INVESTIGATION THE EFFECTS OF DIFFERENT SUPPORT MEDIUM ON PRODUCT WITH NUTRIENT FILM TECHNIQUE

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INVESTIGATION THE EFFECTS OF DIFFERENT SUPPORT MEDIUM ON PRODUCT WITH NUTRIENT FILM TECHNIQUE

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ABSTRACT

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Hydroponics basically is the method of growing plants using mineral nutrient solutions, in water, without soil. Vertical nutrient film technique (NFT) is one of the most used hydroponic technique that has constant flow of nutrient solution. In this study the effects of different support medium on strawberry quality and yield using vertical NFT in glass greenhouse was investigated. NFT-only system was compared to rockwool, coco fiber, perlite and expanded clay as supporting medium for strawberry production. Parameters such as weight of product, amount of product, rate of marketable product, and including physico-chemical properties such as pH, rigidity, color, dry matter amount, EC, vitamin C, sugar content, resistance to certain pathogens were observed among all supporting medium trials. NFT-only system significantly differed from other supporting medium trails by most of the parameters including fruit number per plant, average fruit weight, toughness of the fruit, vitamin C amount, sugar amount and finally soluble solid material amount in water . Revealing the effects of supporting medium on strawberry production shed light on how should NFT must be applied to fruit growing.

Key words: Nutrient Film Technique, Strawberry production, Supporting medium

ÖZ

BESLEYİCİ FİLM TEKNİĞİNDE FARKLI DESTEK MEDYALARININ ÜRÜN ÜZERİNE ETKİSİNİN İNCELENMESİ

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Hidroponik en basit anlamıyla, bitkileri topraksız ortamda, su ve besleyici solüsyon içerisinde büyütmektir. Dikey besleyici film tekniği (NFT) besleyici solüsyonun düzenli akışını sağlayan, en çok kullanılan hidroponik sistemlerden biridir. Bu çalışmada, farklı destekleyici ortamların çilek ürün kalitesi ve verimliliği üzerine etkisi araştırılmıştır. Cam seranın içine kurulacak olan çok katlı besleyici film tekniği (NFT) sisteminde denenecek farklı destek maddelerinin ürün verimine ve kalitesine etkisi araştırılmıştır. Farklı destekleyici ortamlar olarak kaya yünü, hindistancevizi iplikleri, perlit ve sıkıştırılmış kil destekleyici ortamları, destekleyici ortam olmayan NFT sistemi ile karşılaştırılmıştır. Meyve ağırlığı, meyve miktarı, pazarlanabilir meyve oranı, pH, sertlik, renk, kuru madde miktarı, EC, C vitamini, seker miktarı, ve bitki hastalıklarına karşı direnç gibi parametreler karşılaştırılmıştır. Elde edilen bulgular doğrultusunda destekleyici ortam olmayan NFT sisteminin, araştırılan parametreler bağlamında, istatiksel olarak destekleyici ortam kullanılan sistemlere göre daha verimli olduğu gösterilmiştir. Sadece NFT sisteminde büyütülen çileklerde; diğer uygulamalara göre, bitki başına düşen meyve sayısı, ortalama meyve ağırlığı, meyvenin sertliği, C vitamini miktarı, şeker miktarı ve suda çözünebilen katı madde miktarlarında istatiksel olarak bir fark bulunmuştur. Bunların sonucunda, meyve yetiştirilirciğinde NFT sisteminin nasıl uygulanması konusunda önemli bilgiler elde edilmiştir.

Anahtar Kelimeler: Besleyici Film Tekniği (NFT), Çilek yetiştiriciliği, destekleyici ortam

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LIST OF ABBREVIATIONS

B	Boron
Ca	Calcium
Cu	Copper
dS/m	deciSiemens per meter
EC	Electrical Conductivity
Fe	Iron
g	gram
HPLC	High Pressure Liquid Chromatography
K	Potassium
m	meter
Mg	Magnesium
mg/L	milligram per liter
mm	millimeter
mM	miliMolar
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
NFT	Nutrient Film Technique
P	Phosphorus
PP/PVC	Polypropylene/Polyvinyl Chloride
UV	Ultra violet
Zn	Zinc

CHAPTER 1
INTRODUCTION

1.1 Hydroponics

Hydroponics is the method of growing plants without soil, using nutrient solutions in water. It can also be referred as soil-less crop production depending on delivering water and nutrients to plants' root by various methods. Ancient floating gardens of the Aztecs of Mexico and those of the Chinese are counted as the first examples of hydroponic culture according to some records[1]. The first scientific and systemic studies of plant nutrition in liquid culture were conducted in 19th century by Liebig (1803-73) and Knop and Sachs (around 1859) [2]. First commercial use of liquid culture for plant growing was done by Gericke in 1929. The plants were planted in a layer of sand which was supported on the surface of the solution by netting and canvas through which the roots could pass into the liquid phase [2].

There are some specific requirements that a hydroponic system should fulfill for plants with the most reliable and efficient methods of nutrient delivery [3]. First of all, system should provide roots with a fresh and well balanced supply of water and nutrients. Secondly; the system should provide an environment so that high level of gas exchange between nutrient solution and roots must take place. Finally, roots of plants must be protected against root dehydration and immediate crop failure even in the worst case of pump failure or power outrage

1.1.1 Advantages and Disadvantages of Hydroponics

To obtain higher yields and quality, precise control of nutrition to the plants grown in soilless cultures is required. However, this does not necessarily mean that yields from the best cultures in soil are much inferior [4-6]. If there are soil problems such as poor soil, saline soil, toxicities in soil, then soilless culture will produce much better crops compared to conservative plant growing with soil. According to Olympios, many reports were published during the last 15 years presenting results on comparison of soilless methods and soil [7]. Most of the reports show the advantages of soilless culture due to a combination of factors such as reduction of labor, higher yields and the greater uniformity of quality due to the more uniform conditions of growth.

One of the most important advantage of soilless culture compared to conventional cultures is the accurate control of plant nutrition. To various crops, in various environments and at various stages of plant growth; controlled concentrations of nutrients can be applied. Toxic nutrients for plants at certain levels such as Mn, B, Zn, Cu, Pb can be kept at safe concentrations [7]. Another advantage of soilless culture over soil cultures is the uniformity of nutrients. Exact concentrations of nutrients and the exact content of nutrients can be applied to substrate. Finally, according to the requirements of the plants and environmental conditions, adjustment of pH and temperature of the nutrient solution is also possible. Similar control of pH, temperature and applying uniform nutrient content is difficult and expensive [8].

In especially greenhouse environment, due to lack of rainfall when the crop production is required in hot, arid regions of the world; large amounts of water is required for protection of the crop against drought. In such cases, water become the limiting factor for both production and the quality and cost of the process. For certain crop production at some certain soil types, irrigation frequency and duration become more critical when the low water holding capacity of these soil types are compared. When certain soilless systems, for instance the close recirculated ones are considered; they economize water by means of water saving as the drainage and evaporation from the surface is eliminated by the design and operational scheme of the soilless systems [7]. Furthermore, control of water is more accurate in soilless systems. Finally, by means of water, water culture and sub-irrigated substrate systems provide less labor requirements in the time consuming task of checking and cleaning water.

Soilless crop production eliminates all cultural practices related with cultivation of the soil, sterilization of soil, weed control. The labor used in soilless culture depends on the system itself, the degree of automation, the type of substrate, the number of crops raised on each substrate. Although labor used in different types of soilless culture is not same, generally there is a saving in labor when soilless culture is employed.

Sterilization is a must, hard to apply and an expansive operation for greenhouse soil systems but it is very important for plant propagation as soil must be free from any soil-born pathogens before the establishment of any new crop [2]. One of the most effective method for soil sterilization is done by steaming the soil. However, it is expensive due to the high cost of energy and labor, thus it is not much preferred. Another way for sterilization of soil is in chemical ways. Although it is not that expensive compared to steam sterilization, chemical soil sterilization has some disadvantages. For instance applying formaldehyde or methyl bromide are highly phytotoxic and cause chemical residues in plants and environmental pollution [9]. When soilless culture systems are considered, there is no sterilization required for the materials and substrates used as they are only used once. So by that way, in soilless culture systems no sterilization is required and spreading of diseases is avoided by using materials only for once [10,11].

Possibility of more accurate control of root temperature and root oxygen supply are the most striking advantages of soilless culture over traditional culture techniques. Furthermore due to absence of applications like soil cultivation and soil sterilization, crop yield per year can be increased in a given production area by growing crops in soilless culture, because the time interval between crops is nearly zero in hydroponics. Under the conditions of lack of soil or no suitable soil type for culturing , hydroponics provide alternative solutions. For instance, when there is accumulation of soil pathogens in the soil, or when soil salinity is too high for cultivation, hydroponics would be alternative solutions for plant growing under soilless systems [7].

Soilless system is not without any disadvantage. For instance, installation of the system involves construction and the maintenance which is the main expense for soilless system. The degree of outcome changes according to which soilless system will be applied. Expenses may also be changed according to degree of perfection of control measures. For instance installation cost of a Nutrient Film Technique (NFT) system is much more expensive then rockwool system. However, the annual cost of NFT is lower compared to rockwool system[12,13]. Even for NFT system applications, there can be differences by means of cost. Vertical NFT system including raised stands and metal trays is more expensive than the corrugated asbestos sheets used for NFT lettuce production [14]. Outcome of soilless cultures may vary according to countries as prices of materials and services are not the same in all countries. In addition to greenhouse structure installation costs, cost of environmental management devices and control should also be taken into consideration for a successful soilless culture [7].

Risk of disease infection is much higher. Reference also must be made to the simple forms of soilless systems. It is important to remember that soil with its buffering capacity can tolerate any mistake from the grower related to nutrient supply, but a small error in the composition of nutrient solution or the pH will be harmful to plants in soilless culture. Failure to the power supply or water supply can cause total loss in a short period of time.

Soilless culture in not an easy process. The importance of scientific and technical support from the research workers and private companies cannot be ignored. Performing soilless culture in a restricted area is difficult process and it requires a higher degree of management. For management, skilled staffs are required. People in charge of the management of the soilless culture management should be able to prepare and adjust the nutrient solutions, set and control electronic equipment, to have knowledge of plant physiology, to recognize and be able to control plant diseases [7].

1.1.2 Types of Hydroponic Systems

Hydroponic systems can be either passive (static) or active (flowing). If there is re-circulation of the nutrient solution in the system, then the system is called active. On the other hand, there is capillary action, absorption and/or the force of gravity in a passive system in order to replenish the roots with nutrient [15,16]. Mainly, hydroponic systems can be grouped into 6 major systems: Wick system, water culture system, ebb and flow system (flood and drain), drip system, Nutrient Film Technique (N.F.T.) and aeroponic systems.

The Wick system is the simplest type of hydroponic system [17]. This is a passive system, which means there are no moving parts. The nutrient solution is drawn into the growing medium from the reservoir with a wick. The biggest drawback of this system is that plants that are large or use large amounts of water may use up the nutrient solution faster than the wick(s) can supply it.

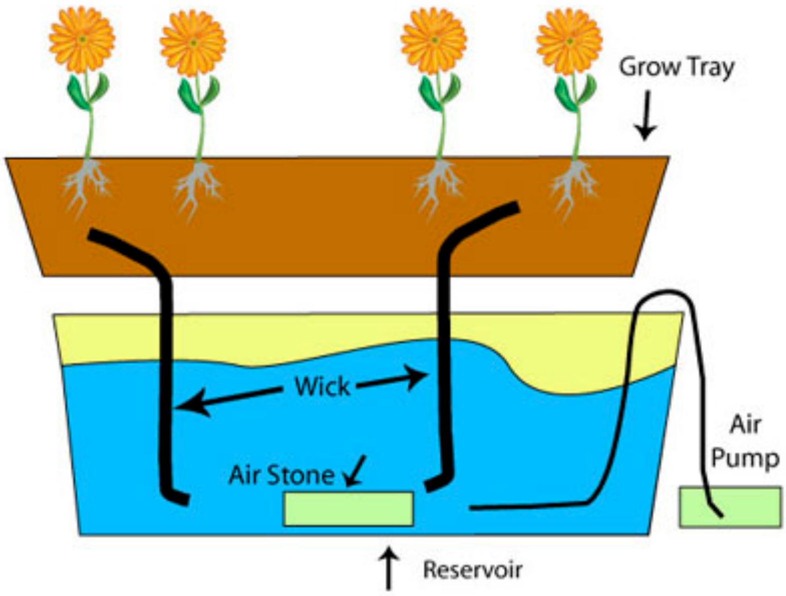

Figure 1.1 The Wick System (Figure taken from http://www.hannainst.com/hydroponics /hydroponic-wick-system.html)

The most simple version of active hydroponic systems is the water culture system [18]. A platform made up of styrofoam holds the plants and floats directly on the nutrient solution. An air pump and air stone are used to supply oxygen for the roots. One of the disadvantages of the system is that the system is not appropriate for long term plant growing or for growing of large plants.

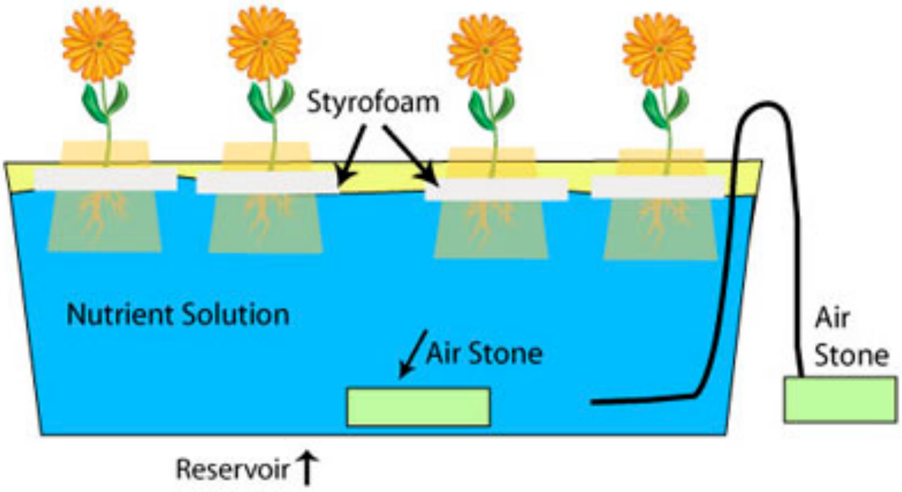

Figure 1.2 Water Culture (Figure taken from http://www.hannainst.com/hydroponics /hydroponic-water-culture-system.html)

The Ebb and Flow system works by temporarily flooding the grow tray with nutrient solution and then draining the solution back into the reservoir [19]. This action is normally done with a submerged pump that is connected to a timer. When the timer turns the pump on nutrient solution is pumped into the grow tray. When the timer shuts the pump off the nutrient solution flows back into the reservoir. The Timer is set to come on several times a day, depending on the size and type of plants, temperature and humidity and the type of growing medium used. The Ebb & Flow is a versatile system that can be used with a variety of growing mediums. The entire grow tray can be filled with Grow Rocks, gravel or granular Rockwool. The main disadvantage of this type of system is that with some types of growing medium (Gravel, Growrocks, Perlite), there is a vulnerability to power outages as well as pump and timer failures. The roots can dry out quickly when the watering cycles are interrupted.

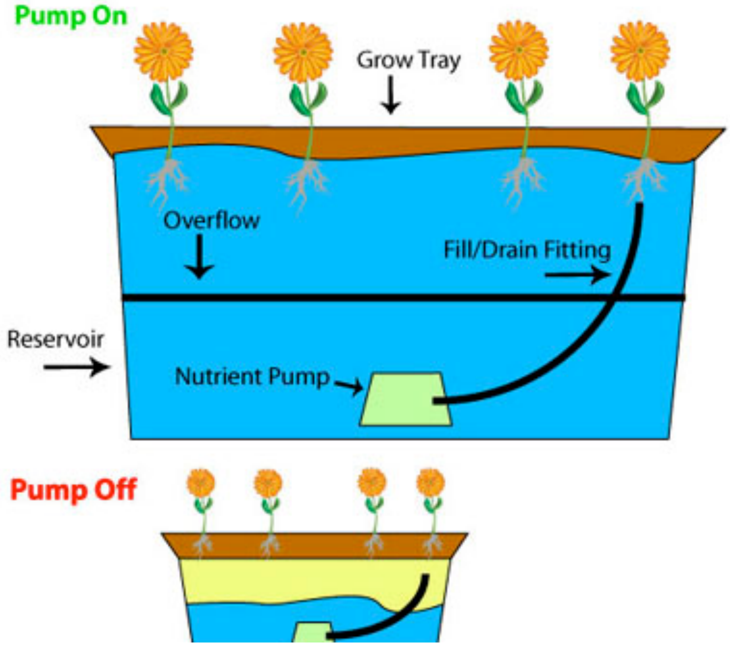

Figure 1.3 Ebb and Flow System (Figure taken from http://www.hannainst.com/ hydroponics /ebb-and-flow-system.html)

Drip systems are probably the most widely used type of hydroponic system in the world [20]. The timer turns the pump on and nutrient solution is dripped onto the base of each plant by a small drip line. In a Recovery Drip System the excess nutrient solution that runs off is collected back in the reservoir for re-use. The Non-Recovery System does not collect the run off. A recovery system uses nutrient solution a bit more efficiently, as excess solution is reused, this also allows for the use of a more inexpensive timer because a recovery system doesn't require precise control of the watering cycles. The non-recovery system needs to have a more precise timer so that watering cycles can be adjusted to insure that the plants get enough nutrient solution and the runoff is kept to a minimum [21]. The non-recovery system requires less maintenance due to the fact that the excess nutrient solution isn't recycled back into the reservoir, so the nutrient strength and pH of the reservoir will not vary. A recovery system can have large shifts in the pH and nutrient strength levels that require periodic checking and adjusting.

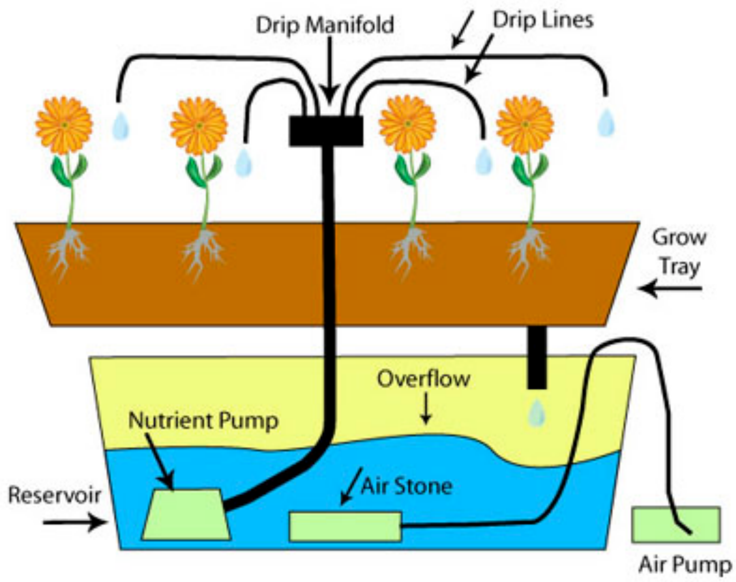

Figure 1.4 Drip System (Figure taken from http://www.hannainst.com/hydroponics /hydroponic-drip-system.html)

Nutrient Film Technique systems have a constant flow of nutrient solution so no timer required for the submersible pump. The nutrient solution is pumped into the growing tray (usually a tube) and flows over the roots of the plants, and then drains back into the reservoir. There is usually no growing medium used other than air, which saves the expense of replacing the growing medium after every crop. N.F.T. systems are very susceptible to power outages and pump failures. The roots dry out very rapidly when the flow of nutrient solution is interrupted.

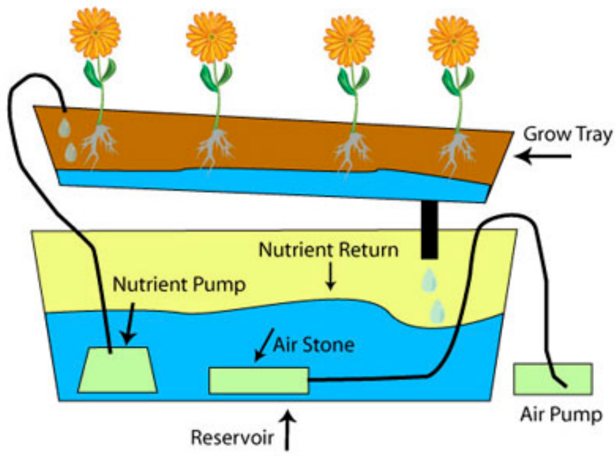

Figure 1.5 Nutrient Film Technique (Figure taken from http://www.hannainst.com/hydroponics/nft-hydroponic-system.html)

Like the N.F.T. system above, the growing medium for Aeroponic system is primarily air. The roots hang in the air and are misted with nutrient solution. The mistings are usually done every few minutes. Because the roots are exposed to the air like the N.F.T. system, the roots will dry out rapidly if the misting cycles are interrupted. A timer controls the nutrient pump much like other types of hydroponic systems, except the aeroponic system needs a short cycle timer that runs the pump for a few seconds every couple of minutes.

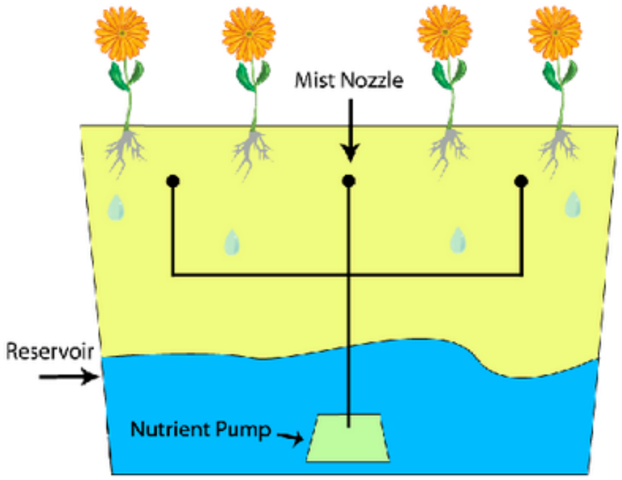

Figure 1.6 Aeroponic System (Figure taken from http://www.hannainst.com/hydroponics/aeroponic-system.html)

1.2 Nutrient Film Technique

The nutrient film technique was developed during the late 1960s by Dr. Allan Cooper at the Glasshouse Crops Research Institute in Littlehampton, England [22]; a number of subsequent refinements have been developed at the same institution [23]. Together with the modified systems to which it has given rise, NFT appears to be the most rapidly evolving type of liquid hydroponic system today [24].

In a nutrient film system, a thin film of nutrient solution flows through the plastic lined channels which contain the plant roots. The walls of the channels are flexible to permit them being drawn together around the base of each plant to exclude light and prevent evaporation.

Nutrient solution is pumped to the higher end of each channel and flows by gravity past the plant roots to catchment pipes and a sump. The solution is monitored for replenishment of salts and water before it is recycled. Capillary material in the channel prevents young plants from drying out, and the roots soon grow into a tangled mat.

A principle advantage of this system in comparison with others is that a greatly reduced volume of nutrient solution is required, which may be easily heated during winter months to obtain optimum temperatures for root growth or cooled during hot summers in arid or tropical regions to avoid the bolting of lettuce and other undesirable plant responses. Reduced volumes are also easier to work with, if treatment of the nutrient solution is required for disease control. A complete description on the design and operation of a NFT system is first published in Horticultural Reviews [23]. In addition to this article, the following discussed points are important for the design of NFT systems.

The maximum length of the channels should not be greater that 15-20 m. In a level greenhouse, longer runs could restrict the height available for plant growth, since the slope of the channel usually has a drop of 1 in 50 to 1 in 75. Longer runs and/or channels, with less slope, may accentuate problems of poor solution aeration [23].

To assure good aeration, the nutrient solution may be introduced into channels at two or three points along their length. The flow of nutrient solution into each channel should be 2-3 liters per minute, depending on the oxygen content of the solution. The temperature of the nutrient should not go above 30°C. Temperature values greater than this value will adversely affect the amount of dissolved oxygen in the solution. There should be approximately 5 ppm or more of dissolved oxygen, especially in the nutrient solution which flows over the root mat in the channel [23].

1.3 Support Media for Hydroponics

Although Rockwool is sometimes used in recirculating systems, its high water holding capacity makes it ideal for use in run-to-waste systems. It only requires watering at a low frequency. It is prone to water-logging and therefore accurate feed regimes are required [25,26,27,28].

Small blocks of Rockwool are commonly used for propagation of cuttings and seedlings which can be subsequently installed in larger systems. Provided it is not over watered, Rockwool offers adequate air filled porosity. Feed volumes and frequency must be adjusted as weather changes [27]. As Rockwool ages however, it can tend to become compressed from the effect of root mat expansion. This reduces the air filled porosity and increases the risk of water-logging.

Coco fiber's high water holding capacity makes it ideal for use in run-to-waste systems. It requires only low frequency watering. It is prone to water-logging therefore accurate feed regimes are required [28]. Coco offers adequate air filled porosity provided it is not over watered. Feed volumes and frequency must be adjusted as weather changes. As coco ages it can tend to become compressed from the effect of root-mat expansion. This will reduce the air filled porosity and increase the risk of water-logging.

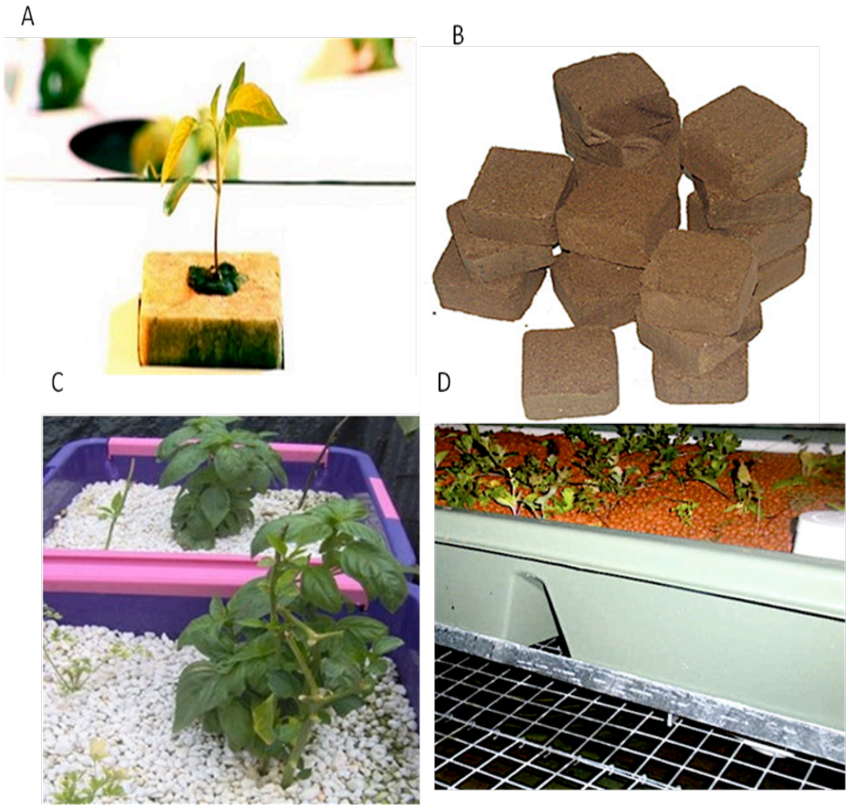

Figure 1.7 Support medium used for hydroponic culture systems: A) Rockwool B) Coco Fiber C) Perlite D) Expanded Clay

Perlite's moderate water holding capacity makes it suitable for either recirculating or run-to-waste systems [27]. It is available in various 'crop specific' grades – finer grades offer higher water holding capacity, whilst coarser grades offer superior air filled porosity. Perlite provides good air filled porosity. Aeration is enhanced when employed in 'flood & drain' systems because the oxygen depleted air is expelled each time the medium is flooded and then replaced with oxygenated air when drained [29]. Recirculating nutrient should be aerated to ensure its oxygen content is adequate.

Expanded clay's poor water holding capacity makes it most appropriate for recirculating systems. Depending on system design, pump failure can result in plant death within a few hours, especially in hot weather. Expanded clay provides good air filled porosity. Aeration is enhanced when employed in 'flood & drain' systems because the oxygen depleted air is expelled each time the medium is flooded and then replaced with oxygenated air when drained. The working nutrient solution should be aerated to ensure its oxygen content is adequate [28].

Table 1.1 Type of hydroponics and support media (Table taken from Olympios, 2007) [25]

SOLUTION CULTURE ("TRUE HYDROPONICS")	AGGREGATE SYSTEMS		
	INORGANIC MEDIA ("HYDROPONIC")		ORGANIC MEDIA
	NATURAL MEDIA	SYNTHETIC MEDIA	
1. STATIC SOLUTIONS	1. SAND	1. FOAM MATS (PUR) (POLYURETHANE)	1. SAWDUST
2. CIRCULATING SOLUTIONS (NFT)	2. GRAVEL		2. BARK
	3. ROCKWOOL	2. "OASIS" (PLASTIC FOAM)	3. WOOD CHIPS
3. AEROPONICS	4. GLASSWOOL	3. HYDROGEL	4. PEAT
	5. PERLITE		5. FLEECE
	6. VERMICULITE		6. MARC
	7. PUMICE		7. COCOSOIL
	8. EXPANTED CLAY		
	9. ZEOLITE		
	10. VOLCANIC TUFF		
	11. SEPIOLITE		

1.4 Strawberry Production

Fragaria × *ananassa*, commonly known as the strawberry or garden strawberry, is a hybrid species that is cultivated worldwide for its fruit, the common strawberry. Strawberry is widely appreciated for its characteristic aroma, bright red color, juicy texture, and sweetness. It is consumed in large quantities, either fresh or in prepared foods such as preserves, fruit juice, pies, ice creams, and milkshakes. Artificial strawberry aroma is also widely used in many industrialized food products. Some contents in the strawberry are medically important. For instance, lignan phytoestrogens are also present as a functional bioactive compounds in strawberries [30] which are crucial for cancer prevention .

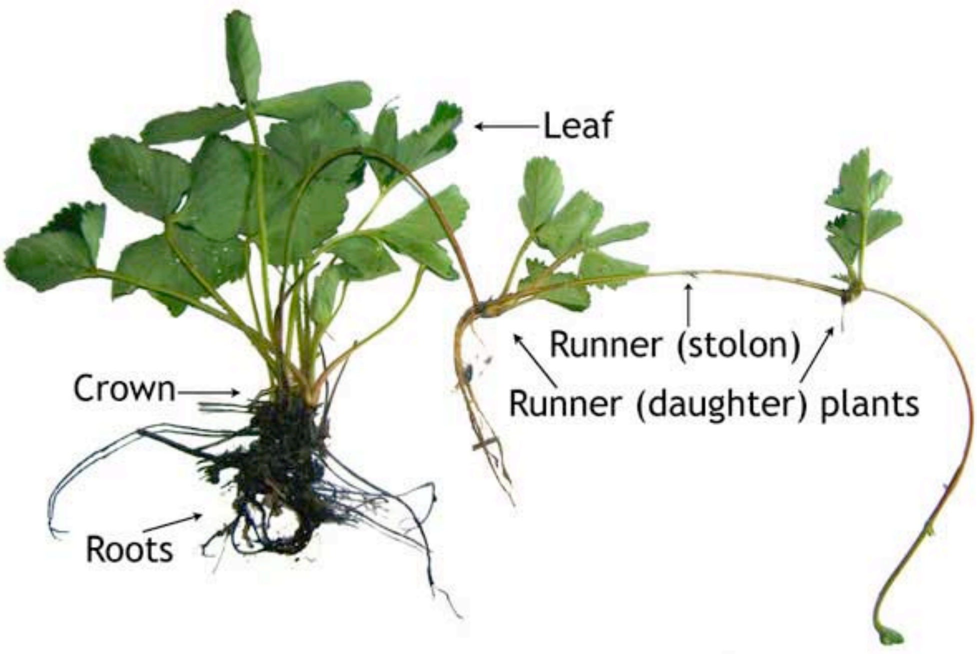

Figure 1.8 Anatomical structure of strawberry plant (Figure taken from http://strawberryplants.org/2010/05/strawberry-plant/)

Fruit of Camarosa is very large and firm and holds up well in rainy weather. It is important to delay picking past the glossy bright red stage and to train pickers to harvest Camarosa when it takes on a darker color to achieve the best Camarosa flavor. Camarosa strawberry plant is an early-season short day cultivar. Fruit is larger and firmer than other types, very flat conic, productive, has good appearance, is very firm, has good flavor, and is widely adapted producing fruit over an extended period at low latitudes.

The harvest season begins in early to mid-May and can last for up to 5 weeks if more than one variety is planted and the weather remains cool. Only fully colored strawberries at their peak of flavor should be harvested since quality will not improve after harvest. Refrigeration will be needed for berries that are stored for a few hours or longer. Strawberries are usually sold in pint and quart plastic or fiber pulp containers. Chandler and Camarosa are two of the most common varieties used in this system. Standard eastern varieties do not work as well because of their long dormancy period. Growers able to provide the earliest crop of these berries will often have the marketing advantage [31].

There is a well-established market when the strawberry production is considered. Turkey is ranked as seventh with the production of 160,000 tones annually all over the world. At the beginning of the 2000s, when European Union countries are considered, Spain is the most strawberry producing country with 308,000 tons per year. Imports of 627,888 tons of strawberries are made annually world-wide and the sales volume is 1,321,346 thousand dollars [32]. According to a more recent survey in 2012, Turkey’s strawberry production exceeds the production in Spain with annual growth of 300,000 tones for Turkey and 275,000 tones for Spain [33]. When market prices are considered, there is a huge fluctuation between summer and winter prices of strawberry. That is why early marketing of the strawberry provides marketing advantage.

1.5 Aim of the Study

Strawberry is an important industrial crop as we discussed above. As the crop time is shortening, the advantage in the market for strawberry becomes higher. NFT is one of the soilless culture techniques that can enhance strawberry production [34]. Moreover as the strawberries are less processed then the demand for less processed fruits will be increased [35]. This soilless culture technique for strawberry production will integrate itself to minimally processed strawberry production technology.In this study, our aim is to optimize the best growing conditions for strawberry production by comparing different support medium in NFT system.

By using rockwool, coco pit, perlite and expanded clay as supporting medium in NFT and comparing the parameters among different applications, we will examine enhancement in strawberry production as it is expected that the supporting medium may affect plant production [36]. This thesis consists of the effects of supporting medium in NFT by means of fruit weight, fruit amount, marketable fruit ratio, pH, toughness, color, odor, solid material amount, EC, vitamin C content, sugar amount, fruiting amount. Furthermore the efficiency of seedlings gathered from plant tissue culture and resistance to specific strawberry pathogens were also studied.

CHAPTER 2

MATERIALS AND METHODS

2.1 Plant Material

Strawberry, *Fragaria* × *ananassa*, is a hybrid species that is cultivated worldwide for its fruit, In a study conducted by Ozdemir *et al* in 2001 [37], 7 types of strawberries tested for efficiency, productivity and quality by several parameters and "Camarosa" type was found to be the highest yield with the highest mass of fruit. This thesis is related with the effect of support medium on fruit production. For that reason, type of strawberry that has highest capacity for fruit production was chosen as plant material to use in this study. Moreover there are several publications related with "Camarosa" that [34,38] the Camarosa type gives the highest yield for fruit production and the fruit produced is suitable for shipping processes.

With these properties and advantages for industry, Camarosa was chosen to be used for comparison of the effects of support medium in NFT system. Commercially available Camarosa plantlets were purchased from local agricultural vendors.

2.2 NFT System in Greenhouse

2.2.1 Greenhouse

Soilless culture experiments by using NFT system was carried out in greenhouse conditions. The greenhouse area was provided by ITC company (http://www.itcturkiye.com /index.php) located in Mamak, Ankara. The company uses “Integrated Solid Waste Management System” to produce biogas and use this biogas for the energy requirements in greenhouse such as heating the environment or for basic electrical needs.

Figure 2.1 Greenhouse area provided by ITC in Mamak, Ankara

2.2.2 Vertical Farming

As the greenhouse area given by the ITC Company was not large enough to perform conventional NFT system application and the trail with different support medium for strawberry fruit production, it was decided to use the area advantage of vertical farming. As can be seen in Figure 2.2 below, NFT system is applicable with vertical farming.

Figure 2.2 A vertical NFT application (Figure taken from http://blog.ecocityhydroponics.com /wp-content/uploads/2012/09/IMG_5297.jpg)

For strawberry production in greenhouse by using NFT system with vertical farming, first of all, overall structure of the NFT system was drawn with the use of AutoCAD-2013 3D software (AutoDesk Company, USA) according to scheme in Figure 2.3a. Overall shape is triangular prism. As can be seen from the plans in Figure 2.3b, there is one channel at the top, there are 5 channels in each side, totally having 11 channels in one structure. Between each channels there is 0.5 meters difference in length as can be seen from the plans represented in the plans. Moreover there is also 0.5 meters distance between two sides of the structure. These distances between each side of the channels provide space for plant growth.

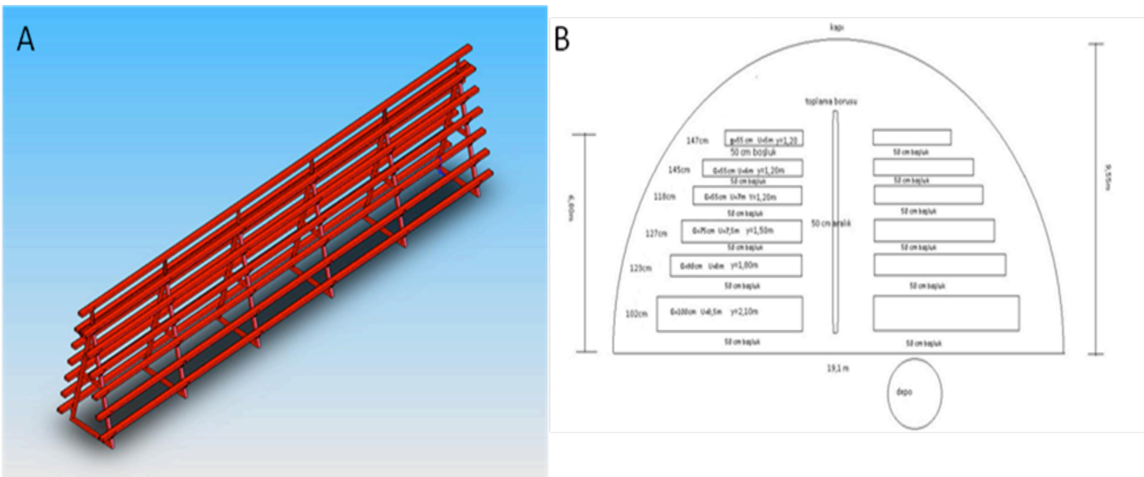

Figure 2.3 A) Vertical Farming Scheme for NFT system B) Vertical Farming Plans for NFT system

2.2.3 NFT System

The standard NFT system includes channels, nutrient solution tank, submersible pump, supporting frame and pots for plant installation. All the plastic materials that are in contact with plants are made up of food-grade lead-free UV-resistant PP/PVC material. Channels have surface for nutrient solution flow and small holes to install plantlets. Nutrient solution tank holds the solution with the submersible pump. By that way, nutrient solution in the tank can be delivered via pipe system to the channels that the plants are located [39]. Final view of the vertical NFT system in ITC greenhouse can be seen from the Figure 2.4.

Figure 2.4 Vertical Farming Installations in ITC Greenhouse

2.3 Growth Condition Optimization of Plants in NFT System

Nutrient solution used in the NFT system for strawberry production was decided according to previous studies [40,41]. According to these studies, nutrient solution should contain Nitrogen, Phosphorus and Potassium as macro nutrients. Nitrogen is primary to foliage plant growth. Phosphorus helps for building strong roots and it is vital for flower and seed production. Final macro-element Potassium is required for increasing chlorophyll in foliage and it also helps to regulate stomata openings and by that way induce better usage of light and air by plants. Nutrient should contain 200 mg/L N, 208 mg/L K and 37 mg/L P. As secondary nutrient, Calcium (167 mg/L) and Magnesium (49 mg/L) were included, mostly functioning as co-factors for several enzymes in molecular reactions. Finally Iron (Fe: 1.53 mg/L), Manganese (Mn: 1.16 mg/L) Boron (B: 0.46 mg/L) Zinc (Zn: 0.09 mg/L) Copper (Cu: 0.03 mg/L) and Molybdenum (Mo: 0.02 mg/L) were included in the nutrient solution as micro-elements [42].

Nutrient solution was prepared by first preparing the solution A and B, which the formulation was defined below. Solution A was prepared by adding 362.5 g Iron EDDHA (FeEDDHA), 884.797g Calcium Nitrate (Tetrahydrate) ($Ca(NO_3)_2.4H_2O$) and 3139.89 g Potassium Nitrate (KNO_3) in 300 liters. By the same way, solution B was prepared by adding 12.96 g Copper Sulfate (pentahydrate) ($CuSO_4.5H_2O$), 943.20g Magnesium Sulfate (Heptahydrate) ($MgSO_4.7H_2O$), 34.15g Manganese Sulfate (Monohydrate) ($MnSO_4.H_2O$), 46.96g Sodium Borate (Decahydrate) (borax) ($Na_2B_4O_7.10H_2O$), 1.51g Sodium Molybdate (Dihydrate) ($Na_2MoO_4.2H_2O$), 4.76g Zinc Sulfate (Dihydrate) ($ZnSO_4.2H_2O$), 1846.46g Potassium Sulfate (K_2SO_4) 1846.46,184.6 and finally 1182.28g Potassium Monobasic Phosphate (KH_2PO_4) into 300 liter solution. After preparing these solutions, final nutrient solution was prepared by using 40 mL of both solution A and solution B in every liter of nutrient solution. Final concentration of each ingredients of the nutrient solution is given below: $N(NO_3)$ 72.0 ppm, K 0.32 ppm, P 35.875 ppm, Mg 75.20 ppm, Ca 85.30 ppm, S 2414.20 ppm, Fe 3.30 ppm, Zn 0.3 ppm, B 11.30 ppm, Cu 0.5 ppm, Mo 0.08 ppm, Na 80.143 ppm, Cl 171.98 ppm, Mn 1.30 ppm and finally $N(NH_4^+)$ 24.3 ppm. In vegetative growth periods nitric acid (HNO_3) and in flowering period phosphoric acid (H_3PO_4) were included in the nutrient solution.

This nutrient solution is placed in nutrient tanks and pumped through the pipes to the NFT channels. Oxygen levels of the solution were arranged by either high density airstone or aquarium bubbler for non-recirculating system. Solution was checked daily during the experiment and EC and pH values were checked instantly in order to keep the pH and EC value constant. EC level (electrical conductivity) is the ability of a solution to transmit an electrical current. The unit of EC is deciSiemens per meter (dS/m) and during the flow of nutrient solution; it was set to EC 1.8-2.2 dS/m (mS/cm) for salt tolerance of the plants. Moreover pH value of the solution was set to pH 5.5-6.5 which is the optimum range for nutrient uptake of plants from the solution. Finally the temperature of solution was kept at 22-26°C. The flow rate of the solution was arranged according to EC. Solutions in the tank were completely renewed every two weeks [43].

Figure 2.5 Functionally Working NFT System in ITC Greenhouse: Strawberry plants growing in vertical NFT

2.4 Support Medium Applications

As mentioned in previous chapters, vertical NFT system includes food-grade lead-free UV-resistant PP/PVC channels. These channels were designed to have space for pots to be installed. By seeding the plantlets into pots and placing the pots including the plants, plants were grown under the optimum conditions as mentioned above. For comparison of the support medium effect on strawberry production, rockwool, perlite, coco fiber and expanded clay were used. Except rockwool, for other three support medium, pots suitable for NFT channels were used. For rockwool, plants were established on small rockwool slabs positioned in channels containing recycled nutrient solution. Compared to the open rockwool system, this procedure reduced the amount of rockwool needed. Rockwool used in a NFT system acts as a nutrient reservoir in case of pump failure, and helps anchor the plants in the nutrient. For other types of support medium, pots were filled with support medium, and then the plants were established in the pot. Finally, pots including support medium and plants were placed in the channels having the holes [44].

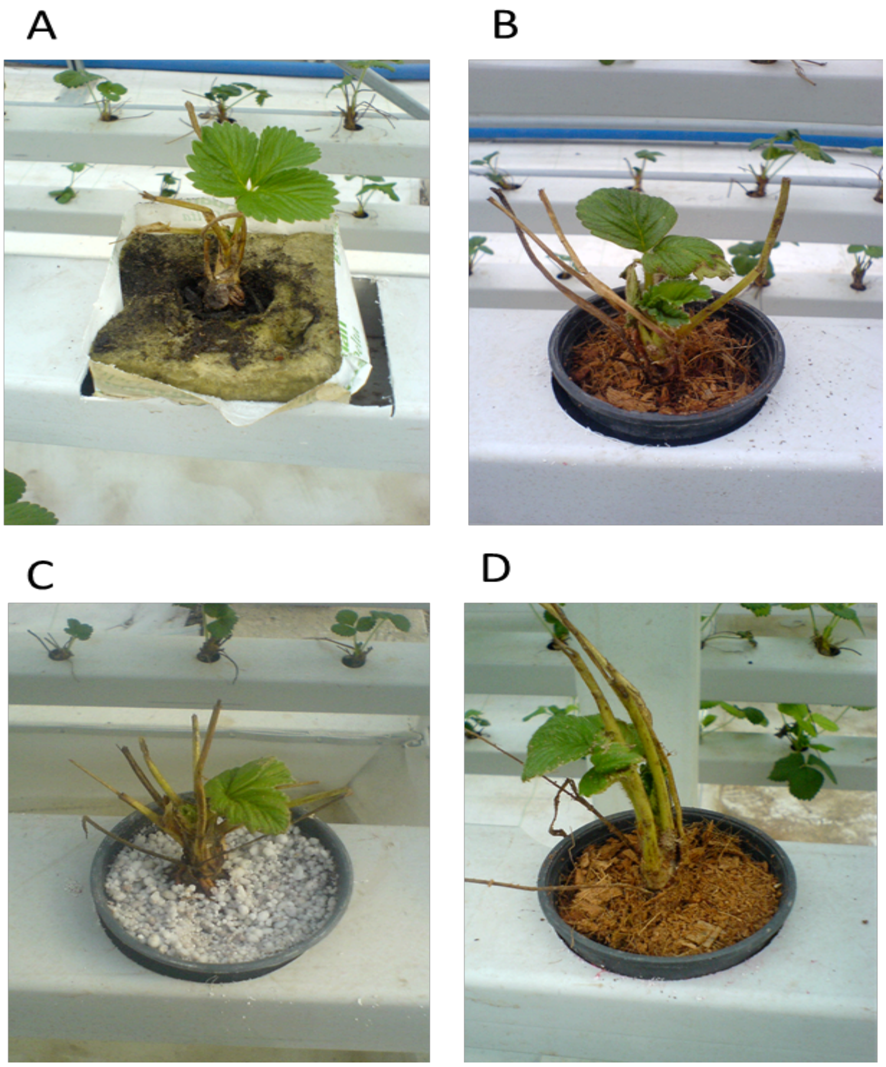

Figure 2.6 Supporting Medium Applications with strawberries: A) Rockwool B) Coco Fiber C) Perlite D) Expanded Clay (Photos taken from the NFT greenhouse in ITC, Mamak)

2.5 Comparison of Parameters for Strawberry Production

In order to compare the effects of the support medium on NFT system for strawberry production, several different parameters were used. These parameters can be obtained by applying some common biochemical assays for plant biochemistry [45]. These parameters include fruit weight, fruit amount, marketable fruit ratio, pH, toughness, color, odor, shape, solid material amount, EC, vitamin C content, sugar amount, fruiting amount, comparison of the efficiency of seedlings gathered from plant tissue culture and resistance to specific strawberry pathogens [40,46].

2.5.1 Fruit Weight and Amount

Fruits harvested twice were weighed by using a standard laboratory balance and the values for fruit weight for each of the support medium trials were recorded. For each support medium trail 5 fruits from 5 different plants were harvested twice (10^{th} and 20^{th} weeks). Totally for weight measurement, 25 samples for each trail were measured. 5 different plants and 5 different fruits were selected randomly and these numbers were selected to increase the sample size for statistical analysis. Efficiency of the seedlings was also determined whether fruits appeared after 4^{th} week of the installation of the plant into NFT system (data not shown). The Average fruit weight (g), average fruit number (number/plant), total productivity (average weight X number of fruit/ plant) for each treatment were calculated and the difference between each treatment were tested if there is any significant difference by using GraphPad Prism Software.

2.5.2 Marketable Fruit Ratio

In order to be presented in the market successfully, fruits that are grown must meet some criteria such as toughness, color, odor and shape. Toughness of the fruit was determined by the instrument penetrometer (with 5mm tip) around the equator of the fruit and expressed as kg cm^{-2}. For color determination, color measurements were done by Minolta CR 300, (Osoka, Japan) for both outside and inside of the fruit. Measurements were performed for the fruits collected at 20^{th} weeks of each trails. Outside color was determined exactly from the equator region of the fruit and for inside color determination, two cheeks region were done by using L*, Choroma, and Hue terms. L* stands for change in the brightness of the color and Chroma is the density of the color and finally Hue is the color angle value [47,48]. Odor and shape determination was done empirically. With these four parameters and also considering the fruit weight and amount; marketability of the fruits was determined for each of the support medium trials.

2.5.3 Fruit Quality Analysis

Fruit quality measurements were done by pH, solid material amount, EC, vitamin C content and sugar amount, [46]. EC and pH values were determined by simple instruments; electrical conductivity meter and pH meter in given order. Value for EC is expressed as μS/cm and EC values were measured from the nutrient solution. pH values were measured directly from the fruits. Solid material soluble in water was measured by refractometer as mentioned by Voca [46]. Vitamin C content of the fruits were measured by Iodometric titration and spectrophotometric measurements [49]. Sugar amount was determined by performing HPLC analysis as mentioned in the research conducted by John et al in 1994 [50,51]. Basically, Five grams of discs that were cut from the middle of fruit was placed in a mesh container and quickly dipped in 25 ml of a medium containing 2 mM $CaCl_2$ and 0.2 M mannitol at 0^0C to remove surface sugar released from cut and damaged cells. The discs were then incubated in 100 ml of the same solution and aerated at 0^0C for various intervals for 2 h. Aliquots of 0.5 mL were withdrawn at the end of each interval for assay. The amount of sugar in each aliquot was determined by high-performance liquid chromatography (HPLC). At the end of the 2 hours incubation period, the sugar remaining in the discs was extracted by boiling for 10 minutes after homogenizing in 5x the volume of 80% ethanol and the amount of sugar was determined by HPLC.

All statistical analyses were done and the related graphs were drawn by using GraphPad Prism Software. For all data, student's T test was applied with non-parametric Mann-Whitney posttest.

CHAPTER 3

RESULTS AND DISCUSSION

As mentioned in the introduction chapter, strawberry is an important industrial crop. As the crop time is shortened, the advantage in the market for strawberry becomes higher. NFT is one of the soilless culture techniques that can enhance strawberry production and further by applying NFT system in greenhouses, seasonal limitations for strawberry production can be eliminated. Furthermore, there are several different types of support medium available for NFT system. In this study, our aim was to optimize the best growing conditions for strawberry production by comparing different support medium in NFT system, NFT only system, Rockwool-NFT, Coco Fiber-NFT, Perlite-NFT and finally Expanded Clay-NFT. In order to critically compare the effects of different supporting medium, we assets some criteria grouped in several ways. First we compared the productivity of strawberry plants by determining the average fruit weight and average fruit number per plant. Second group of criteria includes toughness, color, odor, shape; namely for marketable fruit ratio. The last group of criteria is the fruit quality which includes pH, solid material amount, EC, vitamin C content, sugar amount. Finally all plants that are grown in greenhouse in NFT system with different types of supporting medium were also observed if there is any difference against pathogens, if any presents, and also efficiency of seedlings gathered from plant tissue culture will be observed.

3.1 Plant Productivity Analysis

In order to observe the effects of support medium on plant productivity, fruiting capacity of each plant must be determined. For calculating plant productivity, average fruit weight at the 10^{th} and 20^{th} weeks was calculated and the average fruit number per plants was counted. Finally, these values were multiplied to calculate plant productivity to compare the effects of supporting medium on productivity for each of the supporting medium. For that purpose, at the 10^{th} and 20^{th} week, after planting in NFT system, 5 random plants were chosen. From these 5 random plants, 5 random fruits were picked and were weighed. Values were recorded and average fruit weights were calculated by using 25 fruit samples for each supporting medium as can be seen from Table 3.1. From Figure 3.1, examples photographs of fruits can be seen in order of NFT only system, Rockwool-NFT, Coco Fiber-NFT, Perlite-NFT and finally Expanded Clay-NFT. Values of weight are only for random sampling of the applications. According to these data, significance tests (student's t-test) were applied to each values comparing it to the values of NFT only data. Values of average fruit weights are shown in Figure 3.2.

Table 3.1 Average Fruit Weight Statistics: 5 random fruit samples from 5 random plants were picked (totally 25 samples for each application) and the weights were meausred by using a balance. For each application; mean, standard deviation, minimum and maximum values were determined.

	NFT	**Rockwool**	**Coco Fiber**	**Perlite**	**Expanded Clay**
N	25	25	25	25	25
Mean	21.36	18.10	18.46	15.24	14.34
Std. Deviation	2.49	2.40	3.39	2.44	3.14
Minimum	17.36	14.11	9.40	11.18	8.78
Maximum	26.08	22.55	23.61	19.96	21.05

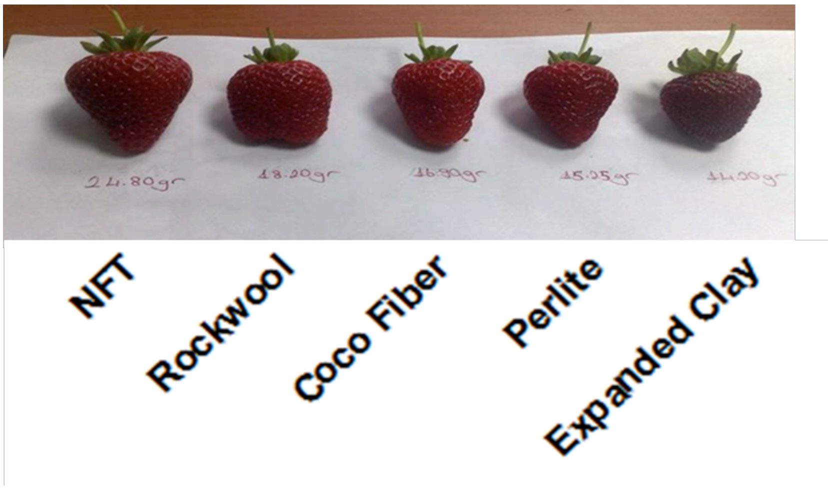

Figure 3.1 Average Fruit Weight at the 20th week. Sample fruit weights for application of supporting medium. (NFT only system; 24.80 g, Rockwool-NFT system; 18.20 g, Coco Fiber-NFT system; 16.90 g, Perlite-NFT system; 15.25 g, Expanded Clay-NFT system; 14.20 g). These values are only for random samples. Average fruits weights were shown in Figure 3.2.

According to data obtained, statistical tests were applied and it was found that NFT only system gives the highest yield by means of average fruit weight with a mean of 21.36 g of average fruit weight. These data significantly differ from other supporting medium applications according to statistical tests applied. Initially student's t-test was applied and then non-parametric Mann-Whitney posttest was applied. Three asterisks indicate p value is lower than 0.001 while two asterisks indicate p value is lower than 0.01. According to Figure 3.2 average fruit weight with NFT only system was significantly higher than the fruit weights in plants that were grown in NFT system with supporting medium.

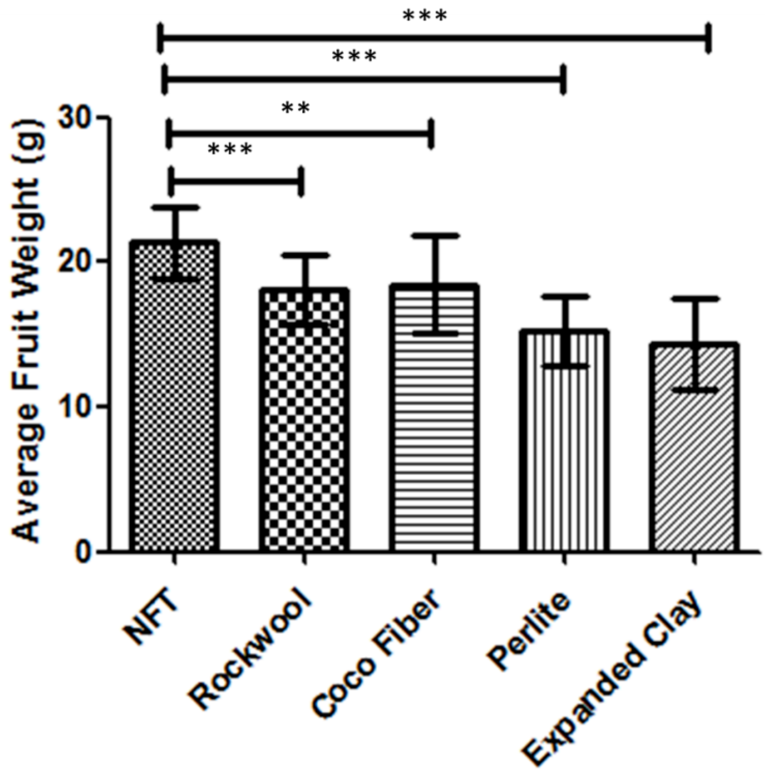

Figure 3.2 Average Fruit Weight graph: NFT only system is significantly different from other applications by means of average fruit weight. Statistical test was done by using GraphPad program. 3 asterisks indicate significance value that the p value is lower than 0.05.

For calculation of productivity, average number of fruits from each support medium applications were also required. For this purpose as done for measuring fruit weight, at the 20th week, 5 random plants were selected for each application, and the number of fruits were counted. Data for average fruit number per plant is represented in Table 3.2.

Table 3.2 Average Fruit Number Statistics: 5 random plants were picked and the fruits were counted For each application; mean, standard deviation, minimum and maximum values were determined.

	NFT	**Rockwool**	**Coco Fiber**	**Perlite**	**Expanded Clay**
N	5	5	5	5	5
Mean	22.29	19.23	19.52	19.60	17.76
Std. Deviation	2.18	1.57	2.59	2.20	1.94
Minimum	19	17	15	17	15
Maximum	24	21	22	22	20

As can be seen from the Figure 3.3, there was not much difference in average number of fruits per plant. Between different supporting medium, there was no significant difference however, NFT-only system slightly differs from Expanded Clay-NFT system.

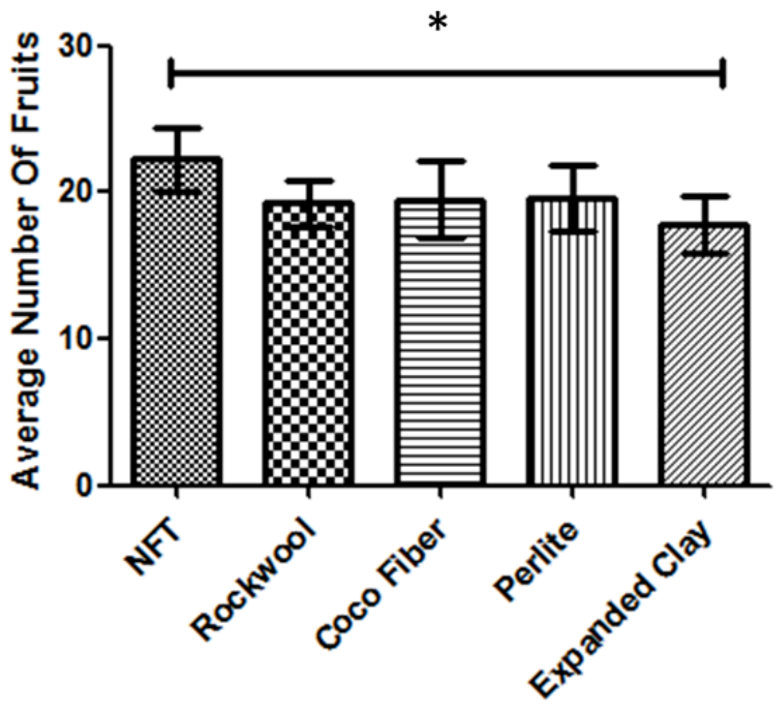

Figure 3.3 Average Number of Fruits: Average fruit number among the supporting medium applications is not significantly different. Only significance is between NFT only system and Expanded Clay-NFT system (single asterisk indicate p value is smaller than 0,05).

Overall productivity of the different applications can be tested by measuring productivity of the plants. That productivity can be calculated by using average fruit number per plant multiplied by average fruit weight. Figure 3.4 shows the graph for productivity of different NFT applications.

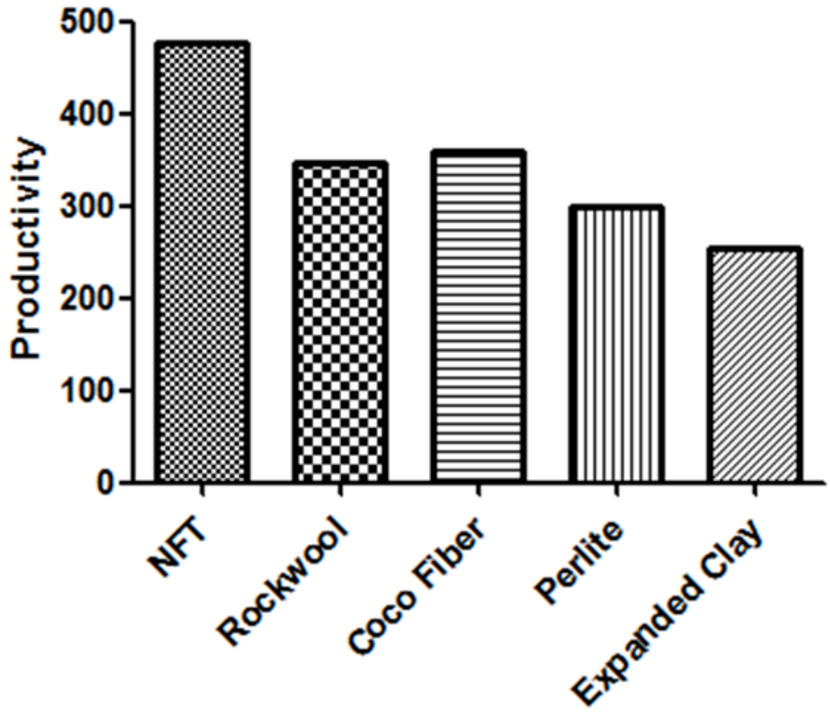

Figure 3.4 Overall Productivity of different NFT systems: Productivity was calculated by multiplication of average fruit number by the average number of fruits per plant.

According to overall productivity of plants, shown in Figure 3.4, NFT-only system improved the productivity compared to other applications. NFT-only system not only significantly increased the average fruit weight but also significantly increased the average fruit number per plant. This was most probably due to absorption capacity of supporting medium. In NFT-only system, plant roots directly interacts with nutrient medium whereas in other applications roots interact with supporting medium and get the nutrients through these supporting medium. These events can cause reduction in overall growth of fruits. However this statement should be proved by other molecular mechanism that involved the capillary interaction of roots with supporting media.

Apart from productivity analysis that was calculated by multiplication of average fruit weight with average fruit number per plant, earliness can be detected by the comparison of the same parameters. For determination of earliness effect of supporting medium on strawberry fruit production, 10^{th} week data were also considered and compared these values within supporting medium trials including 20^{th} week data for productivity. Figure 3.5 shows the average number of fruits for different supporting medium trials and data for both 10^{th} and 20^{th} week. Figure 3.5 shows there was only slight difference between different trials. However NFT only system gives the highest yield compared to other supporting medium applications for 10^{th} week. This was also valid for 20^{th} week as we showed at Figure 3.2. When average fruit number per plant was considered for 10^{th} week, it can be concluded that NFT-only system gives the highest yield compared to other applications. However this difference was not significant by means of statistics.

Comparing all data for all different supporting medium trials and for different time points of harvesting; 10^{th} and 20^{th} week, it can be concluded that, NFT-only system gives the highest yield for both the average fruit weight and average fruit number per plant for 20^{th} week data. When earliness is considered for the plants, NFT-only system is more efficient compared to supporting medium trials. NFT-only system gives the highest fruit number per plant and gives the heaviest fruit weight.

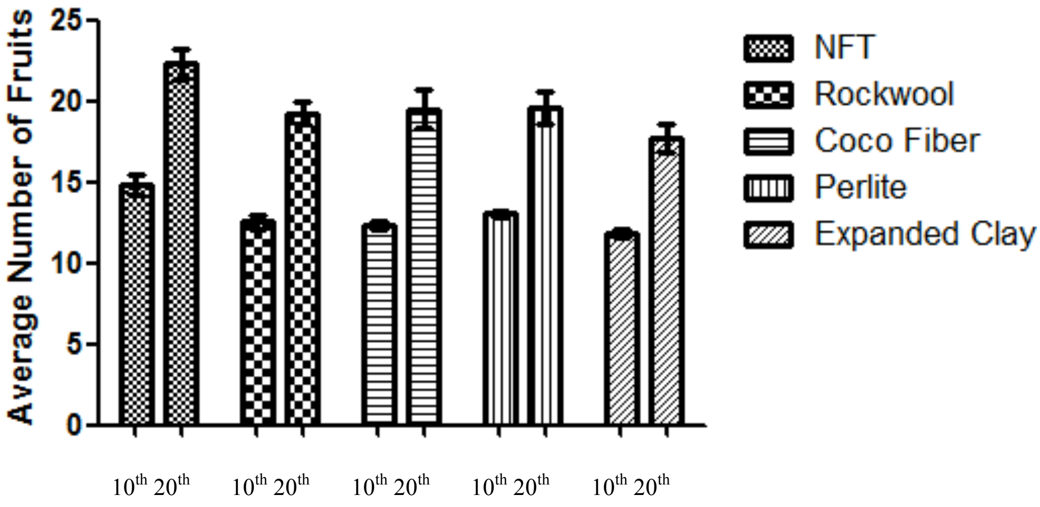

Figure 3.5 Average Number of Fruits for Earliness analysis: Average fruit number among the supporting medium applications is not significantly different. NFT only system slightly differs from other applications

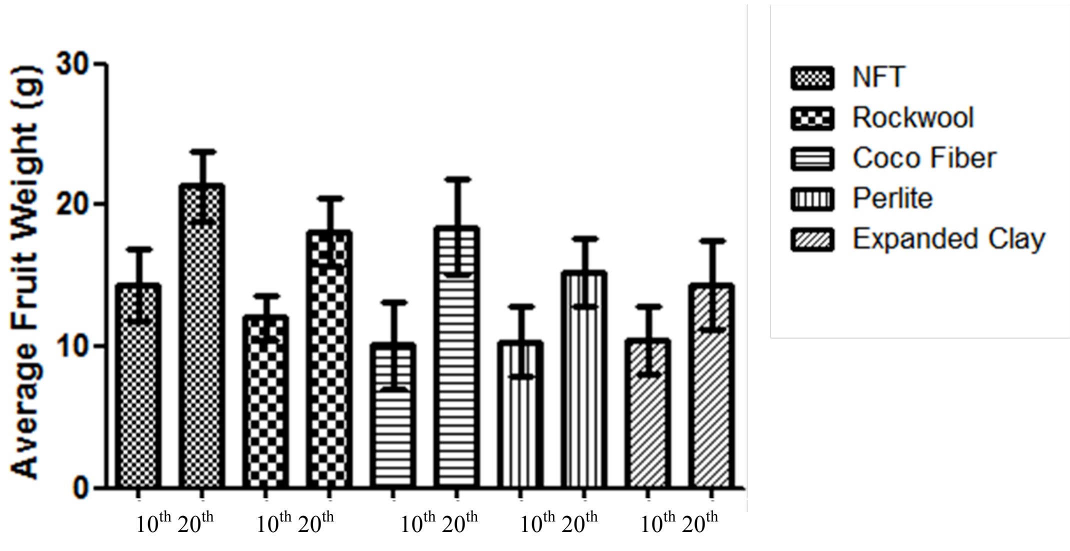

Figure 3.6 Average Fruit Weight for Earliness analysis: Average fruit weight among the supporting medium applications is not significantly different when considered for 10^{th} week data.

Overall, by means of fruit weight and average number of fruits, NFT-only system is the most efficient when compared to supporting medium trails as shown in this section with above tables and graphs. It gives also better results by means of earliness as the average fruit weight and average fruit number per plant is highest for NFT-only system at the 10^{th} week.

3.2 Marketable Fruit Analysis

In order to determine the marketability of the fruits, toughness, color, odor and shape of the fruits were observed. For odor and shape, empirical observations were done. Thus there are no statistical results for these parameters. However, when different applications of supporting medium were considered, there is almost no significant difference. Neither the shape of the fruits nor the odor of the fruits was different from each other among the applications. Other two parameters that determine the marketability of the fruits are toughness and color that can experimentally be determined.

To determine the toughness of the fruit, among each application, 5 random fruits from 5 random plants were picked and the toughness were measured by shorometer through the equator of the fruit and measured values are recorded as unit of kilogram force. Table 3.3 shows the statistics of toughness measurements and Figure 3.5 the graphs for these measurements.

Table 3.3 Toughness of The Fruits: Toughness of the fruits was determined by shorometer by measuring the force among the equators of the fruit. For each application; mean, standard deviation, minimum and maximum values were determined.

	NFT	Rockwool	Coco Fiber	Perlite	Expanded Clay
N	25	25	25	25	25
Mean	0.60	0.55	0.57	0.58	0.53
Std. Deviation	0.05	0.02	0.02	0.03	0.03
Minimum	0.52	0.51	0.52	0.53	0.48
Maximum	0.69	0.59	0.62	0.64	0.58

According to studies conducted by Gunduz [52], there are several factors affecting the toughness of the fruit. As temperature increases, toughness decreases. The toughness is also correlated with the size of the fruit. As the size and weight of the fruit increases, then the toughness increases. These observations revealed by Gunduz also explain the insignificant difference of fruit toughness in NFT-only applications. Although it is not significant, still the toughness of the fruits in NFT-only system was larger than the other applications which can be explained by the size-weight and toughness correlation revealed by Gunduz [52].

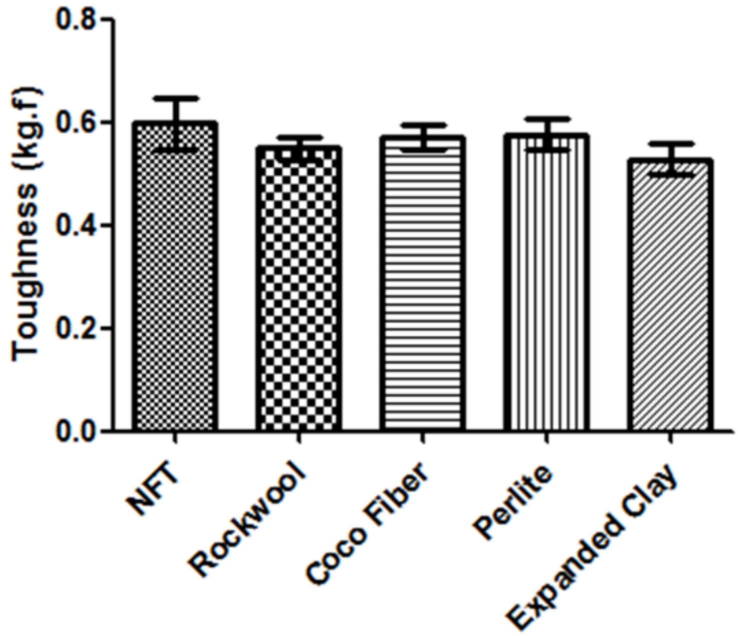

Figure 3.5 Toughness of The Fruits: There is no effect of supporting medium on the toughness of the fruits. The difference among the applications is not significantly different. Still, fruits picked from NFT-only system are tougher than the other fruits grown by other systems.

Color is an important determinant of fruit by means of marketability. By using Minolta instrument, color measurements were done by recording color variables L; color brightness, C (Chroma); color density and H (Hue) value; color angle value. Lower the L and C values, darker the fruit is. For Hue values, there are specific limits for several colors. 0 indicates red-purple, 90 indicates yellow, 180 indicates cyan and 270 indicates blue color [47,48]. Table 3.4 and Table 3.5 summarize the colorimetric values for both inside and outside of the fruit. According to these values there was no significant difference among the applications. As can be seen from Table 3.4 and Table 3.5, in NFT-only systems, according to L and C values, fruits' interior and exterior regions were darker and according to H values, the color of fruits was between purple-red scales.

Table 3.4 Colorimetric Analysis of Fruit Inside Region: H,L and C values from interior region of the fruits were measured for 25 samples for each applications.

		NFT	Rockwool	Coco Fiber	Perlite	Expanded Clay
H value	Mean	37.88	38.11	37.74	38.24	38.97
	Std. Deviation	2.74	1.85	1.87	1.79	2.34
L value	Mean	35.26	36.78	36.61	33.57	36.99
	Std. Deviation	2.49	1.94	3.05	2.51	2.40
C value	Mean	36.89	38.27	37.88	36.37	37.49
	Std. Deviation	1.59	1.63	1.16	1.16	1.31

Table 3.5 Colorimetric Analysis of Fruit Outside Region: H.L and C values from exterior region of the fruits were measured for 25 samples for each applications

		NFT	Rockwool	Coco Fiber	Perlite	Expanded Clay
H value	Mean	39.67	41.13	42.02	39.96	40.01
	Std. Deviation	1.95	1.65	1.36	1.75	2.43
L value	Mean	38.26	39.78	39.61	39.57	40.99
	Std. Deviation	2.00	1.65	3.00	2.80	2.66
C value	Mean	38.89	40.27	39.89	39.37	40.49
	Std. Deviation	1.34	1.42	1.00	1.99	1.45

It can be concluded that exterior region of all fruits among all applications were darker compared to interior region of all fruits. Furthermore, in only NFT system without any supporting medium, both interior and exterior regions of fruits are darker compared to other 4 types of supporting medium. Still when all the values were compared to each other, there is no significant difference among applications. Thus, there is no effect of supporting medium to fruit interior and exterior color.

According to these results related with fruit toughness and color including empirical observations related with shape and odor, there is no significant difference among the application of supporting medium compared to each other. Although there are very minute differences compared to NFT-only system, these differences do not contribute to marketability of the fruit, thus these minute differences can be neglected and it can be concluded as there is no effect of supporting medium on fruit shape, odor, toughness and color.

3.3 Fruit Quality Analysis

Fruit quality analysis includes some basic biochemical assays to determine the values for pH, EC (electrical conductivity), vitamin C content, sugar amount and finally, solid material amount that is soluble in water [53].

pH values of the fruits were measured with a pH meter through interior region of the fruits. As done for previous assays, 5 random fruits from 5 random plants for each of supporting medium trials were picked and used for pH measurements. Optimum pH values for strawberry fruit is between 3.0-4.0. Results obtained in the study were compatible with the expected values as can be seen from Table 3.4. However there was no difference between the pH values of the samples that were grown with different supporting medium. For NFT-only system pH was 4.00 where is for Rockwool-NFT it was 3.95. For Coco Fiber-NFT it was 3.99. for Perlite-NFT it was 3.98 and finally for Expanded Clay-NFT system it was 3.99. When statistical tests were applied and standard deviations of the samples were calculated, it was found that there was no significant change among the samples.

Table 3.6 pH Values of Fruits among Different Applications: Expected strawberry fruit pH value is between 3.0-4.0.

	NFT	Rockwool	Coco Fiber	Perlite	Expanded Clay
Mean	4.00	3.95	3.99	3.98	3.99

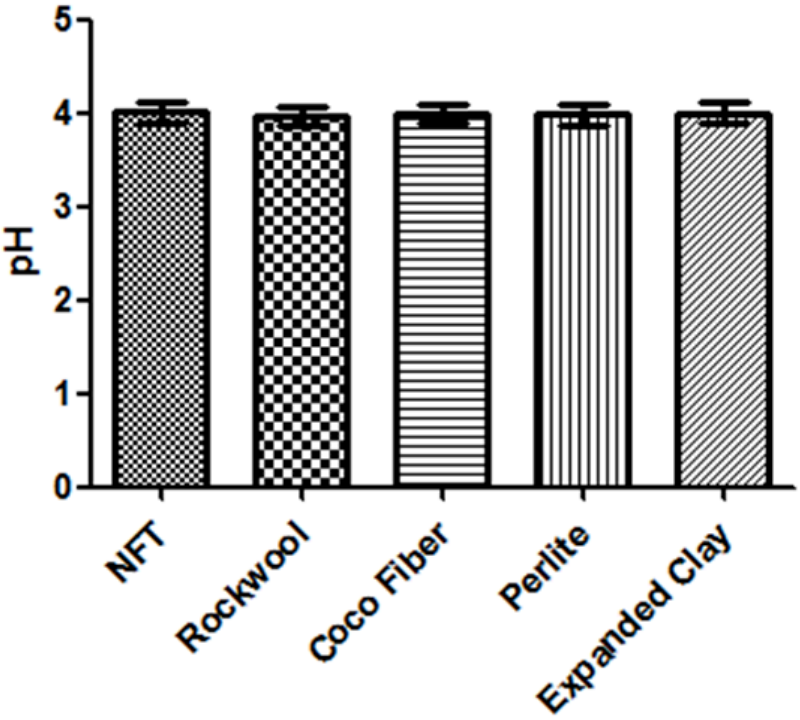

Figure 3.6 pH Values for Strawberry Fruits: There is no significant change among applications by means of pH change after student's T test and non-parametric Mann-Whitney posttest was applied

EC value is the electrical conductivity and it indicates the potential of electricity conductivity property change due to nutrients in the nutrient solution. In NFT systems, each grown crop requires different EC value. EC value has a unit of Siemens/meter, designated as S/m. In some studies it is also possible to measure EC by means of µS/cm. In a previously conducted study [43], in NFT system EC values in nutrient solution for strawberries were found within the limits of 5000-5500 µS/cm. Figure 3.7 summarizes the comparison of the EC values found in this study which were also compatible with the previous study conducted. Although EC values were within the expected limit, as observed for pH values, still there was no significant change among different supporting medium applications after statistical tests were applied and standard deviations of the samples were calculated. However there trails significantly differs from NFT-only system. According to statistical test. NFT-only system has significantly lower EC values ($p<0.001$) compared to all other applications

Table 3.7 EC Values of Fruits among Different Applications: Expected strawberry fruit EC value is between 5000-5500 µS/cm.

	NFT	Rockwool	Coco Fiber	Perlite	Expanded Clay
Median	5061.65	5310.24	5420.24	5351.77	5226.06

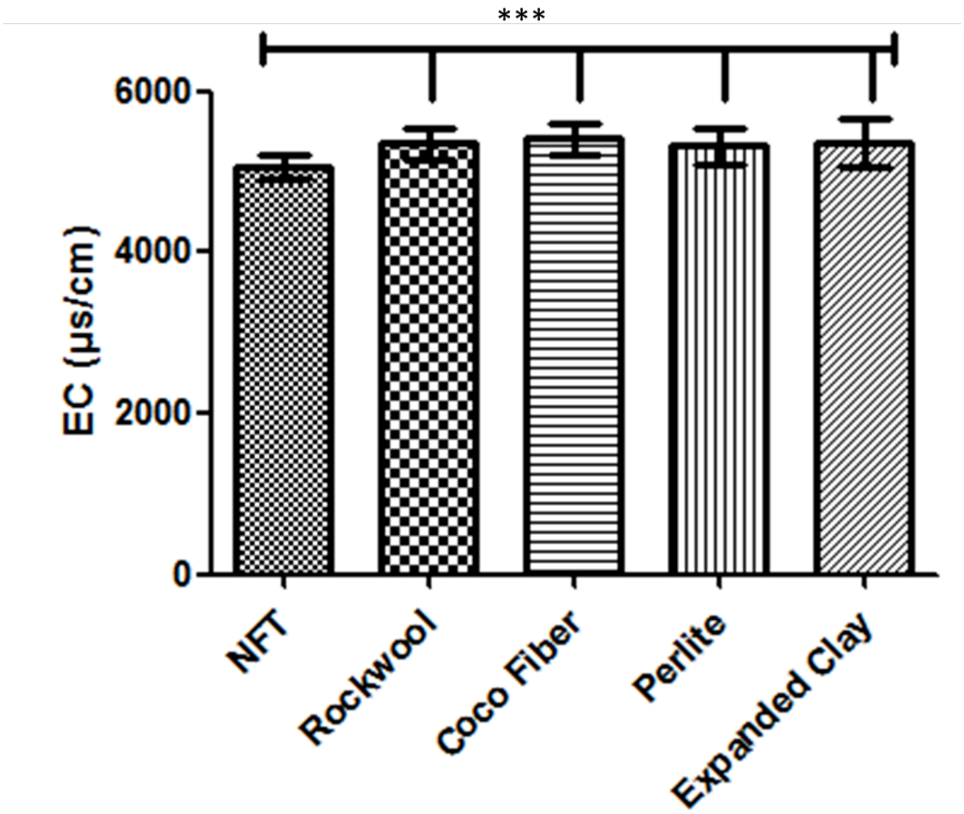

Figure 3.7 EC Values for Strawberry Fruits: There is no significant change among supporting medium by means of EC value change after student's T test and non-parametric Mann-Whitney posttest was applied. However. these 4 applications slightly differ from NFT-only system ($p<0.001$).

As mentioned above EC value indicates electrical conductivity caused by the nutrient in nutrient solution. Since there was no difference in EC values among supporting medium applications. it indicated that there was no change in the plants' capacity for absorbing nutrients from the solutions as EC values remain same among different supporting medium treatments. However in NFT-only system there was no supporting medium thus EC value was not affected. It was also observed that, during trails there was high rate of salification around the supporting medium which can explain increased EC value in supporting medium applications. As there was no signs of salification in NFT only system, there was low value of EC as expected.

Strawberry fruits are rich in Vitamin C. They took the Vitamin C precursor through their roots. That is why in NFT systems, Vitamin C precursor was also included. Vitamin C content is one of the most important criteria for determining the fruit quality, as the difference in Vitamin C content determines the effectiveness of the supporting medium for enhancing the plant growth. Vitamin C content in strawberry fruits in NFT systems was within the limits of 20-30 mg/100 mL according to a previous study [43]. When different supporting medium's effect on Vitamin C content was considered, there appears a significant change among the applications. While supporting medium applications gave a yield between 21.11-22.20 mg/100 mL, NFT only system gave the highest yield by means of Vitamin C content with an average value of 27.85 mg/100 mL. This difference was also found to be significant when statistical tests were applied. Table 3.6 shows the parameters for Vitamin C content data and Figure 3.8 shows the significant difference among the samples.

Table 3.8 Statistics for Vitamin C content among Different Supporting Medium Applications

	NFT	Rockwool	Coco Fiber	Perlite	Expanded Clay
Mean	27.85	21.95	22.20	22.11	21.90
Std. Deviation	0.40	0.57	0.54	0.71	0.65

According to Figure 3.8. only NFT-only system significantly differs from other supporting medium applications according to student's T test and non-parametric Mann-Whitney posttest. Three star indicates p value is smaller than 0.001.

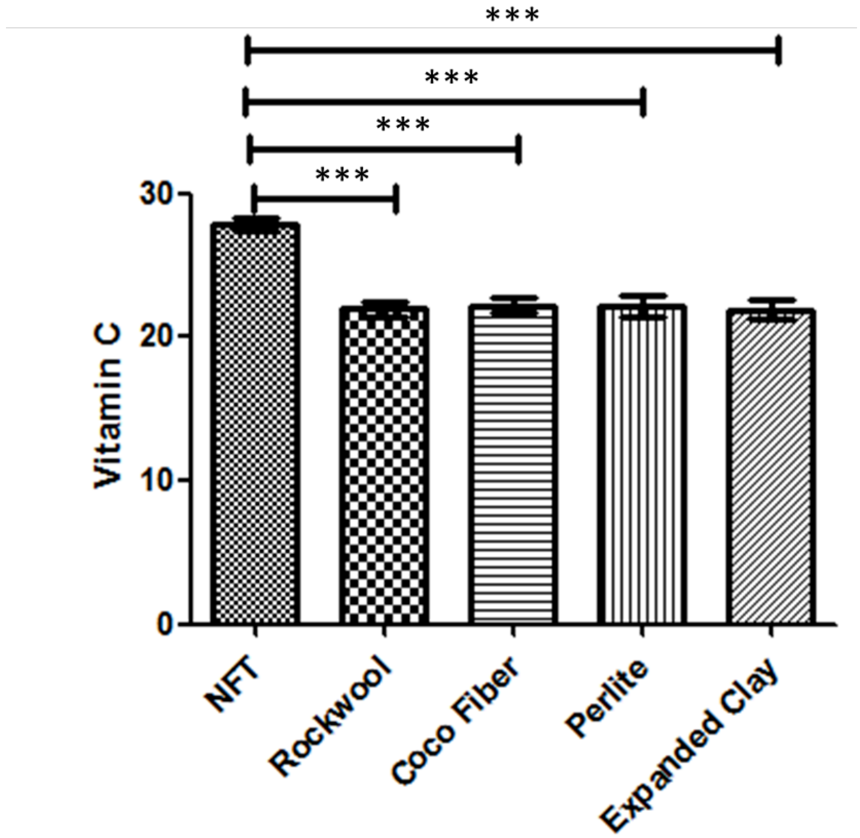

Figure 3.8 Vitamin C content among Supporting Medium Trials: NFT-only system significantly affects the Vitamin C content of fruits.

As discussed above, fruits grown in NFT-only system gave the highest yield by means of Vitamin C content compared to other supporting medium applications. The difference was confirmed to be significant statistically. This is most probably due to the nature of supporting medium and their chemical interaction with Vitamin C [54]. In NFT-only system plant roots directly interacts with nutrient solution and by that mean they may absorb Vitamin C precursor better compared to other plants grown with supporting medium.

Due to the same reasons discussed for vitamin C content in the plants, solid material amount (soluble in water) in the fruits are expected to be higher in NFT-only system compared to other supporting medium trails. Table 3.7 shows the mean values for Solid Material (Soluble in Water) amount and their standard deviations. According to these results plants grown in NFT-only system caused the fruits have more solid material compared to fruits that were grown in other supporting medium. Figure 3.9 shows the significant difference among the applications of supporting medium. Plants grown in NFT-only system gives the highest yield by means of solid material soluble in water compared to other systems.

Table 3.9 Statistics for Solid Material (Soluble in Water) content among Different Supporting Medium Applications

	NFT	Rockwool	Coco Fiber	Perlite	Expanded Clay
Mean	8.35	6.43	5.89	5.97	6.49
Std. Deviation	0.90	1.56	1.73	1.29	1.50

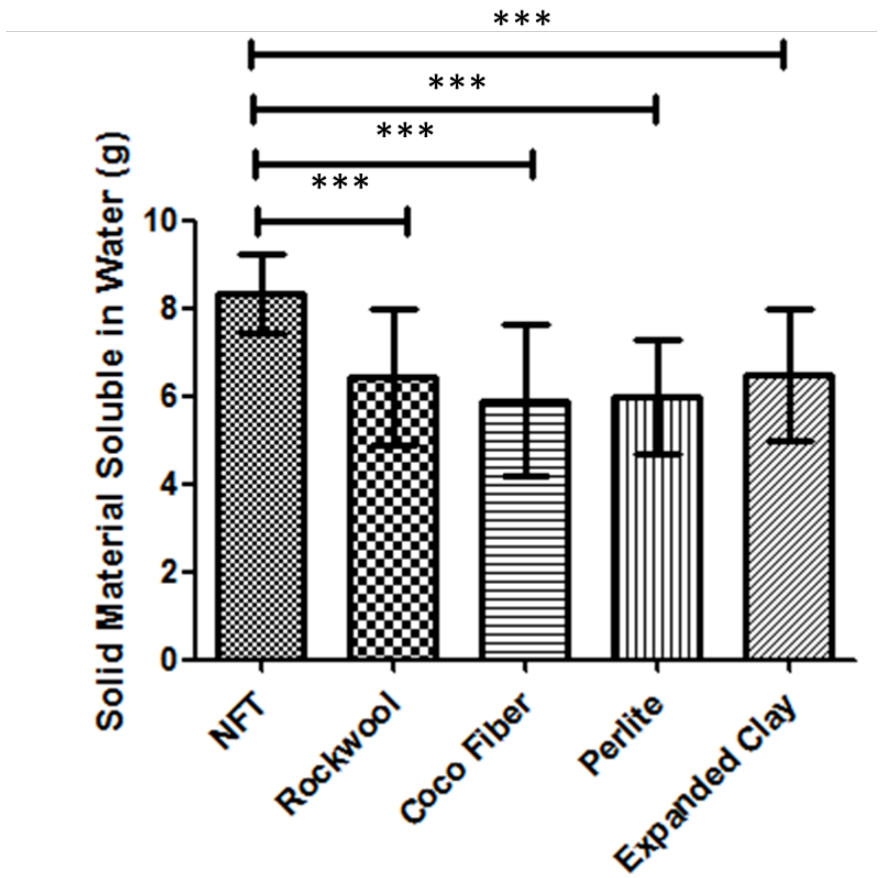

Figure 3.9 Solid Material (Soluble in Water) content among Supporting Medium Trials: NFT-only system significantly affects the Solid Material content of fruits.

The reasoning behind the highest solid material and vitamin C were found in NFT-only system applies also for sugar content for the plants. In other words due to supporting medium effects [54], in all supporting medium applications, sugar content was found to be lower compared to NFT-only system. Table 3.10 shows data for sugar content in plants for different supporting medium applications.

Table 3.10 Statistics for Sugar content among Different Supporting Medium Applications

	NFT	Rockwool	Coco Fiber	Perlite	Expanded Clay
Mean	3.44	2.94	2.88	2.81	2.90
Std. Deviation	0.41	0.43	0.53	0.52	0.45

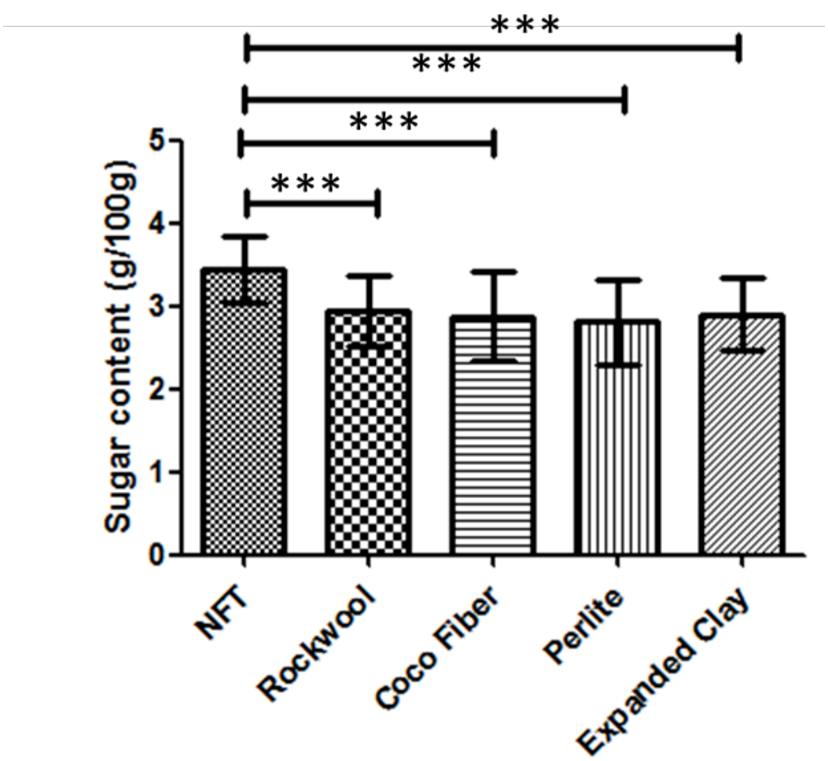

Figure 3.10 Sugar content among Supporting Medium Trials: NFT-only system significantly affects the sugar content of fruits.

For fruit quality analysis. pH, EC values and the Vitamin C, solid material soluble in water and finally sugar content of the fruits were measured and compared for each of the supporting medium trails. According to data observed and statistical calculations, NFT-only system is significantly differs from other applications. Only for pH value, all systems gave the same pH value. For EC value, NFT-only system shows the lowest value which can be explained with salification in supporting medium trials. Vitamin C content, solid material soluble in water amount and finally sugar content of the fruits were highest and significantly different from other systems in NFT-only system which indicates NFT-only system is more successful in growing strawberries in soilless culture by means of fruit quality. Moreover for all the parameters checked, there was almost no change between the supporting medium trials.

3.4 Other Observations

Apart from analysis, data obtained from plants and statistical calculations, in this study some observations without any data were also done. These empirical observations may show some features of the supporting medium applied.

One of the observations was related with the yellow spots on the leaves of the plants. Yellow spots on the leaves may indicate several problems from different types of diseases to inadequate nutrition, or even heat problems related with the greenhouse. During this study, although it was rare and limited to a very small number of plants and leaves, still some yellow spots on the leaves were observed. But this event was limited to only supporting medium applications. This fact eliminates the problems related with the physical conditions of the greenhouse or presence of any infectious agent. As the problem only occurred in supporting medium trials, it was reasoned that this yellow spot may be caused by the salification of the roots, which ultimately burns the leave. As it was observed that EC values of the supporting medium trials were higher due to salification, that salification may cause these yellow spots in the leaves. Yellow spots in the leaves can be caused by burning of the leaves due to salification; in other words lack of required water.

The second empirical experiment was related with physical conditions of the greenhouse. Due to some technical problems, occasionally, power cut happened for a limited time period. Although the system could compensate short term power cuts, there still appeared some problems especially after long term power cuts. NFT system depends on flowing nutrient solution. As the power was cut, then the pumps that are responsible for pumping nutrient solution could not work. When this happens, the system fails to pump the nutrient. Main problem due to inadequate feeding of the plants is the drying of the roots initially and then the leaves. If the power cut took longer, than again yellow spots appears on the leaves. Only once, power cut was that long so that leaves of some plants had these yellow spots due to drying. There are also some minor power cuts which caused drying of the roots. However, this problem was solved as the pumps began to work again. Although this is the case, it was observed that there are differences between the supporting medium trials. NFT only system recovered from power cuts faster than other systems. This can be caused by direct interaction of the roots with nutrient solution and more easy absorption of the nutrients from the solution in NFT-only system.

Final empirical experiment was about a pathogen affecting the strawberry fruits. Thrips are insects that belong to order Thysanoptera. They are presumed to be major cause of the bronzed strawberry [55]. They also cause death of the mature flowers and also irregular fruit structure. During this study, there occurred several thrip infections. Intentionally no precautions were taken and no pesticides were used in order to see the effects of supporting medium trials against thrip pathogen. NFT-only system was observed to be the more resistant to disease and the recovery of the plants in NFT-only system took shorter compared to other supporting medium trials. There were no clear reasons for NFT-only system more resistant to pathogen. However, supporting medium may be more attractive for thrip larvae and provide suitable environment for their development and maturation. That may be the reason why the plants in supporting medium trials were more sensitive to this pathogen.

CHAPTER 4

CONCLUSION

Hydroponics basically is the method of growing plants using mineral nutrient solutions. in water. without soil. Vertical nutrient film technique (NFT) is one of the most used hydroponic techniques that have constant flow of nutrient solution. Especially for some specific regions of the world having infertile soil. NFT system provides excellent solutions for plant cropping.

Strawberry is an important industrial crop. The advantage in the market for strawberry becomes higher as the crop time is shortening. NFT system can enhance strawberry production and may provide earliness for strawberry production as well as it can enhance the productivity of the plants.

To get the most benefits from the NFT system for strawberry production, several different supporting medium were tried in NFT system for increasing strawberry production. These supporting medium included rockwool, coco fiber, perlite and expanded clay. All these supporting medium were compared NFT system with no supporting medium, designated as NFT-only system. Several different parameters were used for this comparison. First, the productivity of strawberry plants was compared by determining the average fruit weight and average fruit number per plant. The second group of criteria includes toughness, color, odor, shape; namely for marketable fruit ratio. Finally, for fruit quality pH, solid material amount, EC, vitamin C content and sugar amount values were obtained and were compared within different supporting medium trials. After all these observations and comparisons, plants grown with different supporting medium were also observed against different stress condition including thrips pathogen and power cut stresses.

According to results obtained during this study. it was found that there is no significant difference between the supporting medium applications other than NFT. However, NFT-only system significantly differed from other systems. First of all, productivity of NFT-only system was higher than the other systems. In other words

NFT-only system resulted in the highest yield by means of average fruit number per plant and average fruit weight. For marketable fruit ratio, toughness, color, odor, shape were measured for all applications. Odor and shape were empirically determined and there were no difference among the applications but for toughness. NFT-only system gave better results. Fruits grown in NFT-only system were tougher compared to other fruits. For color determination, again there was no difference among the samples. Final group of criteria includes pH, solid material amount, EC, vitamin C content, sugar amount value for fruit quality. pH of all the fruits were same among supporting medium trails but for other criteria, NFT-only system was significantly different from other applications. EC values were higher for rockwool, coco fiber, perlite and expanded clay applications. This might be due to salification of the nutrient solution due to supporting medium presence. Moreover, Vitamin C content, sugar amount and finally soluble solid material amount was determined to be high in NFT-only system compared to other applications. That might be caused by the direct interaction of the roots with nutrient solution.

These results suggest that the NFT-only system not only improves productivity of strawberry plants but also increase the fruit quality compared to other supporting medium trials. Apart from these data, it was also observed that the NFT-only system was more resistant to stress conditions such as power cut, failure to flowing nutrient solution and even resistant to thrips pathogen compared to other trials.

Future studies are required to understand the exact mechanisms of how the NFT-only system enhance the fruit productivity and fruit quality. Also, more studies are required to further enhance the strawberry production by applying soilless culture techniques.

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