpine. Souza et al. [31] observed fastest transplanting stage and grafting stage at 30 and 61 days after transplanting under hydroponics system for commercial grafts production in peach. Motosugi et al. [32] reported increase in anthocyanin level with ammonium nitrogen nutrient solution at pH 3–3.5 under NFT in grapevines.

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