SMART GARDEN: HYDROPONIC LED GARDEN

MERT KALAYCI

Master's Thesis

Graduate School

İzmir University of Economics

İzmir

2020

SMART GARDEN: HYDROPONIC LED GARDEN

MERT KALAYCI

A Thesis Submitted to

The Graduate School of İzmir University of Economics

Master's Program in Electrical and Electronics Engineering

İzmir

2020

ABSTRACT

SMART GARDEN: HYDROPONIC LED GARDEN

Kalaycı, Mert

Electrical and Electronics Engineering Master’s Program

Advisor: Prof. Dr. Murat AŞKAR

August, 2020

The world population has increased approximately 4 times in the last 10 years. Climate change caused by global warming seriously damages agricultural activities. In this context, global water and food crisis is expected in 2050. Within the scope of "Smart Garden: Hydroponic LED Garden Project", it is aimed to develop the new generation hydroponic plant production facilities, that produces climate-free production in 4 seasons using 95% less water compared to normal agriculture, which uses the unit area 30 times more efficiently by combining Industry 4.0 and LED Technology and Soilless agriculture without using any pesticides.

Keywords: LED, Grow Lighting, Hydroponic, Aeroponics, Nutrient Film Technique (NFT), Agriculture 4.0, Industry 4.0, IOT(Internet of Things)

ÖZET

SMART GARDEN: HYDROPONIC LED GARDEN

Kalaycı, Mert

Elektrik-Elektronik Mühendisliği Yüksek Lisans Programı

Tez Danışmanı: Prof. Dr. Murat AŞKAR

Ağustos, 2020

Dünya nüfusu son 10 yılda yaklaşık 4 kat artmıştır. Küresel ısınmanın neden olduğu iklim değişikliği ise tarım faaliyetlerine ciddi manada zararlar vermektedir. Bu kapsamda 2050 yılında global çaplı su ve gıda krizi beklenmektedir. Smart Garden: Hydroponic LED Garden Projesi kapsamında Endüstri 4.0 ve LED Teknolojisi ile Topraksız tarım birleştirilerek hiçbir zirai ilaç kullanmadan kat çıkabilme imkanı ile birim alanı 30 kat daha verimli kullanan normal tarıma oranla %95 daha az su kullanarak 4 mevsim iklimsiz üretim yapan yeni nesil topraksız bitki üretim tesislerinin geliştirilmesi hedeflenmiştir.

Anahtar Kelimeler: LED, Bitki Aydınlatma Teknolojileri, Hidroponik, Aeroponik, Besin filmi tekniği (NFT), Tarım 4.0, Endüstri 4.0, Nesnelerin İnterneti

Dedicated to my mother and father

ACKNOWLEDGEMENTS

I would like to thank my respectable consultant Prof. Dr. Murat AŞKAR, and sincerely thank Osman GÖKSAN, Emre KIZILGÜNEŞLER, Ali ÖZPOYRAZ and Selami ÖZPOYRAZ for their support.

The Smart Garden Project was supported by TÜBİTAK 1512 and 1507 Support Programs.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Purpose of the Thesis

There were 2 billion people in the world in 1920 and 4 billion in 1970. Today, there are 7.5 million people in the world. Climate change caused by global warming is affecting agricultural activities negatively. The Smart Garden project is an hydroponics production facility powered by the concept of Internet-of-Things (IoT) technology and LED technology that works with maximum efficiency in minimum space. The aim is to develop the most efficient production scheme in at least one of the systems. Several various sensors, equipments are used and the necessary software has been developed on the system.

1.2 Methodology

The scope of the study is expressed methodologically in Figure 1.1. First of all, we will talk about Soilless Agriculture and types, then Nutrient Film Technique (NFT) and Aeroponics. Secondly, we will talk about Plant Lighting, Photosynthesis and Conditions for Plants, Grow Lighting History and Plant Productivity in Response to LED Lighting System. Finally, we will examine Smart Garden: Hydroponic LED Garden Project system requirements and applications.

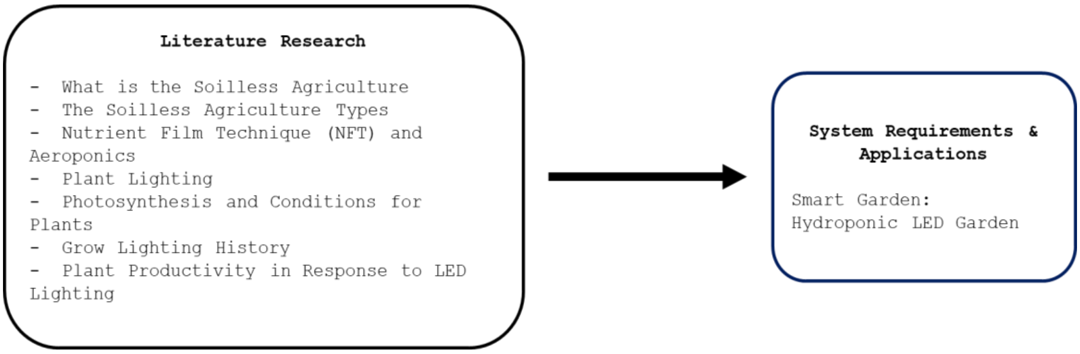

Figure 1.1. Methodology

CHAPTER 2: SOILLES AGRICULTURE (HYDROPONICS)

2.1 Soilless Agriculture Types

In traditional agriculture plants grow in a soil. The plants need nutrients, do not a soil for a grow. In hydroponics soilless agriculture plants are grown in nutrition solutions or any other substrate culture including main, nutrients without soil.

In a traditional agriculture, Plants use main part of their energy growing a big root systems for they have to searching all over in the ground for their water, and nutrition. From this perspective, in soilless agriculture, these energy are existent to the plant's roots. In this scope, plants get everything they need, in totally correct percentage, at exactly the right time and make use of the most effectively with minimum energy. In this respect, plants show their full genetic potential. In this culture; they only remove the medium of soil, but the plants' conditions are reached by water of nutrition-rich. This technique's name is Hydroponic culture (Bansal, 2020).

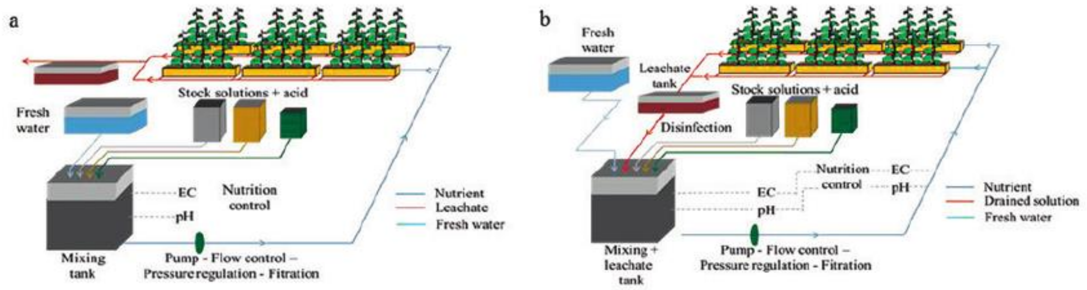

Figure 2.1. Open loop and Close loop. (Source: Putra and Yuliando, 2015)

Soilless culture has two main type; they are open and closed soilless cultures.

Open Soilless Culture Systems: In this soilless systems a new dissolved nutrition solution is related for every irrigation loop. The decreased nutrition solutions are ordinarily reached to the plants using the dripping systems. In this systems, convenient regular cyling loops with a certain and aim to hold the nutrition solutions set in the root cultivation. Soilless cultures use just environments and dribble systems are have a place with open soilless culture. On the other hand, there is a drip system used for closed system in case of use reservoir as recirculating the nutrition solution.

Closed Soilless Culture Systems: Closed soilless culture systems, the nutrition solution are recycled and the nutrition solution concentrations are monitored and stable values in like attitude. The nutrition solution set in such hydroponic systems is a test and the dissolved nutrition solution must be examined and analyzed in any event once every week. The decreased nutrition solutions must be stable value by analyzing results. If they are not control accordingly, the decreased nutrients may disturb the balance of nutrient solutions. The systems contain both basic and advanced soilless cultivation systems. The diagram below shows the types of soilless culture.

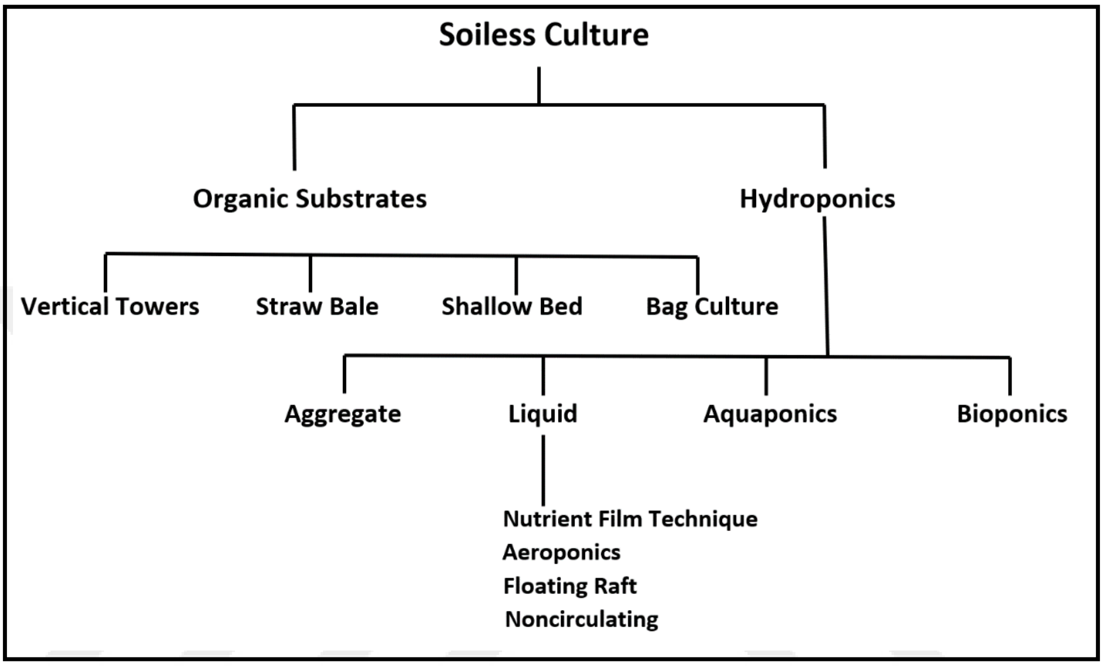

Figure 2.2. Soilless Culture

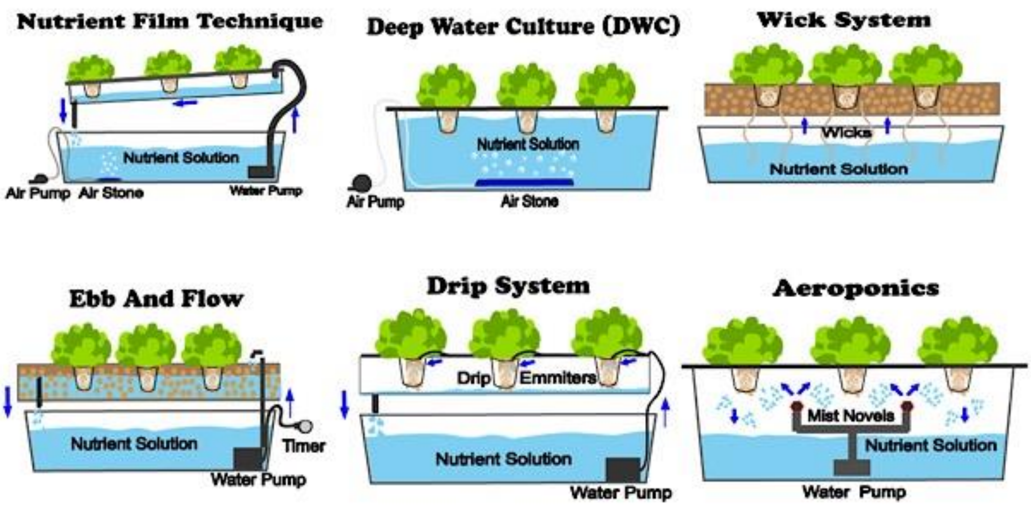

Figure 2.3: Hydroponics Cultures. (Source: Sproutingfarms 2019)

Hydroponics Liquid systems consists of Nutrient Film Technique, Aeroponics, Floating Raft and Noncirculating systems. Deep Water Culture and Nutrient Film

Technique need to air pump for healthy crop. In this thesis examined on Aeroponics and Nutrient Film Technique. However, some tests were first done using the kratky method (Wick System).

2.1.1 Nutrient Film Technique (NFT)

In nutrient film technique, Oxygenated dissolved nutrient solutions recirculated to run highly continuously over the roots of plants entirely a series of path, plants usually grown in small baskets pending in a PVC pipe. Firstly, nutrient enriched water is pumped to pvc pipe from a stock tank, then the water circulate from the sloping pipe is returned to the stock tank (plantozoid, 2019). From this perspective, nutrition solutions are circulated continuously. It can be to change the angle of the pipe size and the number of similar overflow pipe in system. In this scope, when the event of a power or pump failure this system would remain serve to provide a reservoir of nutrients. PVC pipe has small space and the requirement for nutrition solutions must be continuously flow over the roots. On this hand NFT (The Nutrient Film Technique) is especially well suitable for plants that have small roots such as parsley, basil, and herbs.

2.1.2 Aeroponics

In Aeroponics process plants are growing in an air or mist medium, this process does not use of soil or any support environment. Aeroponic system has different from traditional aquaponics, hydroponics, and plant tissue culture growing.

In this scope basis of aeroponic system is to grow plants hanging in a closed environment by spraying the plant's dangling roots and lower stem with sprayed, water of rich nutrient solution. This affects root growth, and roots grow quickly healthy. The leaves and crown extend above in this culture. The plant support structure are separated to roots of the plant. Generally, closed-cell foam is compressed around the lower stem and inserted into an opening in the aeroponic unit, which decreases force and expense; for larger plants, trellising is used to suspend the weight of vegetation and fruit.

Often, the environment is kept free from disease and pests, from this perspective the plants may grow healthier and more quickly than plants grown in a environment. On the other hand, if aeroponic environments are not perfectly closed off to the outside, pests and disease may still cause a threat. Controlled environments are developed to healthy growth, flowering and fruiting of any given plant species and cultivars (van Os & Lieth, 2019).

Because of the sensitivity of root systems and when the aeroponic apparatus fails, the aeroponic is often combined with traditional hydroponic system, which is used as an emergency crop saver backup nutrition solution and water supply.

High pressure aeroponics system is defined as delivering nutrient solution to the roots via 20–50 um mist heads using a high pressure (80 pounds per square inch (550 kPa)) pump (Wikipedia, 2016).

CHAPTER 3: PLANT LIGHTING

3.1 Photosynthesis and Conditions for Plants

Photosynthesis is a chemical process that consist of many forms in bacteria, and almost all plants, including algae, and aquatic plants. Carbon dioxide, water, and sunlight are three simple ingredients in photosynthesis; in this scope plants and bacteria are able to make their own food. The first organisms to photosynthesis were early forms of algae and bacteria. Replenish all the oxygen in the earth's biosphere takes approximately 2,000 years of photosynthetic activity. From this perspective for all animals, including fish and humans, oxygen is a by this process to product. As long as photosynthesis is occurring, oxygen is continuously being released into the air and into the world's rivers, lakes, ponds, and oceans.

The air that humans breathe provides by Photosynthesis of lgae, bacteria, and plants. In plants special cells known as chloroplasts realize to photosynthesis activity. Chlorophyll is a tiny grains of green pigment. We can see the green color in plants. This green pigments are light-absorbing molecules inside the chloroplasts. It came from chloro-green and phyll-leaf.

Chlorophyll has got a different forms and different plants can use several forms in photosynthesis. Carbohydrates has a chemical energy. Chlorophyll-a transforms the chemical energy with sunlight. In this process Chlorophyll-a release carbohydrates' energy. Moreover, some plants include chlorophyll-b and chlorophyll-c, pigments which performs chemical processes.

Conditions for photosynthesis activity;

- Light
- Carbon dioxide (CO2)
- Water (H2O)
- Chlorophyll (type A, B, C)
- Nutrients
- Minerals

3.2 Grow Lighting History

The improvement of plant grow lighting Technologies have three main paths as it developed through its starting years. First of all, there was incandescent lighting, typified with Edison's invention of the incandescent filament lamp. Then, there was open arc lighting, which found its footing in the world used for industrial street lighting. In the late 1800's, finally enclosed gaseous discharge lamps developed primarily developed using mercury vapour (lightning.philips, 2018). Farmers used open arc technology for plant grow lighting in first time.

In 1880, Siemens even ran a research with them futuristically titled, 'Electro-horticulture'. Before the 1900's, it wasn't possible that the gaseous discharge lamps gained any headway in the evolution of artificial plant lighting, because it was around this time that green fingered pioneers began to tinker with the traditionally mercury based gases in the lamp. In 1930's, Argon, Neon and Sodium were some of the first gases to be included which showed great hope during testing at the Boyce Thompson Institute. On the other hand, the real agricultural potential of this ligthing technology wasn't realised until Sodium and Metal Halide lamps were highly pressurised, in the 1950's-1960's (Bansal, 2020).

High Pressure Sodium(HPS), Metal Halide, Ceramic Metal Halide, Fluorescent and LED's are lighting technologies on the market. HPS and LED's are most commonly used as grow lights.

3.2.1 Plant Productivity in Response to LED Lighting

LEDs have great potential as supplemental lighting systems for plant grow lighting production both on and off earth. LEDs' stability, adjustable wavelength , small size, long operating life span, relatively cool emitting heatsink areas and linear photon output with electrical input current make these solid-state light sources ideal use for plant grow lighting systems. Single color, nonphosphor-coated the output waveband of LEDs is much narrower than that of traditional sources of electric lighting used for plant growth,because of the one challenge in designing an optimum plant lighting system is to determine wavelengths and photons essential for specific plants.

Light energy is the most important factor for plant growth. Additional light sources are being used to in regions where the natural light source from solar radiation, is not suitable for growth optimization. Conventional light sources such as high pressure sodium lamps (HPS) and other metal halide lamps are not very efficient and generate high luminiferous heat. From this perspective, new sustainable solutions should be developed for more energy efficient plant grow lighting. Renewed developments in the field of light source technologies have opened up new perspectives for highly efficient and sustainable light sources in the form of LEDs (light-emitting diodes) for plant grow lighting. This part focuses on the potential of LEDs to replace conventional light sources in the plant grow lighting. In a comparative economic analysis of traditional and LED lighting, we can see that the LEDs allows decrease of the production cost of vegetables in the long run of several years, because of the high energy efficiency, low repair cost and longevity of LEDs. In this scope, evaluate LEDs as a true alternative to current lighting sources, species specific plant response to different wavelengths and photons are discussed in a comparative research. In addition that, more detailed scientific researches are necessary to understand the effect of different LED spectrum on plants physiology. Technological developments are required to design and realize an energy efficient plant grow lighting source with a photon and spectra made for ideal plant growth in definite plant kinds.

Advantages of LED(Light emitting diode) technology;

- Physical shocks and shocks are resistant.
- They are trustworthy. Long life span (100,000 hours).
- Due to their low power energy consumption, they are no alternative for solar powered (solar) circuits and mobile applications.
- Provides high efficiency lighting.
- Very low temperature and low light pollution.
- They do not generate Electromagnetic Interference and Noise (HUM).
- Both indoor and outdoor can be used.
- Resistant to moisture and water.
- In the long run there are cheaper energy consumption costs.
- They are single or multiple colors can be used together.
- They have high lighting brightness and high lighting contrast.
- Low Power Consumption, and low heat dissipation.
- Easy to install features.

- They average 1/10 power consumption compared to traditional fluorescent lamp.
- They do not need repair.
- Small size and light weight.
- LEDs are more durable than ordinary electric lighting bulbs because they do not have filaments.

The light specially required by plants for effective photosynthesis involves the red and blue wave lengths. However, the lighting products used for plants are generally conventional artificial lighting sources such as fluorescent, mercury or sodium vapor, which produce light in the yellow and green range of the other white light components, as well as in the infrared and ultraviolet regions. These technologies, which consume much more energy than LED technology in particular, do not have to be regarded as product-oriented structures because they produce light spectra that are unnecessary for plants.

Discharge lamps developed with the purpose of growing plants today; they are far from being energy-efficient light sources in the sense of photosynthesis, albeit expanded with chemicals and gases in addition to light spectra. Many advantages such as the low energy consumption, the adjustment of the target wavelength and the presence of the long life bulbs, which LED technology has brought particularly proved, make this technology much more suitable for plant breeding. The ability to determine plant specific wavelengths allows the adjustment of the appropriate wavelength for each different plant species; making it possible to operate the photosynthesis process with maximum efficiency.

CHAPTER 4: SMART GARDEN: HYDROPONIC SYSTEMS DEVELOPED WITH INDUSTRY 4.0 AND LED TECHNOLOGY PROJECT

There were 2 billion people in the world in 1920 and 4 billion in 1970. Today, there are 7.5 million people in the world. Climate change caused by global warming is affecting agricultural activities negatively. In our country this change is observed in some important agricultural areas, reaching 40-50% of product losses. In addition to these factors, arable land is decreasing as a result of unconscious use of existing agricultural areas. As the need for food grows, resources do not increase at the same rate. It is expected that all these factors will cause global water and food crisis around 2050.

The Smart Garden project is an aeroponic and hydroponic production facility powered by the concept of Internet-of-Things (IoT) technology and LED technology that works with maximum efficiency in minimum space. In this scope it has been studied on the lighting system, the climate control, the soilless agriculture and the IoT innovations of Industry 4.0. A chamber is constructed with a climate control unit and a lighting system composed of five different LED chips. The chamber is also equipped with hydroponic and aeroponic systems.

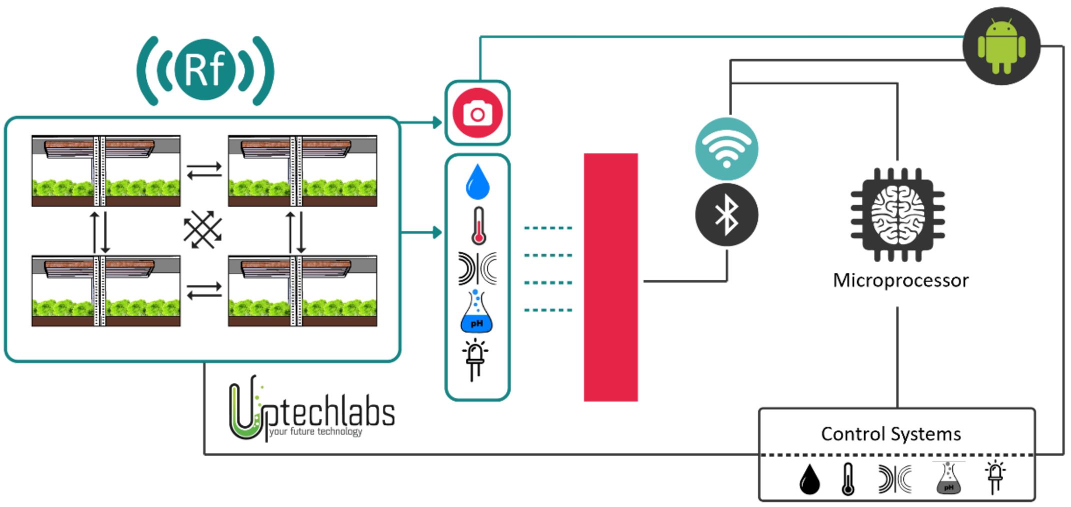

Figure 4.1. System Diagram

The aim is to develop the most efficient production scheme in at least one of the systems. Several various sensors, equipments are used and the necessary software has been developed on the system. It also has a remote control app on a smart phone-tablet. While each block in the system communicates with each other via RF technology, it is aimed to transfer all the data to the main control server and then store the data in the database, and publish it onto the internet environment for selective users. The plant lighting technology is an important issue in this development. There is data on soilless agriculture; but there is not much data about vegetative lighting, and some information is obtained by foreign companies in the form of trade secrets. In the developed system, different feeding strategies will be tried under specific light wavelengths, different light intensities and controlled environmental conditions.

With the developed LED lighting system, it is possible to grow 2.5 times faster than normal; with less than 95% water usage with aeroponic system; with the modular system, the unit provides 30 times more product possibilities; production of the electricity required by the system with solar panels planned to be added; and it is planned to develop a facility that produces maximum efficiency in all seasons with climate control. It is expected that it will be easy to use with the control system developed with user base while doing all these. It is clear that the developed system is at least 30 times more productive when compared to the normal agriculture.

In this scope, with a TUBITAK 1512 Support Program on a 20 m2 area with a budget of 150.000 TL , a laboratory was founded at Izmir University of Economics for grow lighting researches.

Figure 4.2. Smart garden plant growing cabin in IEU

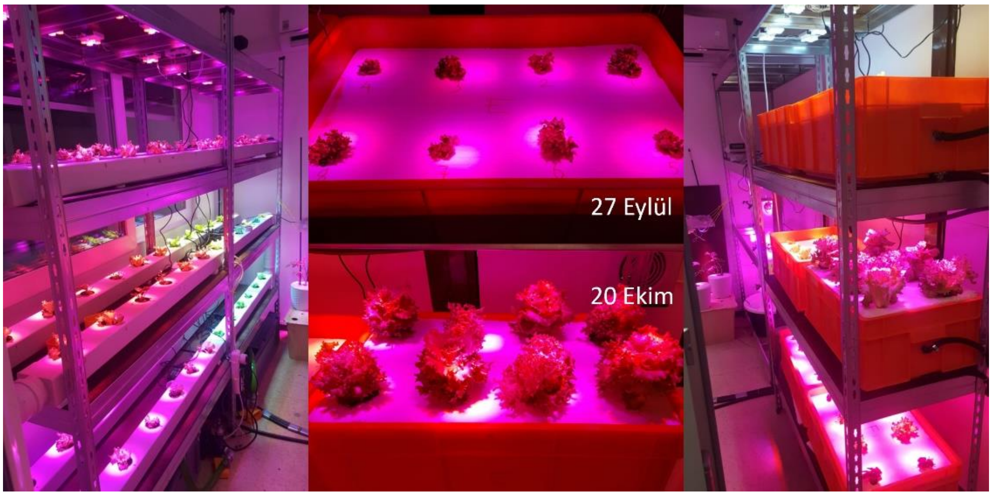

Figure 4.3. Smart garden plant growing cabin

Figure 4.4. Lettuce trials with Kratky method

From this perspective, Lighting optimizations were started on plants with different photon and spectrum values. In this scope, photon and spectrum lighting combination have affected healthy grown.

Table 1. Growth values of plants with different photon and spectrum values

#ID	**1**	**2**	**11**	**12**	**13**	**5**	**15**
DIAMETER	32cm	39cm	32cm	39cm	30cm	27cm	29cm
ROOT LENGTH	40cm	68cm	59cm	41cm	45cm	60cm	51cm
LEAF LENGTH	22cm	20cm	20cm	20cm	18cm	18cm	18cm
WEIGHT	124gr	323gr	245gr	85gr	73gr	104gr	68gr
FOOD CONSUMPTION	1,78 liter	2,79 liter	2,24 liter	1,89 liter	1,74 liter	1,8 liter	1,56 liter

Figure 4.5. Lettuce trials with kratky method

In 2019, with a TUBITAK 1507 Support Program on a 200 m2 area with a budget of 574.079 TL, a laboratory was founded at ITOB for grow lighting researches.

Figure 4.6. Smart Garden Facility Design

There are a total of 35 shelf systems in the laboratory. Hydroponic plant development environment was provided in 14 shelves. It has 8 pieces 3-storey and 5 pieces 2-storey shelving systems and has a total capacity of 300 plants. In addition that, Aeroponic plant development environment was provided in 13 shelves. It has 6 pieces 3-storey, 4 pieces 2-storey and 3 pieces 1-storey shelving systems and has a total capacity of 260 plants and also, 8 pieces 3-storey shelving systems are used for seed-seedling research.

Figure 4.7. Smart Garden Facility

Figure 4.8. Smart Garden Facility

Figure 4.9. Smart Garden Facility

Figure 4.10. Sample plant growth images

In this case, 34 different designs were developed and each design has got 16.000.000 different grown possibilities. Different Photosynthetic Photon Flux Density (PPFD) and spectrum lighting combination have affected on crops' taste and healthy grown.

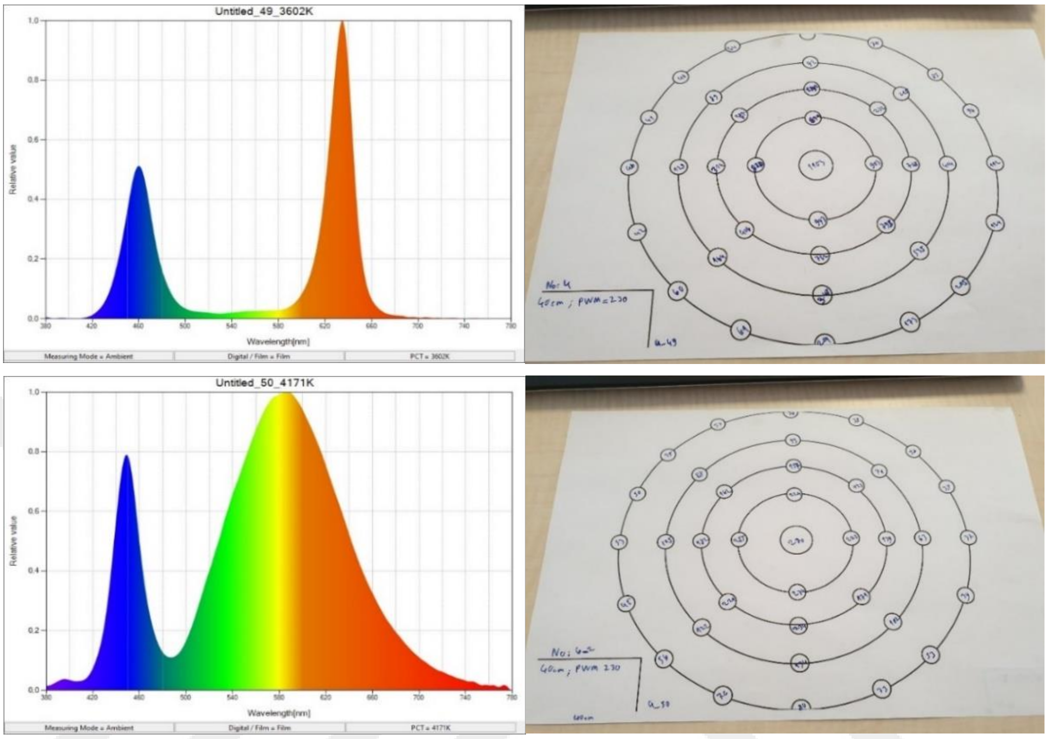

Figure 4.11. Sample Spectrum and PPFD Values

Figure 4.12. Rose, Calendula officinalis, Chrysanthemum

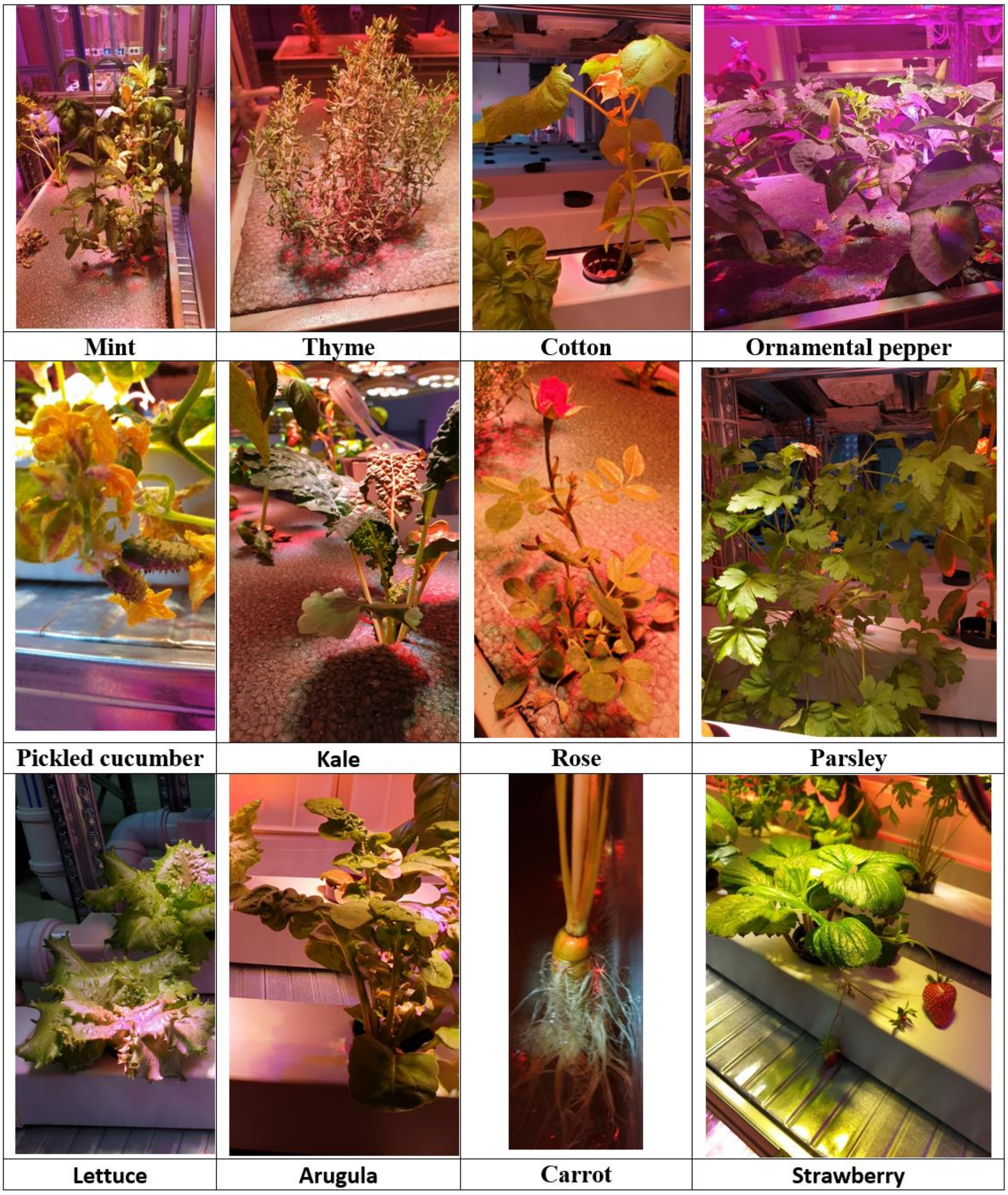

Figure 4.13. Image of growing plant varieties

We research to growth optimization in plants such as mint, thyme, ornamental pepper, cotton, pickled cucumber, carrot, rose, parsley, lettuce, arugula, strawberry, kale, basil, tomato, potato, melon, watermelon, cress, green pepper, cabbage, kidney beans, beans, chickpeas, okra, broad beans, purslane, cloves and sunflower.

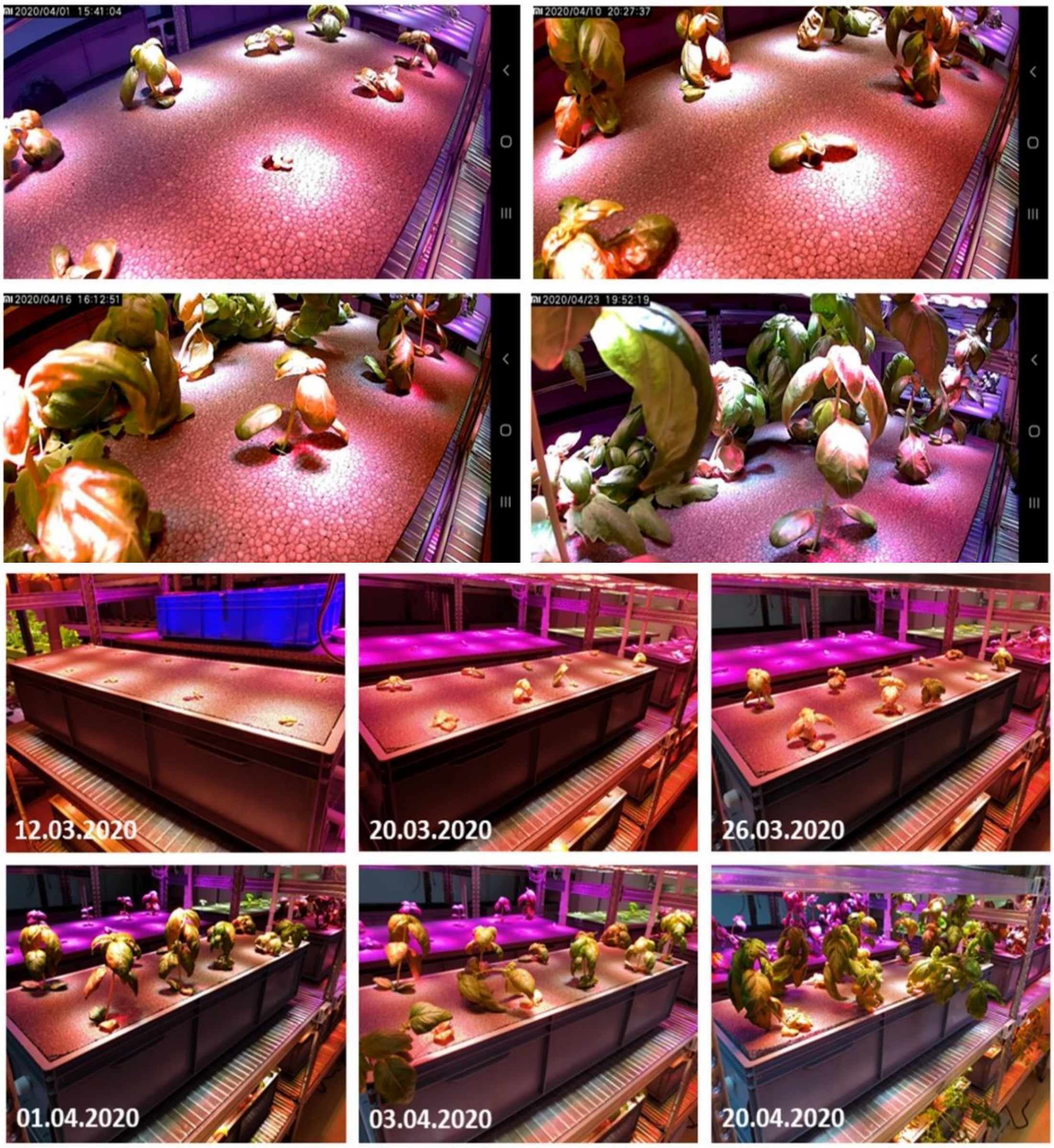

Figure 4.14. Growth stages of Basil

Light optimizations for Genoese, Italian and lemon flavored basil are continue.

The aeroponics system the most effective for root growing and less water usage in Soilless Cultures. However it is the most expensive and it needs regular nozzle repair for healthy working.

Figure 4.15. Growth stages of Calendula officinalis

Figure 4.16. Growth stages of Ornamental Pepper

Figure 4.17. Ornamental Pepper Roots

CHAPTER 5: CONCLUSION

Plant growths were observed with unique lighting units designed for plants. Each lighting units has got different growing algorithm for plants. Developed algorithm code consists of 189 lines.

As a result of our research, growth optimizations were realized in lettuce, arugula, cress, basil, mint, ornamental pepper, strawberry, kale, beans, calendula officinalis and cherry tomato. Pesticides were not used in plant production.

34 different designs were developed and each design has got 16.000.000 different grown possibilities. The plant growth was achieved with the use of aeroponic system 95%, hydroponic system 60% less water than normal agriculture. Plant growth periods accelerated approximately 2 times compared to normal agriculture.

REFERENCES

Powerhousehydroponics: (2018). *Advantages-of-soilless-agriculture*. [Online]. Available at https://www.powerhousehydroponics.com/advantages-of-soilless-agriculture/. (Accessed: 16 November 2019).

Bansal, G. (2020). *Soilless farmin hydroponic crop cultivation*. [Online]. Available at http://www.soilless.org/hydroponics/soilless-farming-hydroponic-crop-cultivation/ (Accessed: 29 January 2020).

Lightning.philips. (2018). Retrieved from lightning.philips: [Online]. Available at https://www.lighting.philips.com/main/products/horticulture/vegetables-and-fruits#vegetable s_and_fruits(Accessed: 27 January 2019).

Plantozoid. (2019). *Indoor growing* [Online]. Available at http://plantozoid.com/category/indoor-growing/(Accessed: 1 January 2020).

Van Os, E., Lieth, J. H. (2007). *Technical Equipment in Soilless Production Systems. In Soilless Culture.* Journal of Soilless Culture vol 5, no.5, pp 158-161.

[Wikipedia]. (2018, March 2). *Aeroponics* [Wiki Article]. Available at: https://en.wikipedia.org/wiki/Aeroponics

[Sproutingfarms]. (2019, November 5). Hydroponics Cultures [Web-based Figure] Available at: https://www.sproutingfarms.org/blog/archives/11-2019

P. A. Putra, H. Yuliando (2015) *Soilless Culture System to Support Water Use Efficiency and Product Quality*, Indonesia: Agriculture and Agricultural Science Procedia 3, pp. 285. [Online]. Available at https://core.ac.uk/reader/82084740 (Accessed 1 June 2020)