

**An-Najah National University**  
**Faculty of Graduate Studies**

**Water and Fertilizers' use Efficiency of Soilless  
Lettuce Plants Grown Under Different Conditions**

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## **Dedication**

I dedicate this work to

My mother soul,

To the person who has been with me since the first breath, the first laugh,  
the first word, and the first step in my life, for my dear father.

To my dear husband "Mohammed" and my children "Zaid, Deema, and  
Shahad", whose support, encouragement and love made this endeavor  
possible.

To the people who gave me all the support, courage, and standing by my  
side no matter what, I walk all the way to achieve all my dreams for my  
family, my husband's family, brothers, and sisters.

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and we had a great time together.

To my professors who taught me in school and university.

Finally, to every one of my relatives.

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I have no valuable words to express my thanks, but my heart is still full of the favors received from every person.

أنا الموقعة أدناه، مقدّمة الرسالة التي تحمل العنوان:

**Water and fertilizers' use efficiency of Soilless lettuce plants grown  
under different conditions**

أقر بأن ما اشتملت عليه هذه الأطروحة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد. وأن هذه الرسالة كاملة، أو أي جزء منها لم يقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

**Declaration**

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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## List of Abbreviations

<b>ANOVA</b>	Analysis of variance.
<b>Ca</b>	Calcium.
<b>°C</b>	Celsius.
<b>Cm</b>	Centimetre.
<b>DFT</b>	Deep flow technique.
<b>DW</b>	Distilled Water.
<b>EC</b>	Electrical Conductivity.
<b>F</b>	Repeated ANOVA measures.
<b>FUE</b>	Fertilizer use efficiency.
<b>G</b>	Gram.
<b>G/L</b>	Gram Per Litre.
<b>K</b>	Potassium.
<b>KG</b>	Kilogram.
<b>Lcd</b>	liters per capita per day.
<b>MI</b>	Milli liter.
<b>N</b>	Nitrogen.
<b>N</b>	Number.
<b>NARC</b>	National Agriculture Research Center.
<b>NFT</b>	Nutrient Flow Technique.
<b>NRW</b>	Non-Revenue Water.
<b>P</b>	Phosphorus.
<b>PWA</b>	Palestinian Water Authority.
<b>RDI</b>	Responsive Drip Irrigation.
<b>SD</b>	Standard Deviation.
<b>SPSS</b>	Statistical Package for the Social Sciences.
<b>T</b>	t-test.
<b>WB</b>	West Bank.
<b>WHO</b>	World Health Organization.
<b>WUE</b>	Water use efficiency.
<b><math>\chi^2</math></b>	Chi-Square Test.

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**Abstract**

**Background:** The Soilless Agricultural is an example of a hydroponic system that provides plants with nutrients and water. This system is highly productive and can address the shortage of land and water concerning the growing demand for food production. Lettuce is one of the best crops for soilless systems because it can be produced in a short period.

**Aim:** The study aims to evaluate biomass, water and fertilizer use efficiency of soilless lettuce grown under two irrigation systems (surface irrigation and responsive drip irrigation (RDI)).

**Method:** An experimental research design was conducted between June to November 2020. Two hundred lettuce seedlings were grown on two irrigation systems "100 on surface irrigation systems and 100 on RDI". 6 channels of lettuce plants "3 surface irrigation and 3 RDI" were selected randomly. Seedlings were inserted into the Nutrient Film Technique channel with 30 cm between each plant and 30 cm apart the channels. Several chemical analyses were performed for media and plant analysis.

**Results:** The study findings showed that the total number of lettuce plants harvested from the RDI system is 90 out of 100 plants, while 66 out

of 100 plants were harvested from the surface irrigation system. The RDI system had lower water consumption and higher productivity than the surface irrigation system. Additionally, the amount of water use efficiency in the RDI system was elevated statistically significant than the surface irrigation system. Fertilizer use efficiency was increased in the RDI system compared to the surface irrigation system.

**Conclusion:** There are statistically significant media trends for Ca, K, P, N, pH and EC levels before, during, and after the growing of the lettuce plants for both irrigation systems. Also, there are statistically significant differences in leaf lettuce plant Ca, K, P and N levels before, during, and after lettuce plants were grown in both irrigation systems. The RDI system had a lower water consumption than the surface irrigation system. The RDI system's productivity was higher than that for surface irrigation system. In the same way, the productivity/plant ratio showed that the RDI system had a higher productivity/plant ratio than a surface irrigation system. Additionally, the amount of water use efficiency in RDI system was elevated statistically significantly than the surface irrigation system. Finally, fertilizer use efficiency was higher in the RDI system than the surface irrigation system.

**Key words:** Water use efficiency, fertilizers' use efficiency, Soilless, lettuce plants, responsive drip irrigation " RDI", and surface irrigation.

# Chapter One

## Introduction

### 1.1. Research overview

The Palestinian population has multiplied over the last 40 years. World population review estimated that population growth in Palestine is about 2.4% per year during 2020, indicating an increase in the demand for water and food (GeoNames, 2020).

World Data Atlas estimated that the urban population makes up 76.4% of the country's total population during 2019 in Palestine, and this percentage is still increasing, with growing numbers using more water-consuming household equipment (showers, bathrooms, washing machines) (World Data Atlas, 2020).

The Palestinian territories are affected by climatic conditions. Most parts are classified as arid and semi-arid areas. Palestine is allocated less than 25 cubic meters of water for domestic and industrial purposes annually. This means that Palestinians immediately need an additional 70 million cubic meters of water per year to bring the domestic consumption per capita to 50 cubic meter per year, which is the minimum requirement for basic water needs (Isaac & Sabbah, 2015).

Global climatic trends demonstrate that water scarcity is expected to exacerbate, resulting in an adverse impact on cereal crop production in the MENA region, which suffers from the highest food deficits among all

world regions. Global climatic projections indicate that cereal crop countries even by up to 80% (Fakhrul & Karim, 2019).

Water conservation and efficient water use can significantly improve local farming systems. An effective alternative suggested by local communities and governments is soilless in the small greenhouse that reduces the need for water. Water-efficient technologies could help communities to optimize the use of limited water resources (FAO, 2017).

Conventional agricultural practices can cause a wide range of negative impacts on the environment. “Conventional” or “modern industrial agriculture” has been historically defined as the practice of growing crops in soil, in the open air, with irrigation, and the active application of nutrients, pesticides, and herbicide (Barbosa, et al., 2015).

Some of the negative impacts of conventional agriculture include the high and inefficient use of water, large land requirements, high concentrations of nutrients and pesticides in the runoff, and soil degradation accompanied by erosion (AlShrouf, 2017).

Alternative food production systems that require limited land, soil, and water, which can be developed in urban areas, may significantly play a major role in future agriculture. Hydroponics is a method of growing plants without soil. Various commercial and specialty crops can be produced using hydroponics, including tomatoes, cucumbers, peppers, eggplants, strawberries, and many more. Leafy vegetables, such as lettuce, can also be grown hydroponically (Medina, Jayachandran, Bhat, & Deoraj, 2015).

Several different hydroponic systems have been developed and were commercially successful for crop production developed (Kaiser & Ernst, 2016).

The Soilless Agriculture is an example of a hydroponic system that provides plants with nutrients and water. This system is highly productive and can address the shortage of land and water concerning the growing demand for food production (Mou, 2008).

Soilless agriculture leads to faster growth, extreme decrease in water and nutrient use. Hydroponics typically uses at least 90% less water than soil-based methods. So much of the water and nutrients are wasted on traditional outdoor soil farms because only a small portion of it makes it to the roots, and the rest ends up in the local water supply (French & Roth, 2019).

A Liquid-medium system is a type of soilless agriculture and is differentiated from solid-medium systems through operation. Liquid systems are generally closed circuits, and the nutrient solution is recirculated from a supply reservoir either continuously or intermittently for days or weeks. The standard liquid systems in use today are nutrient-flow technique (NFT) and gravel-bed culture (Barbosa, et al., 2015).

The NFT growing system consists of a series of narrow channels through which nutrient solution is recirculated from a supply tank. A plumbing plastic tubing system and a submersible pump in the tank are basic components. The channels are generally constructed of plastic pipes.

The NFT system could also be filled with soilless medium and surface drip irrigation is used for irrigation of plants in the channels. Another technique that could be operated intermittently by supplying water for the plant a few minutes every hour or all day by a system called responsive drip irrigation (RDI). RDI is one of the new techniques that increase the efficiency of irrigation water (Johnson, 2016).

Some African countries reduce water irrigation by 50% when using the RDI system. In Pakistan, the researchers that work closely with the National Agriculture Research Center (NARC) increase the yield of leafy crops and decrease energy consumption (RDI. LLC, 2020).

Compared to RDI to standard drip systems, RDI tomatoes are notably healthier 81% of the plants flowering than just 23% for standard drip (RDI. LLC, 2020).

Nutrient and water use efficiency in soilless agriculture is important. It is widely known that the productivity and quality of crops are markedly dependent on the irrigation water's extended plant nutrients acquisition from the growing medium (Valentinuzzi, et al., 2015).

Lettuce is one of the best crops for soilless systems because it can be produced in a shorter period. Unlike tomato and cucumber, a high proportion of the harvested biomass is edible. With lettuce, income per unit area is very high (Khater & Ali, 2015).

Soilless systems offered 11 times higher lettuce yields compared to conventionally produced lettuce (Barbosa, et al., 2015).

Growing medium has shown high effects on dry matter content in lettuce grown in soilless farming (Mastouri, Hassandokht, & Dehkaei, 2005).

This study focusses on hydroponics in the West Bank and determines the effectiveness of this system by evaluating the its advantages and disadvantages, as it aims to compare between two irrigation systems (surface irrigation and responsive drip irrigation).

The Palestinian society suffers from an increase in the population. This increase leads to an increase in the demand on natural resources and thus leads to the depletion and consumption of these resources.

Also, the Palestinian society in west bank suffers from several problems, which are: high unemployment among members of society, high incidence of diseases due to chemical pesticides that are sprayed on crops, high prices of crops, scarcity of agricultural areas and the confiscation of part of this land by the Israeli occupation, and a significant deterioration in natural resources, specifically in water, where the West Bank suffers from great scarcity and a shortage of water. Therefore, hydroponics may alleviate or reduce these problems.

In this study, the researcher will shed light on hydroponics, which will lead to raising the efficiency in the use of water and preventing its depletion, as the water is consumed by the roots only and there is no wastage of water, which leads to saving large quantities of water. It may also contribute to raising the efficiency in the use of fertilizers, as only the needs of the plant are consumed. Also, this type of agriculture is a solution to many soil problems, where the soil is sometimes unsuitable for agriculture or full of weeds, fungal germs, harmful heavy elements and other problems.

Because of all that has been mentioned, the researcher decided to conduct a study about hydroponics and hopes to reach good results and make recommendations for decision makers to solve these problems and develops the field of agriculture.

## **1.2. Research questions**

**The main questions of this study are:**

- What is the efficiency of using biomass, water, and fertilizer of soilless lettuce grown under two irrigation systems (surface irrigation and responsive drip irrigation)?
- What is the productivity of yield biomass under two drip irrigation systems (surface irrigation and responsive drip irrigation)?

### **1.3. Research Significant**

The study's importance lies in its being one of the most important studies that interested in hydroponics -from the researcher's point of view- in Palestine.

Hence, it could open new horizons for further studies and a new comparison between other agriculture systems.

It will also provide officials with the most critical problems and obstacles facing hydroponics in the West Bank, urge them to consider these problems and challenges, and find solutions to increase productivity, effectiveness, and advancement in the agriculture field.

This study's results may contribute to solving some of the economic and social problems of community members, such as unemployment.

The study can help decision-makers amend the current agriculture system of work and change it to suit the situation of farmers and their needs. The researcher hopes that the results will help solve many obstacles facing hydroponics.

### **1.4. Research Hypothesis**

**The research hypothesis will be tested analyzed by static analysis:**

- There is no effect of using biomass, water, and fertilizer of soilless lettuce grown under two irrigation systems at the level  $\leq 0.05$ .

- There is no significant difference in yield biomass productivity under two drip irrigation systems at the level  $\leq 0.05$ .

### **1.5. Objectives**

The study's general objective is to evaluate the biomass, water and fertilizer use efficiency of soilless lettuce grown under two irrigation systems (surface irrigation and responsive drip irrigation).

The specific objectives of the study are:

1. To measure the productivity of yield's biomass under two drip irrigation systems. (surface irrigation and responsive drip irrigation)
2. To identify the amount of water and fertilizers used in two drip irrigation systems. (surface irrigation and responsive drip irrigation).

## **Chapter Two**

### **Literature Review**

#### **2.1. Study definitions**

**Hydroponics:** This is a method of growing crops without soil, and as such these systems are being added to components of aquaculture to create aquaponics systems. Hydroponic development thus, along with the recirculating aquaculture system (RAS), forms a crucial part of the aquaponics system. While developing aquaponics systems, some different proven hydroponic techniques can be used. That depends on the environmental and financial conditions, the type of crop being grown, and the space available (Goddek, Joyce, Kotzen, & Burnell, 2019).

**Soiless:** It is the cultivation of plants in agricultural environments where the soil is not one of its components, and it is fed by using special nutrient solutions that contain the nutrients necessary for plant growth (Al Rawahi, Shamrid, & Salem, 2013).

#### **2.2. Palestinian agriculture situation**

The agricultural sector is one of the most important and oldest Palestinian economic sectors and one of the foundations of Palestinian steadfastness in the face of the Israeli occupation. Therefore, this sector falls within the circle of permanent targeting of the occupation authorities, which caused this sector many losses. Its contribution to the Palestinian economy has declined, as the number of the workforce in this has

decreased. The sector, which witnessed low wages, and a decrease in the percentage of its contribution to gross domestic product (PECDAR, 2020).

According to the Palestinian Central Bureau of Statistics report "The Performance of the Palestinian Economy, 2018" issued in May 2019, the number of workers in the agricultural sector in the year 2018 was about 51,500, of whom 37,000 were from the West Bank and 14,500 from the Gaza Strip, while the number of workers in the agricultural sector in 2013 was about 82,700 of them, 59,900 from the West Bank and 22,800 from the Gaza Strip, (PCBS, 2019).

It is noticeable that the number of workers in the Palestinian agricultural sector is in a state of permanent decline, whether in the West Bank or the Gaza Strip, and this is what the above table shows. Perhaps the reason for this is due to:

- Low average daily wage: According to the PCBS, the real average daily salary in the agricultural sector in 2018 was about 47.0 shekels, an average of 73.1 shekels for a worker in the West Bank and 21.1 shekels for a worker in Gaza Strip. This shows the low wages in the agricultural sector and in particular, in the Gaza Strip.

- Low contribution to gross domestic product (GDP): According to PCBS, the contribution of agricultural activities to the GDP was 4.8% in the Gaza Strip compared to 2.6% in the West Bank, which is a low percentage compared to other sectors, especially the services sector and the trade sector. Note that the agricultural sector's contribution to the GDP

reached about 36% in the mid-seventies, then decreased to 25% in the eighties, and in 1994 it was revised to 13.4%. This percentage continued to decline until it reached 3% in 2018. (PCBS, 2019).

It is well known that the Palestinian agricultural sector suffers from challenges related to Israeli occupation practices and its settlers. Such as confiscation of land, building the apartheid wall, construction of bypass roads, stealing Palestinian water, preventing the import of many medicines and fertilizers, impeding the export of crops, and flooding Palestinian markets with Israeli goods; to hit the Palestinian agricultural, animal and vegetable production (PECDAR, 2020).

### **The most important problems relevant to water sector in Palestine:**

Palestine is experiencing a severe water crisis caused mainly by the lack of control over the Palestinian water resources. At present the average per capita water consumption by the Palestinian population is approximately 55 l/c/d, or 55% of the WHO minimum standard of 100 l/c/d. The communal water supply for the Palestinian population is substantially inadequate by international standards (Abu Zahra, 2001).

The available water resources in the Middle East are scarce, limited, fragile and threatened. They are already exploited, especially in Palestine. The water resources in the countries of the sub-region (the Jordan River Basin) are limited in absolute terms; the average per capita availability is extremely low (Abu Zahra, 2001).

A large proportion of the water resources in the Middle East in general, and in Palestine as particular, are transboundary and final arrangements on water resources allocation between Palestinians and Israelis are not yet in place for “fair and equitable apportionment” (Abu Zahra, 2001).

Average per capita availability in the countries of the Jordan River Basin is about 455 m<sup>3</sup>, which is low compared with other regions, as for example 3283 m<sup>3</sup> in Asia, 5184 m<sup>3</sup> in Western Europe or 18,742 in North America. The average per capita availability in Palestine, which is 105 m<sup>3</sup>d, the lowest in the world (Abu Zahra, 2001).

Palestinian territories face significant and growing shortfalls in the water supply available for domestic use. The World Health Organization (WHO) considers 100 liters per capita per day (lcd) as the benchmark minimum for domestic consumption to achieve full health and hygiene benefits while the Palestinian Water Authority (PWA) has set a target of 120–150 lcd for its population (World Bank Group’s, 2014).

In contrast, available water resources (supplied minus the nonrevenue water [NRW]) for domestic consumption in West Bank is only 62 lcd (World Bank Group’s, 2014).

In sum, in both the West Bank and Gaza there are grave water resource and supply problems. However, in the West Bank the problems are essentially a product of water sector dependency, in Gaza they are, at least in part, a product of water sector ‘independence’ – albeit within an

overall political context of Israeli encirclement and internal economic de-development (Barakat & Heacock, 2013).

In summary, the acute water problems facing Palestinians in both Gaza and the West Bank have grown more critical over time (Barakat & Heacock, 2013).

In the West Bank, acute water shortages are in large part the result of Israel's continued unilateral control over the trans-boundary water resources, and the limited water allocations Palestinians receive (Barakat & Heacock, 2013).

In the Gaza Strip, over abstraction of the underlying portion of the Coastal Aquifer on which Palestinians are forced to rely has led to a rapid deterioration in water quality due to saline intrusion, and the infiltration of raw or partially treated sewage (Barakat & Heacock, 2013).

### **2 .3. Hydroponics situation in Palestine**

Hydroponics is very recent in Palestine, where it appeared as a marketing product at the beginning of 2016 in Beit Lahia, Gaza. After several months, it was present in the town of Ya'bad in the West Bank and then began to appear in the rest of the other areas in a limited way (Wafa Agency, 2020).

Hydroponics is one of the modern, effective agriculture systems based on; grow crops in water without soil; and some nutrients in varying quantities in addition to sunlight to produce more quality and less

expensive vegetables and fruits in small and limited areas. It is an attempt to invest in some places in the absence of arable soil, such as the roofs of houses in cities, or if the soil cannot be used due to its high salinity, as in regions desert (WAFSA Agency, 2020).

Hydroponics is distinguished from traditional agriculture with soil. It saves more than 80% of water, and it also reduces the use of chemical pesticides by more than 90%, meaning it is environmentally friendly. And the production inputs are less than traditional agriculture with soil, besides, it has high economic feasibility, as its production reaches 5 to 10 times the conventional agriculture (WAFSA Agency, 2020).

The crop of lettuce, strawberries, and some medicinal plants such as mint is at the forefront of crops that the Palestinians grow in some of their hydroponic farms (WAFSA Agency, 2020).

The future of hydroponics is promising in Palestine, in light of the scarcity of water and the lands dominated by the Israeli occupation, and in the light of the temperature variation, and the low amount of rain in recent years, some the hydroponic farms have begun to achieve success, and this is consistent with the general tendency of the Palestinian decision- makers to provide food security to the Palestinians, achieve economic independence and get rid of the dependency on the Israeli economy (WAFSA Agency, 2020).

## 2.4. Components of the hydroponics system

A few components are needed to make hydroponics work efficiently to maintain a working hydroponic system.

### - **Growing media:**

Hydroponic plants are mostly grown in inert media that support the plant's weight and anchor the root structure. Rising media is the soil replacement but does not provide the plant with any individual nutrition. Alternatively, this porous media absorbs nutrients and moisture from the nutrient solution it provides to the plant. So many growing media are pH-neutral, so they won't disturb the balance of the nutrient solution. There are various media to choose from, and the particular plant and hydroponic system can decide which media best matches your endeavor (Woodard, 2019).

### - **Air stones and air pumps:**

Plants submerged in water will drown quickly if they are not aerated enough. Air stones scatter tiny bubbles of dissolved oxygen through a pool of nutrient solutions. These bubbles also help in spreading the dissolved nutrients in the solution evenly. Air stones do not contain oxygen by themselves. They must be connected through opaque food grade plastic tubing to an external air pump (the opacity will prevent algae's growth from settling in) (Woodard, 2019).

- **Net pots:**

Net pots are mesh planters that house plants in hydroponic form. The latticed material allows roots to grow out of the plant's sides and bottom, providing increased oxygen and nutrient exposure. Compared with conventional clay or plastic pots, net pots often have superior drainage (Woodard, 2019).

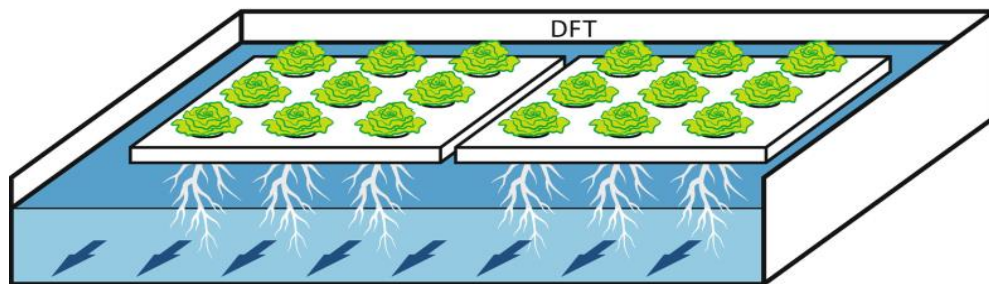
## **2.5. Types of hydroponics systems according to water/ nutrient distribution**

- **Deep Flow Technique (DFT):**

Deep flow technique (DFT), also known as deep water technique, is the production of plants on floating or hanging support (rafts, panels, boards) in containers filled with 10–20 cm nutrient solution; see Figure (1). In AP this can be up to 30 cm. Numerous modes of performance can be differentiated primarily by the solution's depth, volume and the recirculation and oxygenation methods (Goddek, Joyce, Kotzen, & Burnell, 2019).

One of the most manageable systems consists of 20–30 cm deep tanks, which can be made from various materials and waterproofed with polyethylene films. The tanks are fitted with floating rafts (multiple types are available from suppliers) which serve to support the plants above the water while the plants' roots penetrate the water. The system is particularly important because it minimizes costs and management. For example, there

is a limited need for automation of the control, and correction of the nutrient solution, especially in short-lived crops such as lettuce, where the relatively high volume of solution facilitates the replenishment of the nutrient solution, only at the end of each cycle, and only the oxygen content needs to be regularly monitored. Oxygen rates should be above 4–5 mg L<sup>-1</sup>; otherwise, nutrient deficiencies may occur due to poor performance uptake of root systems. The solution's circulation will usually add oxygen, or Venturi systems can be added that significantly increase air into the system. This is particularly important when water temperatures are greater than 23 °C, as these high temperatures will stimulate lettuce bolting (Goddek, Joyce, Kotzen, & Burnell, 2019).

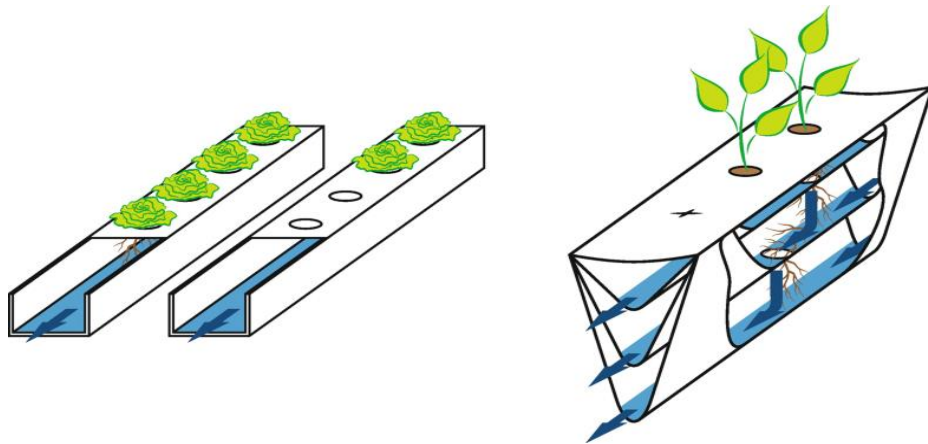


**Figure (1):** Illustration of a DFT system with floating panels. **Source:** (Goddek, Joyce, Kotzen, & Burnell, 2019).

#### - **Nutrient Film Technique (NFT):**

The NFT technique is used ubiquitously and can be considered the classic hydroponic cultivation system, where a nutrient solution flows along and circulates in a 1–2 cm layer of water, see Figure (2). A significant benefit of the NFT system is the nutrient solution's recirculation and the lack of substratum. Another benefit is its strong potential for

automation to save on labor costs (planting & harvesting) and the opportunity to manage the optimal plant density throughout the crop cycle. On the other side, the shortage of substrate and low water levels makes the NFT susceptible to pumps failure, e.g. clogging or power supply failure. Fluctuations in the nutrient solution's temperature cause plant stress followed by diseases (Goddek, Joyce, Kotzen, & Burnell, 2019).



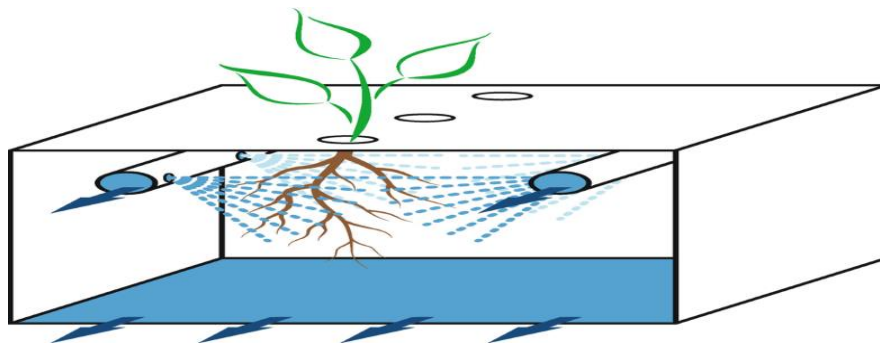
**Figure (2):** Illustration of NFT system (left) and a multilayer NFT trough (right). Source: (Goddek, Joyce, Kotzen, & Burnell, 2019).

The development of the root system, part of which remained suspended in the air above the nutrient flow and subjected to an early aging and functionality loss represents a significant restriction as it inhibits long-cycle crop production (over 4–5 months). This system is not appropriate for cultivation environments characterized by elevated irradiation levels and temperature (e.g., southern Mediterranean basin areas) because of its high susceptibility to temperature variations. However, in response to these challenges, a multilayer NFT trough has been designed, which allows for longer production cycles without clogging problems (NGS). It consists of

several interconnected layers arranged in a cascade so that even in healthy rooting plant species, e.g., tomatoes, the nutrient solution will still find its way to the roots by bypassing the root-clogged layer via a lower positioned layer (Goddek, Joyce, Kotzen, & Burnell, 2019).

- **Aeroponic Systems:**

The aeroponic technique is primarily designed for smaller horticultural plants. It has not yet been commonly adopted due to the high investment, production, and management cost. Plastic panels or polystyrene support the plants; they are placed horizontally or on inclined tops of growing boxes. These panels are supported by a structure constructed of inert materials (plastic, plastic-coated steel, polystyrene boards) to form closed boxes in which the suspended root system can develop, see Figure (3) (Goddek, Joyce, Kotzen, & Burnell, 2019).



**Figure (3):** Illustration of the aeroponics technique. Source: (Goddek, Joyce, Kotzen, & Burnell, 2019).

The nutrient solution is sprayed directly on the roots that are suspended in the box in the air, with static sprinklers (sprayers), inserted on pipes housed inside the box module. The spray duration ranges from 30 to

60 s, whereas the frequency differs depending on the species, the time of day, the cultivation period, and the plants' growth stage. Some systems use vibrating plates to produce microdroplets of water, which create steam that condenses on the roots. The leachate is collected on the bottom of the box modules and conveyed to the storage tank for reuse (Goddek, Joyce, Kotzen, & Burnell, 2019).

## 2.6. Plants that can be grown

Table (1) displays the most common varieties of plants that can be grown by the hydroponic system around the world.

**Table (1): Plants that can be grown using a hydroponics system.**

1. Eggplant	2. Cucumber	3. Red pepper
4. Courgetti	5. Tomato	6. Green pepper
7. Onion	8. Peas	9. Spinach
10. Arugula	11. Garlic	12. Strawberries
13. Parsley	14. Cherry tomato	15. Mung bean
16. Cabbage	17. Lettuce	18. Bean
19. Okra		

## 2.7. Advantages and disadvantages of hydroponics

In the last 30 years, we've noticed the fast growth of hydroponic systems, which may be attributed to their independence from the soil and other related problems, for example, the existence of soil-borne pathogens at the beginning of the crop, and the decrease of soil structure and fertility, caused by the constant cultivation for the same or relevant crop types. The safest and most effective alternative for these problems is soilless agriculture. It comes to solve soil diseases utilizing methyl bromide. This

solution becomes the most important way in protected cultivation, not only in modern glasshouses but also in traditional greenhouses that are constructed for favorable climatic conditions.

These are the advantages of hydroponic systems:

1. Getting rid of soil-borne pathogens.
2. Safe substitution to soil disinfection.
3. Possibility to produce high amounts of crops with good quality even in non-arable soils with poor structure, or sodic or saline soils.
4. Easy to control nutrition, it can be better controlled than in soil-growth crops.
5. There's no need for soil preparation and plowing, which leads to an increase in the length of crop and total yield in greenhouses.
6. Enhancement of early yield in crops planted during cold weather due to the increase of root zone temperatures during the day.

(Savvas & Gianquinto, 2013), (Oklahoma State University, 2020) and (Dunn, 2020).

Despite the considerable advantages of commercial soilless culture, disadvantages are limiting its expansion in some cases:

1. High installation and construction costs compared to traditional production systems.

2. Technical skills requirements, compared to traditional production systems.
3. Not economically viable for some crops.
4. Greater risks of crop exposure to the problems of nutrient deficiency.
5. System failure causes rapid plant death.

(Abu Dhabi Farmers Services Center, 2014).

## **2.8 Literature review**

Many articles in the published literature agreed that the soilless cultivation is extensively used in protected agriculture to strengthen and improve control over the growing environment and prevent uncertainties in the soil's water and nutrient status.

When reviewed the literature, the researcher read several books and guides, one of them was written by Simon Goddek, Alyssa Joyce, Benz Kotzen, and Gavin M. Burnell. It is an open-access publication; it was published in Switzerland at 2019. It provides an overview of different hydroponic types, including substrates, nutrients and nutrient solutions, and disinfection methods of the recirculating nutrient solutions (Goddek, Joyce, Kotzen, & Burnell, 2019).

Keith Roberto wrote another book in 2003. It intends to construct and run a hydroponic indoor and outdoor garden that includes comprehensive guidance, photographs, and step by step plans. The book

also describes include all details on how to build and operate the hydroponic and aeroponic systems. It also explains how to grow herbs, favorite flowers, and veggies with hydroponic technology (Roberto, 2003).

In addition, a guide that was written by Pay Drechsel, et al; in 2015. It seeks to enhance general awareness of the best management practices for the usage of water and fertilizers worldwide to increase crop production, improve farm profitability and resource efficiency, and reduce environmental impacts associated with crop production (Drechsel, Heffer, Magen, Mikkelsen, & Wichelns, 2015).

Ibrahim M. Makhadmeh et al., in 2017, studied the effects of growth medium and planting density on the production of lettuce under a closed soilless system. The findings showed that planting density and growth medium exhibited significant effects on the total number of leaves, number of inner leaves, number of outer leaves, number of non-consumable leaves, leaves weight (outer, inner), stem weight, plant height (cm) head mass and marketable head mass (Makhadmeh, et al., 2017).

Guilherme Lages Barbosa et al., (2015) compared the water, land, and energy needs of hydroponic with those of traditional agriculture by the example of lettuce production in Yuma, Arizona, USA. Data were collected from crop budgets and governmental agricultural statistics and compared with theoretical data for hydroponic lettuce production derived using engineering equations populated with literature values. Lettuce yields per greenhouse unit (815 m<sup>2</sup>) of  $41 \pm 6.1$  kg/m<sup>2</sup> /y had energy and water

demands of  $20 \pm 3.8$  L/kg/y and  $90,000 \pm 11,000$  kJ/kg/y ( $\pm$ standard deviation), respectively. In contrast, traditional production produced  $3.9 \pm 0.21$  kg/m<sup>2</sup> /y of produce, with energy and water demands of  $250 \pm 25$  L/kg/y and  $1100 \pm 75$  kJ/kg/y, respectively. Hydroponics gave  $11 \pm 1.7$  times higher yields but required  $82 \pm 11$  times more energy than traditionally produced lettuce (Barbosa, et al., 2015).

Additionally, a study by Rodolfo De la Rosa-Rodríguez, et al, 2019, evaluated the efficiency of use of water and fertilizers in closed and open hydroponic tomato production systems under greenhouse conditions. Two treatments were assessed with eight replications; each replicate consisted of 67 containers, each with two plants. One was a closed hydroponic system (with recirculation of the nutrient solution), while the other was an open hydroponic system (with a non-recirculating solution of nutrients). The authors quantified the quantities of fertilizers and water added and the losses (drained nutrient solution), during the entire cycle of tomato in the two treatments. In the Nutrient Solution, the researchers also calculated electrical conductivity, the pH, the volume applied, drained volume, and total fruit weight (25 pickings). It showed no significant differences between the two treatments on fruit production. The closed system's water usage efficiency was  $59.53$  kg/fruit/m<sup>3</sup>, while in the open system was  $46.03$  kg/fruit/m<sup>3</sup>. The closed system produced  $13.50$  kg more fruit per cubic meter of water relative to the open system, although only  $10.31$  grams' fewer fertilizers per kilogram of fruit produced were applied. The efficiency of water and fertilizers use was higher in the closed system by

22.68% and 22.69%, respectively. More efficiency was obtained in the closed system, regarding the open system. The researchers concluded that the closed system is a good alternative to tomato production and conservation of the resources used in the process (like fertilizers and water), thus minimizing pollution (Rosa-Rodríguez, et al., 2019).

Agung Putra P., Henry Yuliando; 2015, clarified the basic purpose of soilless cultivation specifically in the close-loop system and how substrate nutrition produces better yields. The researchers concluded initially the soilless production system was conducted by mimicking traditional methods focused on production in soil or soil-based systems. Soilless cultivation can be an essential method for raising crop yield. If closed irrigation systems are implemented, it may increase water-use efficiency and minimize greenhouse and nursery environmental impacts (Putra & Yuliando, 2015).

Moreover, a study conducted by Sundar Sapkota, Sanjib Sapkota and Zhiming Liu, at Eastern New Mexico University, USA, in 2019 examined the effects of various nutrient solutions on the growth and weight of two lettuce cultivars grown in a floating hydroponic system. Two cultivars of lettuce, Buttercrunch and Black Seeded Simpson, were exposed to 1 of 4 different nutrient concentrations of N, K, and Ca at 150, 100, and 150 ppm (N1), 210, 235, and 200 ppm (N2), 250, 300 and 250 ppm (N3), and 300, 350, and 350 ppm (N4), respectively. The cultivar Buttercrunch and N3 treatment were considerably more productive than the other

cultivar/treatment combinations. The most significant fresh weights were reported for Butter crunch and Black Seeded Simpson in the N3 nutrient solution, 115.33 and 93.17 g/plant, respectively. Buttercrunch had the most considerable fresh weight, number of leaves, and leaf & root length in all nutrient solutions. For both cultivars, the solutions' nitrogen content displayed a significant positive relationship with chlorophyll content. The production of a low-cost and easy-to-use hydroponic system is expected to help farmers to produce high-quality organic vegetables, like lettuce (Sapkota, Sapkota, & Liu, 2019).

Saha, Monroe, and Day (2016) the growth, yield, quality, and nutrition of the aquatic species to those basil plants (*Ocimum basilicum* L.) cultivar Aroma 2, Non-circulating floating raft systems were designed using 95 L polyethylene tanks. In both systems, the same amounts of start-up fertilizer dose were added. The goal was to understand how the additional crayfish-related nutritional dynamics affect the basil crop. Weights of both new and dry basil plants were collected after harvest, followed by leaf nutrient analysis. The amount of leaf chlorophyll, water pH, nitrogen, and the temperature were periodically calculated. Aquaponic basil (AqB) reported 14% compared to hydroponic basil (HyB), 56%, and 65% more height, fresh weight, and dry weight, respectively. It is rational to conclude that crayfish waste (excreta and unconsumed feed) supplied AqB with additional nutrients, leading to increased growth and yields. However, the content of chlorophyll (plant quality) or leaf nutrients did not differ between AqB and HyB (Saha, Monroe, & Day, 2016).

## **Chapter Three**

### **Methodology**

#### **3.1. Research design**

An experimental research design was used in this thesis (complete randomized block design), (Three for surface drip irrigation and three for responsive drip irrigation).

Whereas, experimental research is research that uses two sets of variables and is conducted with a scientific approach. The first set acts as a constant, and it is used to measure the second set's differences. It collects the needed data to help make better decisions (Mitchell, 2016).

#### **3.2. Study Population**

The population of the thesis is the lettuce plant and its growing media. The total number was 200 lettuce seedlings.

#### **3.3. Study setting**

This study was conducted in Palestine, West Bank, at National Agriculture Research Center (NARC) allowed to the Palestinian ministry of agriculture Jenin in a small greenhouse with average temperature (20-25°C) and humidity (70%).

#### **3.4. Study period**

The study was conducted from June to November 2020.

### **3.5. Sampling and Sample size**

The study's sampling is a systemic random sample to select one from every five-lettuce plant as well as one from every five-growing media.

The researcher selected 40 samples from the lettuce plant and 40 samples from growing media.

### **3.6. Study tool**

In this study, soilless lettuce was used under Nutrient Film Technique (NFT). Seedlings are inserted into NFT channel media with 30 cm between each plant and the other.

#### **The two irrigation systems:**

- Surface drip irrigation: The diameter is 0,5 inches with 30 cm between dripper along a plastic pipe with flow rate around 8 liter / hour / dripper.
- Responsive drip irrigation: which grow stream uses an understanding of plant physiology and organic chemistry to create a symbiotic relationship between plant roots, media and water. When crops and plants need water and nutrients, they emit root exudates that allow them to uptake what they need from the surrounding media (RDI. LLC, 2020).

The two irrigation systems are a closed system, where a closed system is a system in which the surplus nutrient is recovered after use and then recycled through the system. Lettuce is placed along a plastic pipe (e.g. PVC pipe), closed trough (channel) so that only the roots extend inside the standard channel with 6-meter length, 5 cm depth, and 10 cm width. (NFT) plastic pipes were filled media Peat moss, perlite and vermiculite are mixed to gather and placed in it. The total numbers of channels are 6 (3 for surface and 3 for RDI), representing 3 replications for each system .

A shallow stream of nutrient solution constantly flows over the pipes' bare roots. The pipes are placed on a slight decline (1-3%), generally at bench height. The nutrient solution was added to 120 liters of water in a plastic tank for each irrigation system.

### **3.7. Data collection**

A continuous reading of the amount of water that was consumed during the seasonal cultivation period was taken from both systems by using a measured meter and recording the readings.

Before the cultivation process, a sample was taken from the lettuce plant and the media in which the cultivation was carried out. The samples were analyzed in the laboratory.

During the cultivation period, specifically in the middle of the season, samples were taken from the lettuce leaf and the media for both systems, and they were analyzed in the laboratory.

At the end of the season (harvested time), samples were taken from lettuce leaf and the media, for both systems, and they were analyzed in a laboratory.

**Daily practices:**

- The two systems were monitored daily, by providing them with water and fertilizer necessary for the planting process's success from the beginning of the season to its end.
- The presence of insects like the whitefly was observed on the lettuce plant's leaves, and it was eliminated by spraying it with an insecticide called (Insect Free).
- The lettuce plant was inspected daily, and yellow or unwanted leaves were removed.

**3.8. Data entry and analysis**

**3.8.1. Chemical analysis**

Chemical analysis was performed at the center for An Najah National University's chemical analysis.

a) Media analysis:

**Plants need two types of nutrients: macro and micronutrients:**

- Macro-nutrients: They are consumed in large quantities by the plant from a nutrient solution is well known as (N-P-K).
  - Micro-nutrients: They are consumed in small quantities. These nutrients are available in trace quantities in plants and are less known than macronutrients, such as calcium (Ca). (Roberto, 2003).
- b) Plant analysis: random sample (Leaf plant) of 5 plants per plot will be analyzed for macro and micro-nutrient before planting, at the middle and the end of the growing season.

All plant and media samples were dehydrated to obtain dry samples in a 105°C oven.

Each media and plant have almost the same procedure for analysis. All these analyses were done based on the International Center for Agricultural Research in the Dry Areas (ICARDA) protocol, which is listed in (Methods of Soil, Plant, and Water Analysis -Third Edition-).

These analyses are:

- Total Media N (mainly organic) is generally measured after wet digestion using the well-known Kjeldahl procedure. The media was digested in concentrated  $H_2SO_4$  with a 14g of  $K_2SO_4$  and 0.04g of  $CuSO_4$  for each sample. then the samples were put in a Vapodest 20s device. This procedure involves digestion and distillation.

- Organic Phosphorus (P) content in soils, by the Ignition Method, is estimated by igniting the soil at 550°C. After that, ash was dissolved in a volumetric flask with 100 ml of distilled water and add 1 ml H<sub>2</sub>SO<sub>4</sub> for each sample, tested by molybdate- blue method. This was done by using the Spectrophotometer device.
- Potassium (k) content in media, by the Ignition Method, is estimated by igniting the media at 550°C. After that, d ash was dissolved in a volumetric flask with 100 ml of distilled water (DW) and add 1 ml H<sub>2</sub>SO<sub>4</sub> for each sample. A flame photometer device was used to calculate this procedure.
- Calcium (Ca): The sample dissolve in 100 ml DW, titrated against 0.01 molar EDTA. (Estefan, Sommer, & Ryan, 2013).

But media has additional analyses, unlike plants. These analyses are pH and EC (electrical conductivity). Each pH and EC have the same procedure for analysis. But each of them is analyzed using a different device. The procedure is:

- The amount of 50 ml dried sample was mixed with the same DW amount.
- Mix well, transfer the beaker to a shaker machine for 30 minutes with speed (200-300) rpm.
- Filter the mixture by using filter paper 41.

As for devices, the pH was done by using a pH meter with a combined electrode device, while EC was done by using a Conductivity meter device. (Estefan, Sommer, & Ryan, 2013).

### **3.8.2. Water use**

The total added consumed, and drained water out of channels throughout the experiment was recorded to compute for total water use and water use efficiency. The total water used by plants (liters/ channel) was computed according to the equation:

Total water = Total added water in Irrigation - Total drained water out of channels.

Water use efficiency (WUE) in kg fresh weight/L water was computed according to the equation:

$$WUE = \frac{\text{Total Productivity produced (kg/channel)}}{\text{Total water used (liter/channel)}}$$

(Al-Karaki & Al-Hashimi, 2012).

### **3.8.3. Fertilizer use**

Fertilizer was added to the water in the tanks of the systems continuously for each system.

Were 750 g of fertilizer (13-13-13) was added to each system during the cultivation period, at a rate of 250 g per 120 liters, according to recommendations.

Also, 20 gm of iron granules (EDDHA-Fe-6%) were added for each system.

The two systems have been provided with an amount of calcium (Habical. Ca s) during the growth period, which is estimated at 20 mm per system.

To calculate the effectiveness of the plant and the media from the use of fertilizers, samples were analyzed in the laboratory and the elements contained in them were calculated.

Nitrogen element was calculated according to the following equation:

$$\% \text{ Nitrogen} = \frac{(V_{\text{ml}} - V_{\text{blank}}) \times N \times 1.401}{W(\text{g sample})}$$

Where:

V= ml of titrant of sample (HCl)

V blank = ml of titrant of blanks

N= molarity of standard acid

W= weight of dry sample (g).

Handbook for Kjeldahl Digestion was obtained, which is a recent review of the classical method with improvements developed by FOSS (Persson, Wennerholm, & O'Halloran, 2008).

Also, the phosphorus was calculated according to the following equation:

$$\text{Total P (ppm)} = \text{ppm P (from calibration curve)} \times \frac{V}{Wt} \times \frac{V2}{V1}$$

It was obtained from *Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North Africa region* (Estefan, Sommer, & Ryan, 2013).

Where:

V = Total volume of the digest tube (mL).

Wt. = Weight of air-dry soil (g).

V1 = Volume of soil digest used for measurement (mL).

V2 = Volume of flask used for measurement (mL).

In addition, the potassium was calculated according to the following equation:

$$\text{Extractable k (ppm)} = \text{ppm k (from calibration curve)} \times \frac{V}{Wt}$$

It was obtained from *Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North Africa region* (Estefan, Sommer, & Ryan, 2013). Where:

V = Total volume of the soil extract (mL).

Wt. = Weight of air-dry soil (g).

Moreover, calcium was calculated according to the following equation:

$$\text{Soluble Ca} = \frac{V \times 40}{Wt}$$

It was obtained from Official methods of analysis of AOAC international - 20th edition. (AOAC International, 2016). Where:

V = Volume of EDTA titrated from the sample (ml).

Wt. = weight of dry sample (g).

Fertilizer use efficiency (FUE) in kg fresh weight/g fertilizer was computed according to the equation:

$$\text{FUE} = \frac{\text{Total Productivity produced (kg/channel)}}{\text{Total fertilizer used (g/channel)}}$$

#### **3.8.4. Statistical analysis**

- The data was analyzed using SPSS V25.0 program.
- Microsoft Office programs (such as Excel and Word software) and other software were used for data analysis and interpretation.

## **Chapter Four**

### **Results**

#### **4.1 Introduction**

This chapter points out the statistical analysis results, including descriptive analysis that presents the study and the answers to the study's questions. two hundred lettuce plants were grown on two irrigation systems, 100 lettuce plants were grown on surface irrigation systems, and 100 lettuce plants were grown on RDI. The researcher used a random sample to selected 6 channels of lettuce plants, and they were divided into two groups. The first group was 3 channels of lettuce plants from surface irrigation, and the second group was 3 channels of lettuce plants that used new responsive drip irrigation (RDI) to evaluate biomass, water and fertilizer use efficiency of soilless lettuce grown under two irrigation systems and calculate the amount of water and fertilizers that used in two drip irrigation systems. The researcher used proper statistical calculation, including percentage change (% change) for and mean (SD) for numerical data. The researcher also used repeated ANOVA measure (F-test) to compare surface irrigation and the RDI with showing Mauchly's test of sphericity and effect size.

However, pairwise comparisons were used to compare between media and leaf plant parameters levels before, during and after lettuce plants had grown and Z-test for two proportion was used to test statistical

differences between the two proportions. P-value was significant at  $P \leq 0.05$ .

## **4.2 The levels of tested parameters in the soilless media among surface and RDI irrigation systems planted with lettuce plant.**

### **4.2.1 Levels of calcium in the soilless media among surface irrigation and RDI.**

Table 4.2 illustrated media calcium levels among surface irrigation and RDI used for growing lettuce plants. Repeated ANOVA measures pointed out that there was a statistically significant trend in media calcium levels before, during, and after lettuce plants growing in both irrigation systems (surface irrigation and RDI), and the effect size was 99.8% ( $F=2586.084$ ,  $P < 0.001$ ).

The content of calcium gradually increased with values of  $1.23 \pm 0.00$ ,  $1.52 \pm 0.28$ , and  $2.69 \pm 0.28$  g/L for surface irrigation and  $1.23 \pm 0.00$ ,  $1.66 \pm 0.24$  and  $2.67 \pm 0.12$  g/L for RDI in media before, during, and after lettuce plants have grown, respectively (Figure 4.1).

The Pairwise Comparisons test (LSD) demonstrated that there was statistically significant difference before lettuce plants growing compared to during and after growing in both surface irrigation and RDI systems ( $P=0.027$  &  $P < 0.001$ , respectively).

The results showed a statistically significant difference in media calcium levels during lettuce plants growing compared to after lettuce plants growing in both surface irrigation and RDI systems ( $P=0.003$ ).

The percentages change in media calcium levels were 23.85% and 118.7% between before and during lettuce plants growing in surface irrigation and RDI, respectively. However, the calcium levels in media were 118.97% and 116.80% between before and after lettuce plants growing in surface irrigation and RDI, respectively, while there was decreasing in media calcium levels between during and after lettuce plants growing in surface irrigation and RDI (76.81% & 60.97%, respectively).

Repeated ANOVA measures illustrated that there was no statistically significant difference in media calcium levels between surface irrigation and RDI systems with an effect size was 0.057% ( $F=0.243$ ,  $P = 0.648$ , Mauchly's test of sphericity= 0.286).

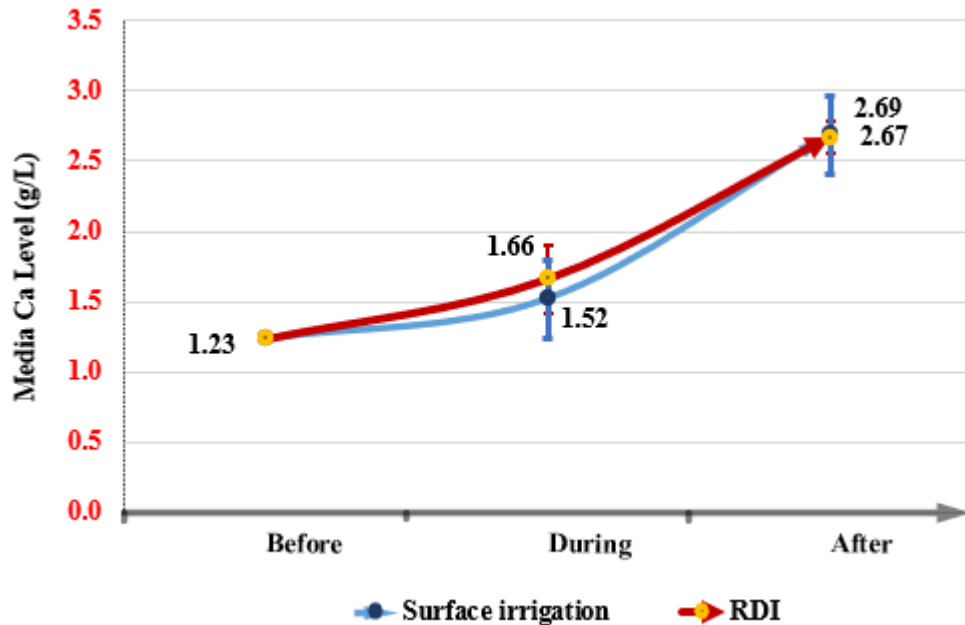
The percentages change in media calcium levels between surface irrigation and RDI before, during and after lettuce plants growing were 0.00%, 8.75% and -0.99%, respectively.

**Table (4.1): Media calcium levels among surface irrigation and RDI for lettuce plants grown.**

Media Ca levels (g/L)		Irrigation systems Mean±SD		Statistical test <sup>£</sup>			
		Surface (n=3)	RDI (n=3)	% change	F	P-value	Effect Size
Ca (Before)		1.23±00	1.23±00	0.00 <sup>d</sup>	0.243	0.648	0.057
Ca (During)		1.52±0.28	1.66±0.24	8.75 <sup>e</sup>			
Ca (After or harvested)		2.69±0.28	2.67±0.12	-0.99 <sup>f</sup>			
Statistical test <sup>€</sup>	% change	23.85 <sup>a</sup>	34.69 <sup>a</sup>				
		118.97 <sup>b</sup>	116.80 <sup>b</sup>				
		76.81 <sup>c</sup>	60.97 <sup>c</sup>				
	Mauchly's test of sphericity	0.286					
	F	2586.084					
	P-value	<0.001 <sup>*</sup>					
	Effect size	0.998					
	Pairwise Comparisons (P-value)	0.027 <sup>* a</sup>					
		< 0.001 <sup>* b</sup>					
0.003 <sup>* c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **Ca**: calcium; **RDI**: responsive drip irrigation; **n**: number of planting basin; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in surface irrigation vs. RDI media before lettuce plants grown in planting basin; <sup>e</sup>: % change in surface irrigation vs. RDI media during lettuce plants grown in planting basin and <sup>f</sup>: % change in surface vs. RDI media after lettuce plants grown in planting basin. <sup>£</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of **ca** (g/L) within surface irrigation and RDI media. Effect Size calculated by Partial Eta Squared.

Figure (4.1) shows that the media's calcium levels among surface irrigation and RDI systems were equal. This means that the calcium conditions in the media were identical in both systems.



**Figure (4.1):** Media calcium levels among surface irrigation and RDI for lettuce plants grown.

This study differs with the study conducted by Diana Frezza and others in 2005, which aimed to evaluate butterhead lettuce quality in a soilless culture system. In which the lettuce was grown in two different seasons with different methods to compare calcium levels in the nutrient solution, add it concluded that the growing cycles varied according to the culture system. where plants harvested from the soilless culture had a lower dry weight and leaf area, however significant differences were observed in productivity (Frezza, et al., 2005).

#### **4.2.2 K levels in the soilless media among surface irrigation and RDI for growing lettuce plants**

The K contents in the media among surface irrigation and RDI used for growing lettuce plants are illustrated in Table 4.2. Repeated ANOVA measures pointed out that there were statistically significant trends in media K levels before, during, and after lettuce plants grown in both irrigation systems (surface irrigation and RDI), and the effect size was 0.927% ( $F=1354.445$ ,  $P<0.001$ ).

The contents of K gradually increased with values of  $0.025\pm 0$ ,  $0.168\pm 0.012$ , and  $0.135\pm 0.023$  g/L for surface irrigation and  $0.025\pm 0$ ,  $0.375\pm 0.027$ , and  $0.085\pm 0.022$  g/L for RDI in media before, during, and after lettuce plants growing, respectively (Figure 4.2).

The Pairwise Comparison test (LSD) demonstrated a statistically significant difference before lettuce plants grown compared to during and after lettuce plants grown in both surface irrigation and RDI systems ( $P<0.001$  and  $P=0.001$ , respectively).

However, there was a statistically significant difference in K contents during and after the lettuce plants were grown in both surface irrigation and RDI systems ( $P<0.001$ ). The contents of K in media were 572.0% and 1400.0% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

However, the percentage changes in media K levels were 440% and 240% between before and after lettuce plants that were grown in surface irrigation and RDI, respectively. In comparison, there were lower K levels between during and after lettuce plants grown in surface irrigation and RDI (-19.64% and -77.33%, respectively).

Repeated ANOVA measures illustrated a statistically significant difference in media K levels between surface irrigation and RDI systems with an effect size of 0.927 ( $F=50.51$ ,  $P=0.002$  and Mauchly's test of sphericity=0.438).

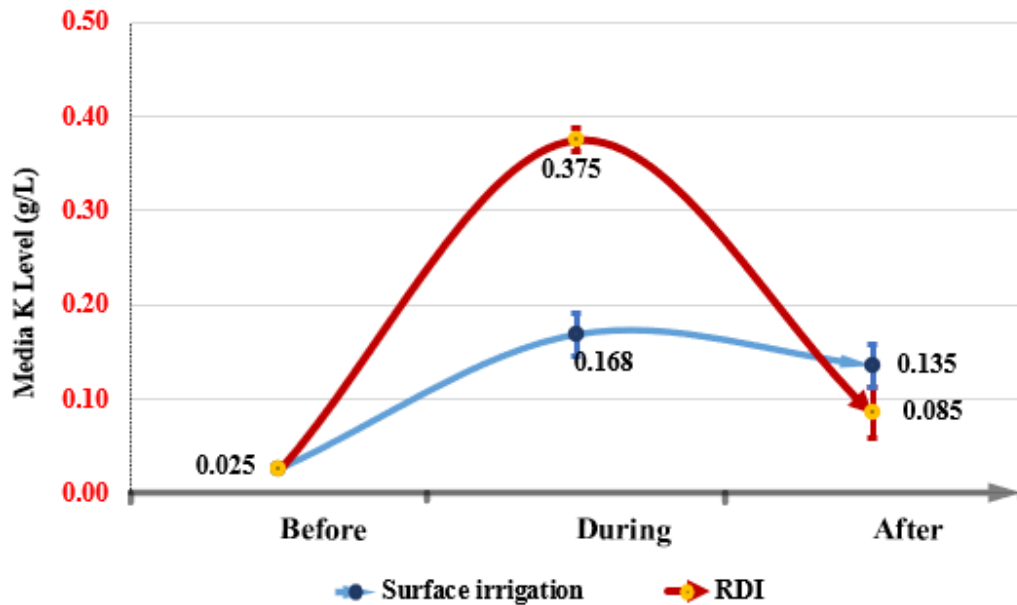
Also, the percentages change in media K levels between surface irrigation and RDI before, during and after lettuce plants growing were 0%, 123.21%, and -37.04%, respectively.

**Table (4.2): Media K levels among surface irrigation and RDI for lettuce plants grown**

Media K levels (g/L)		Irrigation systems Mean±SD		Statistical test <sup>£</sup>			
		Surface (n=3)	RDI (n=3)	% Change	F	P-value	Effect Size
K (Before)		0.025±0	0.025±0	0.00 <sup>d</sup>	50.510	0.002	0.927
K (During)		0.168±0.012	0.375±0.027	123.21 <sup>e</sup>			
K (After or harvested)		0.135±0.023	0.085±0.022	-37.04 <sup>f</sup>			
Statistical test <sup>£</sup>	% Change	572.00 <sup>a</sup>	1,400.00 <sup>a</sup>				
		440.00 <sup>b</sup>	240.00 <sup>b</sup>				
		-19.64 <sup>c</sup>	-77.33 <sup>c</sup>				
	Mauchly's test of sphericity	0.438					
	F	1354.445					
	P-value	< 0.001 <sup>**</sup>					
	Effect size	0.997					
	Pairwise Comparisons (P-value)	0.000 <sup>* a</sup>					
		0.001 <sup>* b</sup>					
< 0.001 <sup>* c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **K**: potassium; **RDI**: responsive drip irrigation; **n**: number of planting basin; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in surface irrigation vs. RDI media before lettuce plants grown in planting basin; <sup>e</sup>: % change in surface irrigation vs. RDI media during lettuce plants grown in planting basin and <sup>f</sup>: % change in surface vs. RDI media after lettuce plants grown in planting basin. <sup>£</sup> Statistical test between surface irrigation and RDI; <sup>£</sup> Statistical test between the level of **K (g/L)** within surface irrigation and RDI media. Effect Size calculated by Partial Eta Squared.

As for potassium levels in media, Figure (4.2) shows that it was higher in the RDI during the period of growth than in the surface system.



**Figure (4.2):** Media K levels among surface irrigation and RDI for lettuce plants grown.

The results agree with the study that was done by S. Tangolar and others in 2019. In which, Berry were growing in three media using Hoagland nutrient solution under plastic cover. And two potassium (K) levels were tested, and the researchers concluded that the berry weight and volume were not clearly affected by the K levels. Moreover, the results showed that the soilless culture can provide high yield for table grapes without negative effects on cluster and berry quality (Tangolar, Tarım, Ada, Torun, & Ertargın, 2019).

### **4.2.3 phosphorus levels in the soilless media among surface irrigation and RDI for growing lettuce plants.**

Table 4.3 summarized the media P levels among surface irrigation and RDI used for growing lettuce plants. Repeated ANOVA measures described a statistically significant difference in media P levels in before, during, and after lettuce plants were grown in surface irrigation and RDI and the effect size was 99.8 % ( $F=1659.073$ ,  $P<0.001$ ).

The P contents were changed with values of  $0.7\pm 0$ ,  $0.77\pm 0.095$ , and  $0.26\pm 0.095$  g/L for surface irrigation and  $0.7\pm 0$ ,  $0.826\pm 0.169$ , and  $0.167\pm 0.045$  g/L for RDI in media before, during and after lettuce plants have grown, respectively (Figure 4.3).

Pairwise Comparisons test (LSD) illustrated a statistically significant difference before and after lettuce plants grown compared to after lettuce plants grown in both surface irrigation and RDI systems ( $P<0.001$ ). Simultaneously, there were statistically significant differences between before and during the lettuce plants.

Also, there were statistically significant differences between before and during the lettuce plants grown in both surface irrigation and RDI systems ( $P=0.154$ ). The statistical test pointed out that there is a statistically significant difference in media P levels during lettuce plants grown compared to after lettuce plants were grown in both surface irrigation and RDI systems ( $P=0.002$ ).

The percentages change in media P levels were 10.0% and 18.0% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

Regarding the percentages change in media P levels, the results showed a lowering between before and after lettuce plants growing in surface irrigation and RDI were -62.86% and -76.14%, respectively. In the same away there were a lowering in percentages change in media P levels between during and after lettuce plants growing in surface irrigation and RDI (-66.23% and -79.78%, respectively).

Repeated ANOVA measures illustrated the efficiency of RDI on media for growing lettuce plants compared to surface irrigation and it is shown there is no statistically significant difference in media P levels between surface irrigation and RDI systems with an effect size was 4.6% ( $F=0.194$ ,  $P=0.682$  and Mauchly's test of sphericity= $0.074$ ).

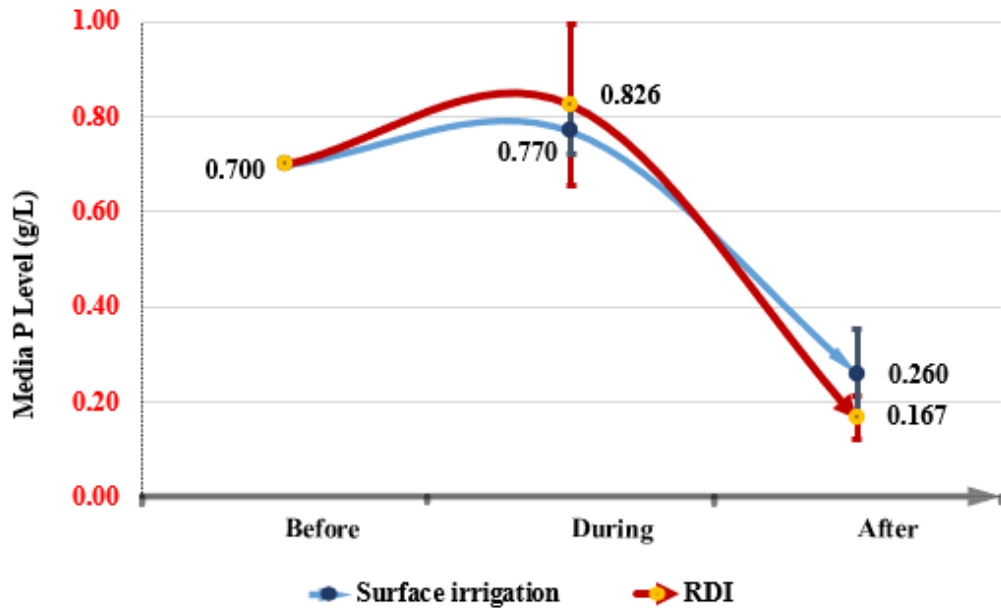
However, the percentages change in media P levels between surface irrigation and RDI before, during and after lettuce plants growing were 0.0%, 7.32%, and -35.9%, respectively.

**Table (4.3): Media P levels among surface irrigation and RDI for lettuce plants grown**

Media P levels (g/L)		Irrigation systems Mean±SD		Statistical test <sup>‡</sup>			
		Surface (n=3)	RDI (n=3)	% Change	F	P-value	Effect Size
<b>P (Before)</b>		0.70±0.0	0.70±0.0	0.00 <sup>d</sup>	0.194	0.682	0.046
<b>P (During)</b>		0.77±0.095	0.826±0.169	7.32 <sup>e</sup>			
<b>P (After or harvested)</b>		0.26±0.095	0.167±0.045	-35.9 <sup>f</sup>			
Statistical test <sup>€</sup>	% Change	10.0 a	18.0 <sup>a</sup>				
		-62.86 b	-76.14 <sup>b</sup>				
		-66.23 c	-79.78 <sup>c</sup>				
	Mauchly's test of sphericity	0.074					
	F	1659.073					
	P-value	< 0.001 <sup>*</sup>					
	Effect size	0.998					
	Pairwise Comparisons (P-value)	0.154 <sup>a</sup>					
		< 0.001 <sup>* b</sup>					
0.002 <sup>* c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **P**: Phosphorus; **RDI**: responsive drip irrigation; **n**: number of planting basin; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in surface irrigation vs. RDI media before lettuce plants grown in planting basin; <sup>e</sup>: % change in surface irrigation vs. RDI media during lettuce plants grown in planting basin and <sup>f</sup>: % change in surface vs. RDI media after lettuce plants grown in planting basin. <sup>‡</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of **P** (g/L) within surface irrigation and RDI media. Effect Size calculated by Partial Eta Squared.

Regarding Phosphorous levels, figure (4.3) shows that the Phosphorous levels in the media among surface irrigation and RDI systems was equal, this means that the media's Phosphorous conditions were identical in both systems.



**Figure (4.3):** Media P levels among surface irrigation and RDI for lettuce plants grown

#### 4.2.4 N levels in the soilless media among surface irrigation and RDI systems.

Table 4.4 illustrated N levels in the soilless media among surface irrigation and RDI used for growing lettuce plants. The statistical test illustrated statistically significant differences in media N levels before, during, and after lettuce plants were grown in both surface irrigation and RDI with an effect size of 99.9% ( $F=3864.141$ ,  $P<0.001$ ).

On the others hand, the contents of N were changed with values of  $2.77\pm 0$ ,  $1.04\pm 0.57$ , and  $6.33\pm 0.23$  g/L for surface irrigation and  $2.77\pm 0$ ,  $0.74\pm 0.19$ , and  $6.78\pm 0.3$  g/L for RDI in media before, during and after lettuce plants had grown, respectively (Figure 4.4).

The Pairwise Comparisons test (LSD) in Repeated ANOVA measures showed that there was a statistically significant difference before lettuce plants grown compared to during and after lettuce plants grown in both surface irrigation ( $P < 0.001$ ) and RDI systems ( $P < 0.001$ ).

However, the results showed a statistically significant difference in media N levels during lettuce plants compared to after lettuce plants were grown in both surface irrigation and RDI systems ( $P < 0.001$ ). The N levels in media were -62.45% and -73.29% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

In the same way, the percentages change in media N levels were 128.52% and 144.77% between before and after lettuce plants growing in surface irrigation and RDI, respectively while there are increased in percentages change in media N levels between during and after lettuce plants growing in surface irrigation and RDI (508.65% and 816.22%, respectively).

Repeated ANOVA measures illustrated that there is no statistically significant difference in media N levels between surface irrigation and RDI systems with an effect size of 4.5% ( $F=0.19$ ,  $P=0.685$  and Mauchly's test of sphericity=0.234).

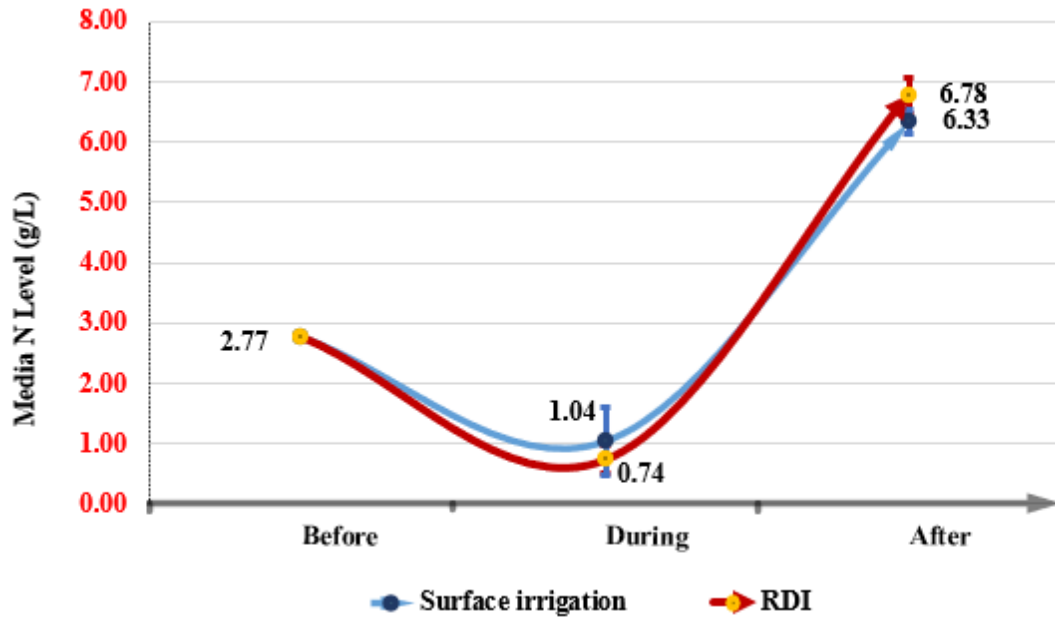
The percentages change in media N levels between surface irrigation and RDI for before, during, and after lettuce plants growing were 0%, -29.39% and, 7.11%, respectively.

**Table (4.4): Media N levels among surface irrigation and RDI for lettuce plants grown**

Media N levels (g/L)		Irrigation systems Mean±SD		Statistical test <sup>£</sup>			
		Surface (n=3)	RDI (n=3)	% Change	F	P-value	Effect Size
N (Before)		2.77±0.0	2.77±0.0	0.0 <sup>d</sup>	0.190	0.685	0.045
N (During)		1.04±0.565	0.74±0.19	-29.39 <sup>c</sup>			
N (After or harvested)		6.33±0.23	6.78±0.3	7.11 <sup>f</sup>			
Statistical test <sup>€</sup>	% Change	-62.45 <sup>a</sup>	-73.29 <sup>a</sup>				
		128.52 <sup>b</sup>	144.77 <sup>b</sup>				
		508.65 <sup>c</sup>	816.22 <sup>c</sup>				
	Mauchly's test of sphericity	0.234					
	F	3864.141					
	P-value	< 0.001 <sup>*</sup>					
	Effect size	0.999					
	Pairwise Comparisons (P-value)	< 0.001 <sup>*a</sup>					
		< 0.001 <sup>*b</sup>					
< 0.001 <sup>*c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **N**: Nitrogen; **RDI**: responsive drip irrigation; **n**: number of planting basin; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in surface irrigation vs. RDI media before lettuce plants grown in planting basin; <sup>e</sup>: % change in surface irrigation vs. RDI media during lettuce plants grown in planting basin and <sup>f</sup>: % change in surface vs. RDI media after lettuce plants grown in planting basin. <sup>£</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of N (g/L) within surface irrigation and RDI media. Effect Size calculated by Partial Eta Squared.

As well as figure (4.4) shows that the Nitrogen levels in the media among surface irrigation and RDI systems were equal. This also means that the media's Nitrogen conditions were identical in both systems.



**Figure (4.4):** Media N levels among surface irrigation and RDI for lettuce plants grown.

The results agree with the study that was done by S. Tangolar and others in 2019. In which, Berry were growing in three media using Hoagland nutrient solution under plastic cover. And two nitrogen levels were tested, and the researcher concluded that the berry weight and volume were not clearly affected by the N levels. In addition, the results showed that the soilless culture can provide high yield for table grapes without negative effects on cluster and berry quality (Tangolar, Tarım, Ada, Torun, & Ertargın, 2019).

#### **4.2.5 pH levels in the soilless media among surface irrigation and RDI system.**

Table 4.5 pointed out media pH levels among surface irrigation, and RDI used for growing lettuce plants. The statistical test showed statistically significant differences in media pH levels before, during, and after lettuce plants were grown in both irrigation systems (surface irrigation and RDI), and the effect size was 100% ( $F=59109.282$ ,  $P < 0.000$ ).

The mean of media pH levels was changed with values of  $8.27 \pm 0.06$ ,  $5.79 \pm 0.06$ , and  $5.74 \pm 0.11$  for surface irrigation and  $8.27 \pm 0.06$ ,  $6.05 \pm 0.21$ , and  $5.78 \pm 0.07$  for RDI in media before, during and after lettuce plants have grown, respectively (Figure 4.5).

Statistical test by Pairwise Comparisons test (LSD) demonstrated that it is statistically significant difference before lettuce plants grown compared to during and after lettuce plants grown in both surface irrigation and RDI systems ( $P < 0.001$  and  $P < 0.001$ , respectively).

In contrast, there is no statistically significant difference in media pH levels during lettuce plants grown compare to after lettuce plants were grown in both surface irrigation and RDI systems ( $P = 0.059$ ).

The percentages change in media pH levels were -29.99% and -26.84% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

However, the percentages change in media pH levels were -30.59% and -30.11% between before and after lettuce plants growing in surface irrigation and RDI, respectively, while there are lowering in percentages change in media pH levels between during and after lettuce plants growing in surface irrigation and RDI (-0.86% and -4.46%, respectively).

Repeated ANOVA measures showed that there is no statistically significant difference in media pH levels between surface irrigation and RDI systems with an effect size was 45.5% ( $F=3.342$  and  $P = 0.142$  and Mauchly's test of sphericity = 0.568).

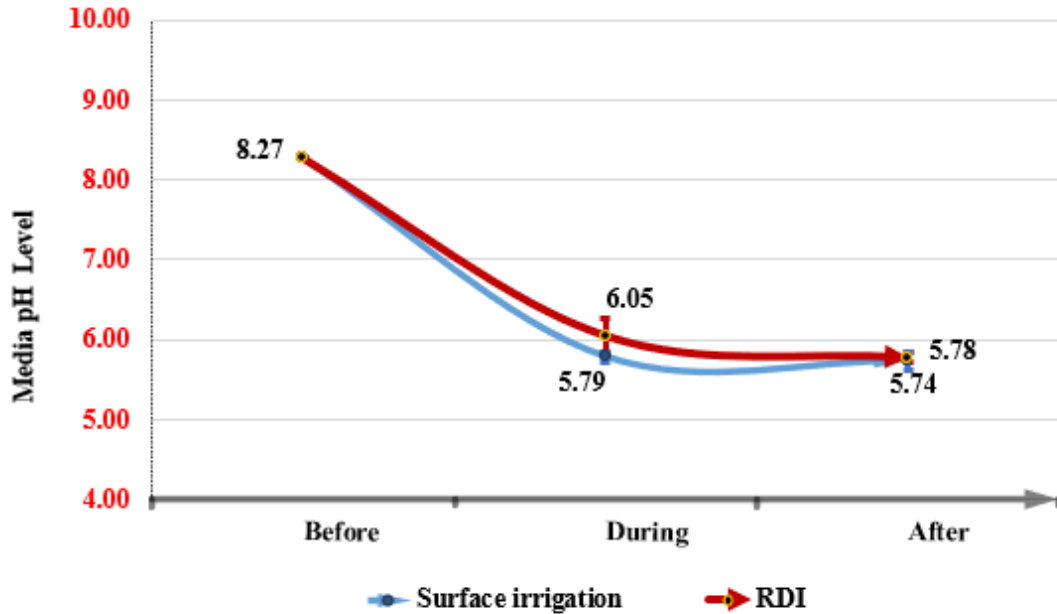
The percentages change in media pH levels between surface irrigation and RDI before, during, and after lettuce plants growing were 0.00%, 4.49% and, 0.7%, respectively.

**Table (4.5): Media pH levels among surface irrigation and RDI for lettuce plants grown**

Media pH levels		Irrigation systems Mean±SD		Statistical test <sup>£</sup>			
		Surface (n=3)	RDI (n=3)	% Change	F	P- value	Effect Size
<b>pH (Before)</b>		8.27±0.0	8.27±0.0	0.00 <sup>d</sup>	3.342	0.142	0.455
<b>pH (During)</b>		5.79±0.06	6.05±0.21	4.49 <sup>e</sup>			
<b>pH (After or harvested)</b>		5.74±0.11	5.78±0.07	0.7 <sup>f</sup>			
Statistical test <sup>€</sup>	% Change	-29.99 <sup>a</sup>	-26.84 <sup>a</sup>				
		-30.59 <sup>b</sup>	-30.11 <sup>b</sup>				
		-0.86 <sup>c</sup>	-4.46 <sup>c</sup>				
	Mauchly's test of sphericity	0.568					
	F	59109.282					
	P-value	< 0.001 <sup>*</sup>					
	Effect size	1.000					
	Pairwise Compariso ns (P-value)	< 0.001 <sup>* a</sup>					
		< 0.001 <sup>* b</sup>					
0.059 <sup>c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **pH**: potential of hydrogen' or 'power of hydrogen' and it is a scale used to specify the acidity or basicity; **RDI**: responsive drip irrigation; **n**: number of planting basin; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in surface irrigation vs. RDI media before lettuce plants grown in planting basin; <sup>e</sup>: % change in surface irrigation vs. RDI media during lettuce plants grown in planting basin and <sup>f</sup>: % change in surface vs. RDI media after lettuce plants grown in planting basin. <sup>£</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of **pH** within surface irrigation and RDI media. Effect Size calculated by Partial Eta Squared.

Also, Figure (4.5) shows that the media's pH levels among surface irrigation and RDI systems were equal. This also means that the media's pH conditions were identical in both systems.



**Figure (4.5):** Media pH levels among surface irrigation and RDI for lettuce plants grown

Jacek Dyśko, Waldemar Kowalczyk and Stanisław Kaniszewski were conducted a study in 2006 and aimed to determine the influence of nutrient solution of different pH on the yield and nutritional status of tomato plants grown in soilless culture in organic and inert medium. In which the nutrient solution pH and the kind of applied growing substrates were exerted significantly influence on the height of total and marketable yield of tomato (Dyśko, Kowalczyk, & Kani, 2009).

#### **4.2.6 EC levels in the soilless media among surface irrigation and RDI system.**

The media EC levels among surface irrigation and RDI used for growing lettuce plants was shown in Table 4.6. Repeated ANOVA measures pointed out that there are statistically significant differences in media EC levels before, during, and after lettuce plants were grown in both

irrigation systems (surface irrigation and RDI), and the effect size was 98.9% ( $F=355.333$ ,  $P < 0.001$ ).

Figure 4 .6 illustrated the mean levels of media EC changed with values of  $4.1\pm 0$ ,  $4.74\pm 1.67$ , and  $2.92\pm 0.11$  mS for surface irrigation and  $4.1\pm 0$ ,  $2.69\pm 0.46$ , and  $2.93\pm 0.41$  mS for RDI in media before, during and after lettuce plants have grown, respectively.

EC levels among surface irrigation and RDI for lettuce plants grown were tested by the Pairwise Comparisons test (LSD). It is statistically significant difference before lettuce plants grown compared to after lettuce plants grown in both surface irrigation and RDI systems ( $P=0.485$ ,  $P=0.001$ , respectively).

However, there is no statistically significant difference in media EC levels during lettuce plants grown compared to before and after lettuce plants were grown in both surface irrigation and RDI systems ( $P= 0.485$  &  $P=0.159$ , respectively).

The percentages change in media EC levels were 15.61% and -34.39% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

Also, the percentages change in media EC levels were -28.78% and -28.54% between before and after lettuce plants growing in surface irrigation and RDI, respectively, while there are lowering in percentages

change in media EC levels between during and after lettuce plants growing in surface irrigation and RDI (-38.4% and 8.92%, respectively).

Repeated ANOVA measures illustrated that there is no statistically significant difference in media EC levels between surface irrigation and RDI systems with an effect size 44.6% ( $F=3.224$ ,  $P=0.147$  and Mauchly's test of sphericity=0.062).

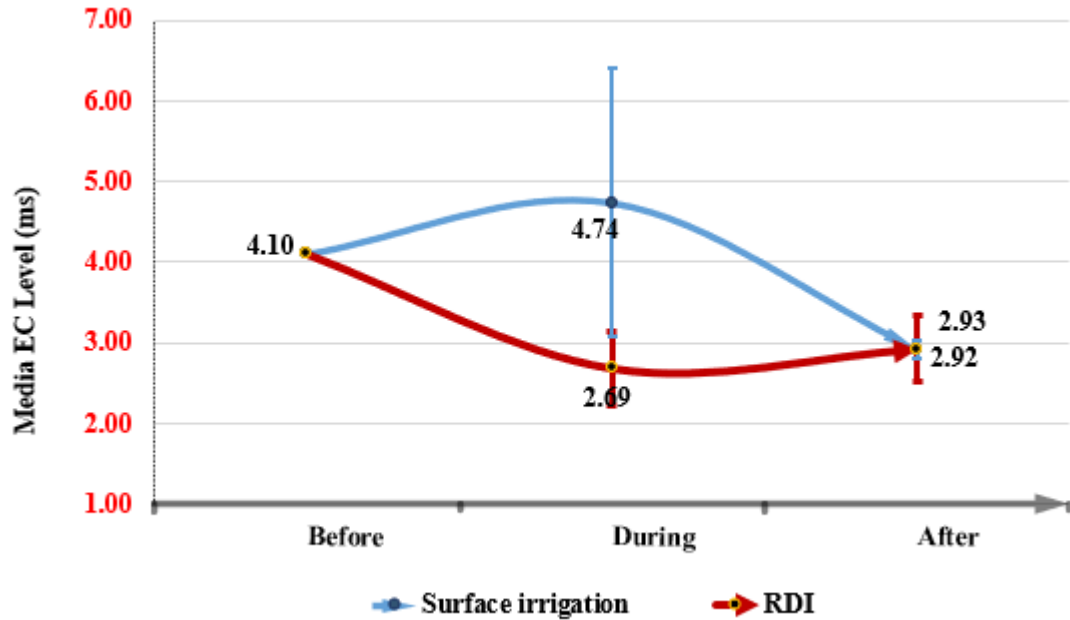
Also, the percentages change in media EC levels between surface irrigation and RDI for before, during and after lettuce plants growing were 0.0%, -43.36% and, 0.34%, respectively.

**Table (4.6): Media EC levels among surface irrigation and RDI for lettuce plants grown**

Media EC levels (mS)		Irrigation systems Mean±SD		Statistical test <sup>£</sup>			
		Surface (n=3)	RDI (n=3)	% Change	F	P-value	Effect Size
EC (Before)		4.1±0	4.1±0	0.00 <sup>d</sup>	3.224	0.147	0.446
EC (During)		4.74±1.67	2.69±0.46	-43.36 <sup>e</sup>			
EC (After or harvested)		2.92±0.11	2.93±0.41	0.34 <sup>f</sup>			
Statistical test <sup>€</sup>	% Change	15.61 <sup>a</sup>	-34.39 <sup>a</sup>				
		-28.78 <sup>b</sup>	-28.54 <sup>b</sup>				
		-38.4 <sup>c</sup>	8.92 <sup>c</sup>				
	Mauchly's test of sphericity	0.062					
	F	355.333					
	P-value	< 0.001 <sup>*</sup>					
	Effect size	0.989					
	Pairwise Comparisons (P-value)	0.485 <sup>a</sup>					
0.00 <sup>*1</sup> <sup>b</sup>							
0.159 <sup>c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **EC**: electrical conductivity; **RDI**: responsive drip irrigation; **n**: number of planting basin; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in surface irrigation vs. RDI media before lettuce plants grown in planting basin; <sup>e</sup>: % change in surface irrigation vs. RDI media during lettuce plants grown in planting basin and <sup>f</sup>: % change in surface vs. RDI media after lettuce plants grown in planting basin. <sup>£</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of EC within surface irrigation and RDI media. Effect Size calculated by Partial Eta Squared.

Figure (4.6) shows that the media EC levels during lettuce plants growing were higher in the surface system than in the RDI system.



**Figure (4.6):** Media EC levels among surface irrigation and RDI for lettuce plants grown

Cristian Moya, Eduardo Oyanedel, and Gabriela Verdugo were conducted a study in 2017. In which a tomato crop was grown in soilless culture with various levels of electrical conductivity (EC). The effect of nutrient solutions with moderately high EC on fertigation parameters and the emission of nutrients to the environment, total crop productivity, distribution of fruit sizes, and dietary and organoleptic qualities were measured. Nutrient solutions of moderately high EC decreased total and commercial yield. A considerable decrease in extra-large and large fruits was also observed (Moya, Oyanedel, & Verd, 2017).

### **4.3 Levels of tested parameters in the leaf of lettuce plant grown under surface irrigation and RDI systems.**

#### **4.3.1 Levels of calcium in the lettuce leaf among surface irrigation and RDI systems.**

Ca levels lettuce leaf among surface irrigation and RDI used for growing lettuce plants are illustrated in Table 4.7. Statistical test pointed out there were statistically significant differences in leaf lettuce plant Ca levels before, during, and after lettuce plants were grown in both irrigation systems (surface irrigation and RDI), and the effect size was 99.6% ( $F=945.358$ ,  $P<0.001$ ).

The content of Ca levels curved change with values of  $1.89\pm 0$ ,  $2.84\pm 0.17$ , and  $1.87\pm 0.33$  g/L for surface irrigation and  $1.89\pm 0$ ,  $3.25\pm 0.53$ , and  $1.68\pm 0.29$  g/L for RDI in leaf lettuce plant before, during, and after lettuce plants have grown, respectively (Figure 4.7).

In surface irrigation and RDI on lettuce plants grown, the Pairwise Comparisons test (LSD) demonstrated statistically significant difference during lettuce plants grown compared to before and after lettuce plants grown in both surface irrigation and RDI systems ( $P=0.002$ ,  $P=0.003$ , respectively).

In contrast, there was no statistically significant difference in leaf lettuce plant's calcium levels before lettuce plants grown compared to after lettuce plants were grown in both surface irrigation and RDI systems ( $P=0.411$ ).

The Ca contents in leaf lettuce plants were 50.26% and 71.96% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

However, the percentages change in leaf lettuce plant Ca levels were -1.06% and -11.11% between before and after lettuce plants growing in surface irrigation and RDI, respectively.

There are lowering in percentages change in leaf lettuce plant's Ca levels between during and after lettuce plants growing in surface irrigation and RDI (-34.15% and -48.31%, respectively).

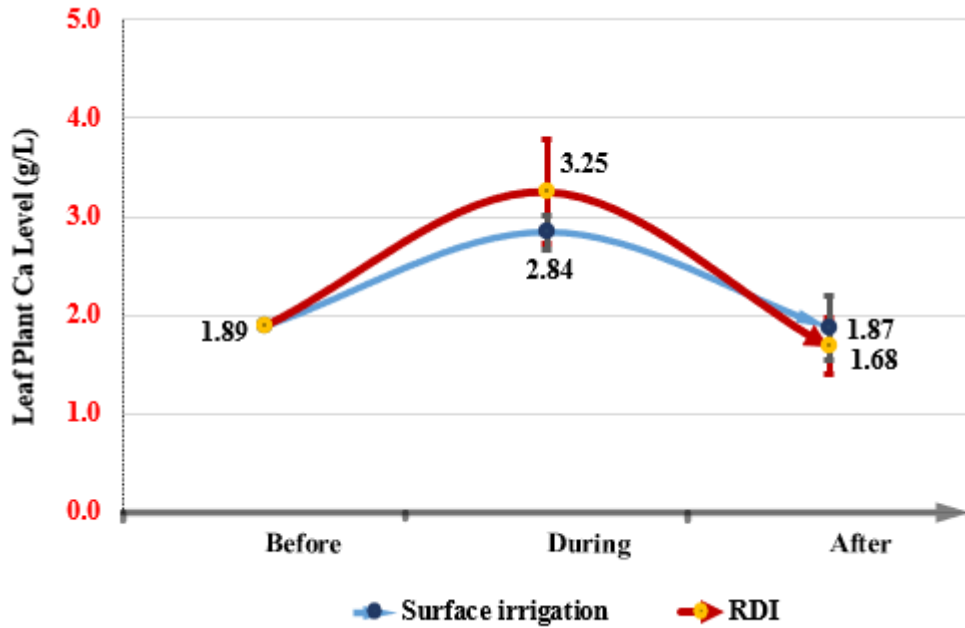
Repeated ANOVA measures illustrated that there is no statistically significant difference in leaf lettuce plant Ca contents between surface irrigation and RDI systems with an effect size was 6.2% ( $F=0.262$ ,  $P=0.636$  and Mauchly's test of sphericity=0.706).

Also, the percentages change in leaf lettuce plant Ca levels between surface irrigation and RDI for before, during and after lettuce plants growing were 0.0%, 14.45% and, -10%, respectively.

**Table (4.7): Leaf lettuce plants calcium levels among surface irrigation and RDI for lettuce plants grown**

Leaf lettuce plant Ca levels (g/L)		Irrigation systems Mean±SD		Statistical test <sup>£</sup>			
		Surface (n=3)	RDI (n=3)	% change	F	P-value	Effect Size
Ca (Before)		1.89±0.0	1.89±0.0	0.0 <sup>d</sup>	0.262	0.636	0.062
Ca (During)		2.84±0.17	3.25±0.53	14.45 <sup>e</sup>			
Ca (After or harvested)		1.87±0.33	1.68±0.29	-10 <sup>f</sup>			
Statistical test <sup>€</sup>	% change	50.26 <sup>a</sup>	71.96 <sup>a</sup>				
		-1.06 <sup>b</sup>	-11.11 <sup>b</sup>				
		-34.15 <sup>c</sup>	-48.31 <sup>c</sup>				
	Mauchly's test of sphericity	0.706					
	F	945.358					
	P-value	0.000					
	Effect size	0.996					
	Pairwise Comparisons (P-value)	0.002 <sup>* a</sup>					
		0.411 <sup>b</sup>					
0.003 <sup>* c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **Ca**: calcium; **RDI**: responsive drip irrigation; **n**: number of leaf lettuce plant; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in leaf lettuce plants Ca levels in surface irrigation vs. RDI before leaf lettuce plants are grown in planting basin; <sup>e</sup>: % change in leaf lettuce plants Ca levels in surface irrigation vs. RDI during leaf lettuce plants grown in planting basin and <sup>f</sup>: % change in leaf lettuce plants Ca levels in surface irrigation vs. RDI after lettuce plants are grown in planting basin. <sup>£</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of **Ca (g/L)** within surface irrigation and RDI in leaf lettuce plant. Effect Size calculated by Partial Eta Squared.



**Figure (4.7):** Leaf plant calcium levels among surface irrigation and RDI for lettuce plants grown

#### **4.3.2 K levels in the leaf of lettuce plants among surface irrigation and RDI system.**

Table 4.2 illustrated leaf lettuce plant K levels among surface irrigation and RDI used for growing lettuce plants. Repeated ANOVA measures pointed out that there are statistically significant differences in leaf lettuce plant K levels before, during, and after lettuce plants were grown in both irrigation systems (surface irrigation and RDI), and the effect size was 99.7% ( $F=1386.15$ ,  $P<0.001$ ).

As results showing, the K content was changed with values of  $0.519\pm 0$ ,  $0.684\pm 0.114$ , and  $0.595\pm 0.058$  g/L for surface irrigation and  $0.519\pm 0$ ,  $0.823\pm 0.026$ , and  $0.658\pm 0.039$  g/L for RDI in plant leaves before, during, and after lettuce plants have grown, respectively (Figure 4.8).

The Pairwise Comparisons test (LSD) demonstrated that it is statistically significant difference before lettuce plants grown compared to during and after lettuce plants grown in both surface irrigation and RDI systems ( $P=0.002$ ,  $P=0.006$ , respectively).

However, there is a statistically significant difference in leaf lettuce plant K levels during lettuce plants grown compared to after lettuce plants were grown in both surface irrigation and RDI systems ( $P=0.004$ ).

The percentages change in leaf lettuce plant K levels were 31.79% and 58.57% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

However, the percentages change in leaf lettuce plant K levels were 14.64% and 26.78% between before and after lettuce plants growing in surface irrigation and RDI, respectively while there are lowering in percentages change in leaf lettuce plant K levels between during and after lettuce plants growing in surface irrigation and RDI (-13.01% and -20.05%, respectively).

Repeated ANOVA measures illustrated that there were no statistically significant differences in leaf lettuce plant K levels between surface irrigation and RDI systems with an effect size was 49.3% ( $F=3.883$ ,  $P=0.120$  and Mauchly's test of sphericity=0.398).

Also, the percentages change in leaf lettuce plant K levels between surface irrigation and RDI for before, during and after lettuce plants growing were 0.0%, 20.27% and, 10.47%, respectively.

**Table (4.8): Leaf plants K levels among surface irrigation and RDI for lettuce plants grown**

Leaf plants K levels (g/L)		Irrigation systems Mean±SD		Statistical test <sup>£</sup>			
		Surface (n=3)	RDI (n=3)	% Change	F	P-value	Effect Size
K (Before)		0.519±0	0.519±0	0.00 <sup>d</sup>	3.883	0.120	0.493
K (During)		0.684±0.114	0.823±0.026	20.27 <sup>e</sup>			
K (After or harvested)		0.595±0.058	0.658±0.039	10.47 <sup>f</sup>			
Statistical test <sup>€</sup>	% Change	31.79 <sup>a</sup>	58.57 <sup>a</sup>				
		14.64 <sup>b</sup>	26.78 <sup>b</sup>				
		-13.01 <sup>c</sup>	-20.05 <sup>c</sup>				
	Mauchly's test of sphericity	0.398					
	F	1386.150					
	P-value	< 0.001 <sup>*</sup>					
	Effect size	0.997					
	Pairwise Comparisons (P-value)	0.002 <sup>* a</sup>					
		0.006 <sup>* b</sup>					
0.004 <sup>* c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **K**: potassium; **RDI**: responsive drip irrigation; **n**: number of leaf lettuce plant; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in leaf lettuce plants K levels in surface irrigation vs. RDI before leaf lettuce plants are grown in planting basin; <sup>e</sup>: % change in leaf lettuce plants K levels in surface irrigation vs. RDI during leaf lettuce plants grown in planting basin and <sup>f</sup>: % change in leaf lettuce plants K levels in surface irrigation vs. RDI after lettuce plants grown in planting basin. <sup>£</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of **K** (g/L) within surface irrigation and RDI in leaf lettuce plant. Effect Size calculated by Partial Eta Squared.

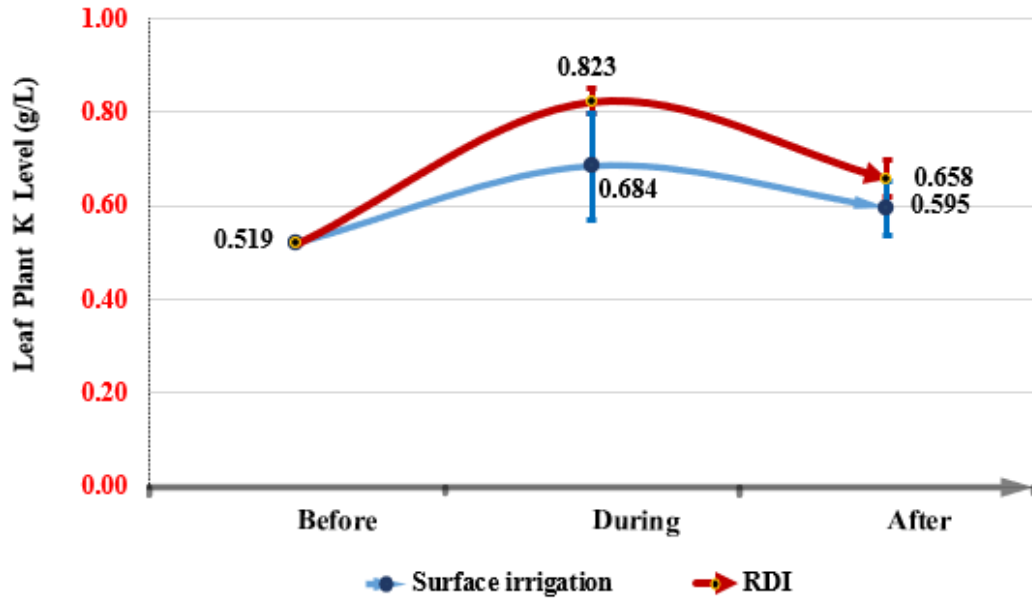


Figure (4.8): Leaf lettuce plants K levels among surface irrigation and RDI for lettuce plants grown

#### 4.3.3 P levels in the leaf of lettuce plants among surface irrigation and RDI system.

The P levels in lettuce plant's leaves among surface irrigation and RDI used for growing lettuce plants are illustrated in Table 4.9.

Repeated ANOVA measures showed that there are statistically significant differences in leaf lettuce plant P levels in before, during, and after lettuce plants are grown in both surface irrigation and RDI with the effect size was 99.8% ( $F=1658.491$ ,  $P<0.001$ )

As presented in the table, the P content were changed with values of  $0.49\pm 0$ ,  $1.06\pm 0.087$ , and  $1.018\pm 0.123$  g/L for surface irrigation and  $0.49\pm 0$ ,  $0.47\pm 0.157$ , and  $0.533\pm 0.085$  g/L for RDI in leaf lettuce plants before, during and after lettuce plants have grown, respectively (Figure 4.9).

Also, the Pairwise Comparisons test (LSD) demonstrated that there is statistically significant difference before lettuce plants grown compared to during and after lettuce plants were grown in both surface irrigation and RDI systems ( $P=0.006$ ,  $P=0.003$ , respectively).

In contrast, there is no statistically significant difference in media P levels during lettuce plants grown compared to after lettuce plants grown in both surface irrigation and RDI systems ( $P=0.902$ ).

The percentages change in leaf lettuce plant P levels were 116.33% and -4.08% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

Additionally, the percentages change in leaf lettuce plant P levels were 107.76% and 8.78% between before and after lettuce plants growing in surface irrigation and RDI, respectively while there are lowering in percentages change in leaf lettuce plant P levels between during and after lettuce plants growing in RDI but elevated in leaf lettuce plants P levels in surface irrigation (-3.96% and 13.4%, respectively).

Repeated ANOVA measures illustrated that there is no statistically significant difference in leaf lettuce plant P levels between surface irrigation and RDI systems with an effect size was 96.7% ( $F=116.124$ ,  $P<0.001$  and Mauchly's test of sphericity=0.233).

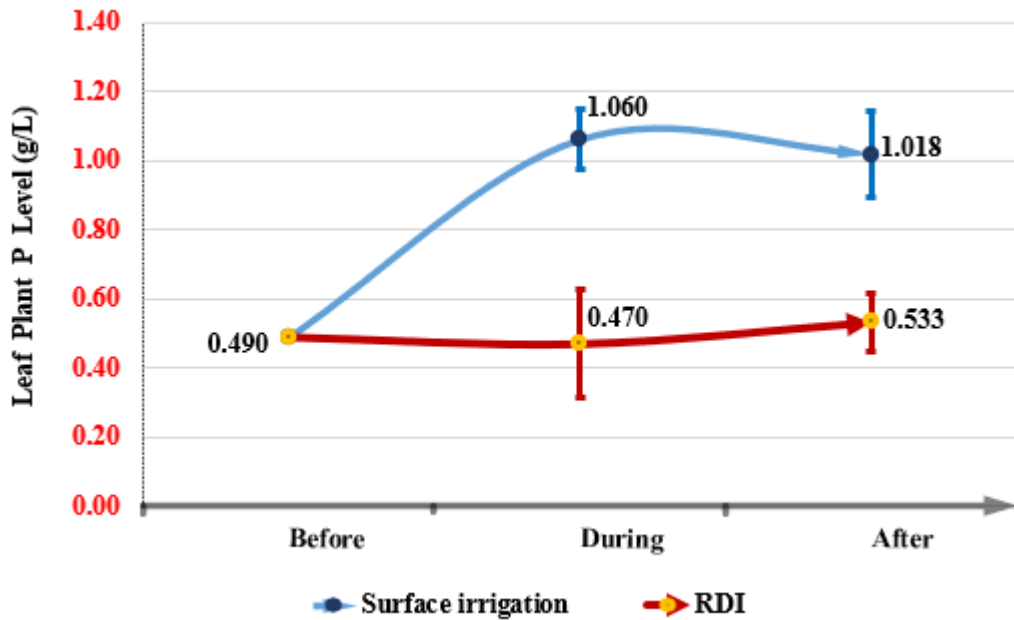
Also, the percentages change in leaf lettuce plant P levels between surface irrigation and RDI for before, during, and after lettuce plants growing were 0%, -55.66% and, -47.61%, respectively.

**Table (4.9): Leaf lettuce plants P levels among surface irrigation and RDI for lettuce plants grown**

Leaf lettuce plants P levels (g/L)		Irrigation systems		Statistical test <sup>‡</sup>			
		Mean±SD		% Change	F	P-value	Effect Size
		Surface (n=3)	RDI (n=3)				
P (Before)		0.49±0.0	0.49±0.0	0 <sup>d</sup>	116.124	< 0.001 <sup>*</sup>	0.967
P (During)		1.06±0.087	0.47±0.157	-55.66 <sup>c</sup>			
P (After or harvested)		1.018±0.123	0.533±0.085	-47.61 <sup>f</sup>			
Statistical test <sup>€</sup>	% Change	116.33 <sup>a</sup>	-4.08 <sup>a</sup>				
		107.76 <sup>b</sup>	8.78 <sup>b</sup>				
		-3.96 <sup>c</sup>	13.4 <sup>c</sup>				
	Mauchly's test of sphericity	0.233					
	F	1658.491					
	P-value	< 0.001 <sup>*</sup>					
	Effect size	0.998					
	Pairwise Comparisons (P-value)	0.006 <sup>*a</sup>					
0.003 <sup>*b</sup>							
0.902 <sup>c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **P**: Phosphorus; **RDI**: responsive drip irrigation; **n**: number of leaf lettuce plant; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in leaf lettuce plants P levels in surface irrigation vs. RDI before leaf lettuce plants grown in planting basin; <sup>e</sup>: % change in leaf lettuce plants P levels in surface irrigation vs. RDI during leaf lettuce plants grown in planting basin and <sup>c</sup>: % change in leaf lettuce plants P levels in surface irrigation vs. RDI after lettuce plants grown in planting basin. <sup>‡</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of P (g/L) within surface irrigation and RDI in leaf lettuce plant. Effect Size calculated by Partial Eta Squared.

As for leaf plant P levels, Figure (4.9) shows that it was higher in the surface system than in the RDI system.



**Figure (4.9):** Leaf lettuce plants P levels among surface irrigation and RDI for lettuce plants grown.

Jacek Dyśko, Waldemar Kowalczyk and Stanisław Kaniszewski were conducted a study in 2006. In which the phosphorus content was higher in the leaves of tomato plants grown in rockwool compared to those in the organic media (Dyśko, Kowalczyk, & Kani, 2009).

#### **4.3.4 N levels in the leaf of lettuce plants among surface irrigation and RDI system.**

Table 4.10 illustrates N levels status in leaf lettuce plant among surface irrigation and RDI used for growing lettuce plants.

Repeated ANOVA measures pointed out that there is showing statistically significant differences in leaf lettuce plant N levels

before, during, and after lettuce plants were grown in both irrigation systems (surface irrigation and RDI). The effect size was 99.9% ( $F=6968.736$ ,  $P<0.001$ ).

The N content gradually increased with values of  $3.32\pm 0$ ,  $3.84\pm 0.488$ , and  $4.16\pm 0.513$  g/L for surface irrigation and  $3.32\pm 0$ ,  $3.72\pm 0.269$ , and  $4.047\pm 0.225$  g/L for RDI in leaf lettuce plant before, during and after lettuce plants have grown, respectively (Figure 4 .10).

The Pairwise Comparison test (LSD) demonstrated statistically significant differences before, during, and after lettuce plants were grown in both surface irrigation and RDI systems ( $P=0.046$ ,  $P=0.008$ , respectively).

However, there were statistically significant difference in leaf N levels during lettuce plants grown compared to after lettuce plants were grown in both surface irrigation and RDI systems ( $P=0.332$ ).

The percentages change in leaf lettuce plant N levels were 15.66% and 12.05% between before and during lettuce plants growing in surface irrigation and RDI, respectively.

Also, the percentages change in N levels were 25.3% and 21.9% between before and after lettuce plants growing in surface irrigation and RDI, respectively while there are lowering in percentages change in leaf lettuce plant N levels between during and after lettuce plants growing in surface irrigation and RDI (8.33% and 8.79%, respectively).

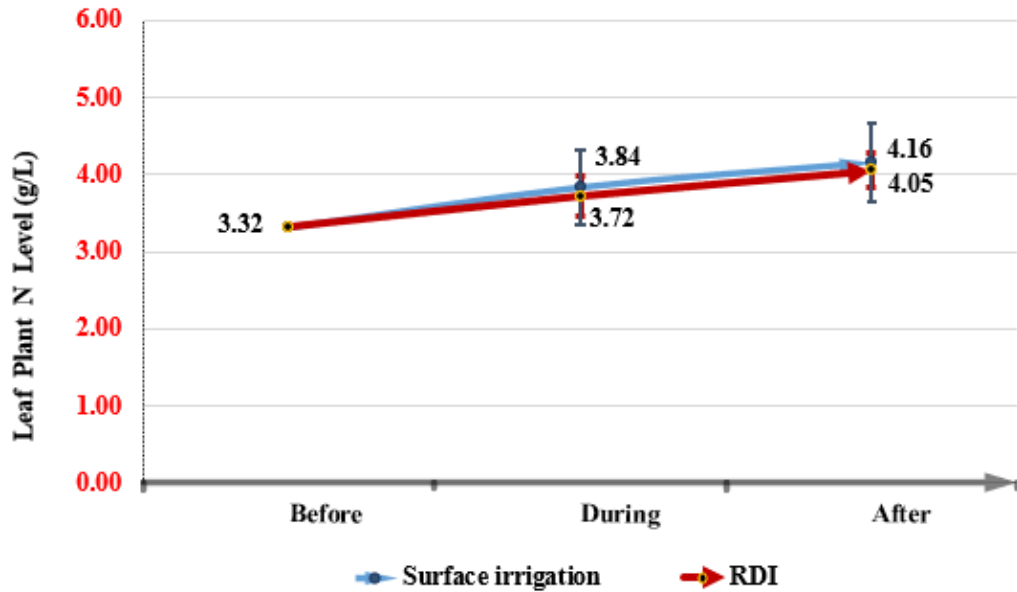
Repeated ANOVA measures illustrated that there is no statistically significant difference in leaf lettuce plant N levels between surface irrigation and RDI systems with an effect size is 15.9% ( $F=0.756$ ,  $P=0.434$  and Mauchly's test of sphericity=0.120).

Also, the percentages change in leaf lettuce plant N levels between surface irrigation and RDI for before, during and after lettuce plants growing were 0%, -3.13% and, -2.72%, respectively.

**Table (4.10): Leaf lettuce plants N levels among surface irrigation and RDI for lettuce plants grown**

Leaf lettuce plants N levels (g/L)		Irrigation systems Mean±SD		Statistical test <sup>‡</sup>			
		Surface (n=3)	RDI (n=3)	% Change	F	P-value	Effect Size
N (Before)		3.32±0.0	3.32±0.0	0.00 <sup>d</sup>	0.756	0.434	0.159
N (During)		3.84±0.488	3.72±0.269	-3.13 <sup>e</sup>			
N (After or harvested)		4.16±0.513	4.047±0.225	-2.72 <sup>f</sup>			
Statistical test <sup>€</sup>	% Change	15.66 <sup>a</sup>	12.05 <sup>a</sup>				
		25.3 <sup>b</sup>	21.9 <sup>b</sup>				
		8.33 <sup>c</sup>	8.79 <sup>c</sup>				
	Mauchly's test of sphericity	0.120					
	F	6968.736					
	P-value	* < 0.001					
	Effect size	0.999					
	Pairwise Comparisons (P-value)	0.046 <sup>a</sup>					
		0.008 <sup>b</sup>					
0.332 <sup>c</sup>							

\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **N**: Nitrogen; **RDI**: responsive drip irrigation; **n**: number of leaf lettuce plants; **SD**: standard deviation; **F**: repeated ANOVA measures; Pairwise Comparisons (LSD) <sup>a</sup>: Before vs. During; <sup>b</sup>: Before vs. After; <sup>c</sup>: During vs. After; <sup>d</sup>: % change in leaf lettuce plants N levels in surface irrigation vs. RDI before leaf lettuce plants are grown in planting basin; <sup>e</sup>: % change in leaf lettuce plants N levels in surface irrigation vs. RDI during leaf lettuce plants grown in planting basin and <sup>f</sup>: % change in leaf lettuce plants N levels in surface irrigation vs. RDI after lettuce plants grown in planting basin. <sup>‡</sup> Statistical test between surface irrigation and RDI; <sup>€</sup> Statistical test between the level of N (g/L) within surface irrigation and RDI in leaf lettuce plants. Effect Size calculated by Partial Eta Squared.



**Figure (4.10):** Leaf plants N levels among surface irrigation and RDI for lettuce plants grown.

#### **4.4 Water and fertilizers' use efficiency of soilless lettuce plants grown under surface irrigation and RDI systems.**

Table 4.11 and Figure 4.11 illustrate water and fertilizers use, the efficiency of soilless lettuce plants grown among surface irrigation and RDI 200 lettuce plants were grown in irrigation systems, 100 lettuce plants were grown in surface irrigation systems and 100 lettuce plants were grown in RDI.

The total number of lettuce plants harvested from the RDI system were 90 out of 100 plants while 66 out of 100 plants were harvested from the surface irrigation system.

The harvested proportion from the RDI system was higher statistically significant than the surface irrigation system (57.69% vs.

42.31%, respectively, % change= 36.36%, Z-test=2.175 and P=0.015, Figure 4.11a).

Regarding the amount of water consumption, the RDI system a lower water consumption compared to the surface irrigation system (340 vs. 440 L, respectively) and the Z-test pointed out that the RDI system was lower statistically significant than surface irrigation system in water consumption (43.59%, vs. 56.41% respectively, % change = -22.73%, Z-test = -1.813 and P = 0.035, Figure 4.11b).

The productivity of the RDI system was higher than the surface irrigation system (7,755 vs. 2885 Kg, respectively), and the statistical test showed that the RDI system was higher statistically significant in productivity than the surface irrigation system (72.89% vs. 27.11., respectively, % change = 168.8%, Z-test = 6.474 and P < 0.001; Figure 4.11c).

In the same way productivity/ plant ratio showed that RDI system were higher statistically significant in productivity/ plant ratio than surface irrigation system (66.35% vs. 33.65%, respectively, % change = 97.14%, Z-test = 4.625 and P < 0.001; Figure 4.11d).

Additionally, the amount of water use efficiency in RDI system was elevated statistically significant than surface irrigation system (22.81 vs. 6.56 g/L, respectively) and the Z-test illustrated that the amount of water use efficiency in RDI system was higher statistically significant than

surface irrigation system (77.67% vs. 22.33%, % change = 247.86%, Z-test = 7.826 and  $P < 0.001$ ; Figure 4.11e).

These results agreed with Sezen et al. (2010) where they obtained highest yield and fruit number from the use of soilless media for growing tomato. The highest irrigation water use efficiency obtained from once a day irrigation level. Water use efficiency decreased in all treatments as the amount of irrigation water increased (Sezen, Celikel, Yazar, Tekin, & Kapur, 2010).

Parra et al. (2009) studied recirculation strategies in three different substrates as an alternative to soilless culture in open system. The results indicate that the closed system saved up to 45% of water applied, and up to 69% of the water discharged (Parra, Raya, Cid, & Haroun, 2009).

Finally, fertilizer use efficiency was increased in the RDI system compared to the surface irrigation system (10.34 vs. 3.85 Kg/g) and the statistical test showed that the fertilizer use efficiency in RDI system were higher statistically significant than surface irrigation system (27.11% vs. 72.89%, % change = 168.8%, Z-test = 6.474 and  $P = 0.001$ ; Figure 4.11f).

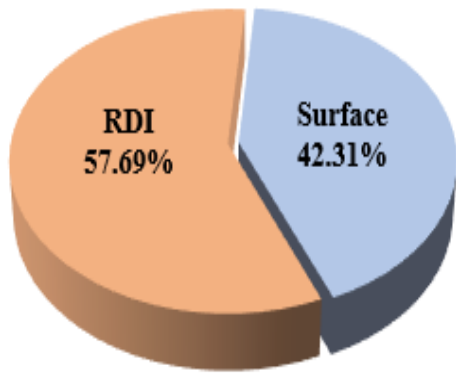
These results agree with the study conducted by Rodolfo De la Rosa-Rodríguez, et al, 2019, evaluated the efficiency of use of water and fertilizers in closed and open hydroponic tomato production systems under greenhouse conditions. It showed no significant differences between the two treatments on fruit production. The closed system's water usage efficiency was 59.53 kg/fruit/m<sup>3</sup>, while in the open system was 46.03

kg/fruit/m<sup>3</sup>. The closed system produced 13.50 kg more fruit per cubic meter of water relative to the open system, although only 10.31 grams' fewer fertilizers per kilogram of fruit produced were applied. The efficiency of water and fertilizers use was higher in the closed system by 22.68% and 22.69%, respectively. More efficiency was obtained in the closed system, regarding the open system (Rosa-Rodríguez, et al., 2019).

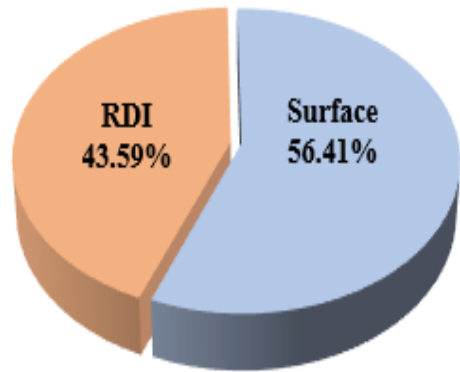
**Table (4.11): Water and fertilizers' use efficiency of soilless lettuce plants grown among surface irrigation and RDI for lettuce plants grown**

Parameters	Irrigation systems				Statistical test		
	Surface (n=100)	RDI (n=100)	% of Total		% Change	Z-test	P-value
			Surface	RDI			
Numbers of harvested leaf plants (Total n=156)	66	90	42.31	57.69	36.36	2.175	0.015
The amount of water consumption (L)	440	340	56.41	43.59	-22.73	-1.813	0.035
Productivity (g)	2,885	7,755	27.11	72.89	168.80	6.474	< 0.001
Productivity/ plant ratio (g)	43.71	86.17	33.65	66.35	97.14	4.625	< 0.001
Water use efficiency (g/L)	6.56	22.81	22.33	77.67	247.86	7.826	< 0.001
Fertilizer use efficiency (Kg/g)	3.85	10.34	27.11	72.89	168.80	6.474	< 0.001

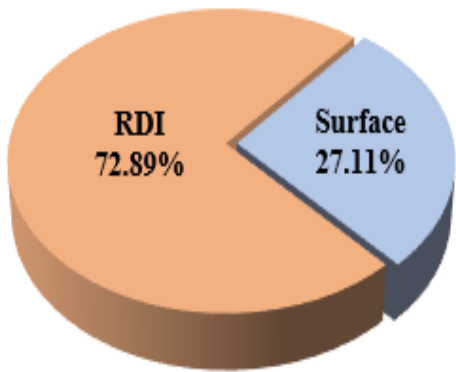
\* Significant at  $P \leq 0.05$ ;  $P > 0.05$ : Not significant; **RDI**: responsive drip irrigation and **n**: number of plants.



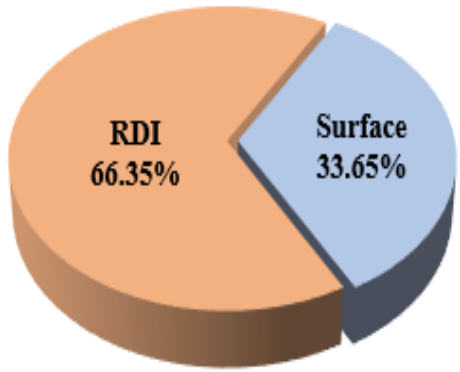
a) Numbers of harvested leaf plants



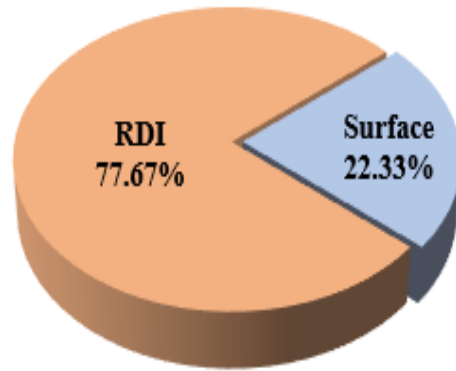
b) Water consumption



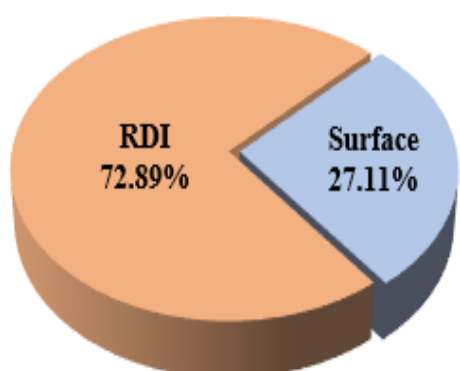
c) Productivity



d) Productivity/ plant ratio



e) Water use efficiency



f) Fertilizer use efficiency

**Figure 4.11** Efficiency of soilless lettuce plants grown among RDI and surface irrigation for lettuce plants grown a) numbers of harvested leaf plants b) water consumption c) productivity d) Productivity/ plant ratio e) Water use efficiency & f) Fertilizer use efficiency.

Ibrahim M. Makhadmeh et al., in 2017, studied the effects of growth medium and planting density on the production of lettuce under a closed soilless system. The findings showed that planting density and growth medium exhibited significant effects on the total number of leaves, number of inner leaves, number of outer leaves, number of non-consumable leaves, leaves weight (outer, inner), stem weight, plant height (cm) head mass and marketable head mass (Makhadmeh, et al., 2017).

Also, there is a study was conducted by M.M. Maboko, C.P. Du Plooy and I. Bertling in 2009, to compare yield and quality parameters of tomato cultivars cultivated in-soil under a shadenet structure with an open bag hydroponic (soilless) system in a plastic tunnel. Four tomato cultivars, were included using a randomized complete block design with four replicates for both trials. the tomato juice was determined. Results showed that plants in the soilless system developed faster with higher total yield compared with in-soil cultivation. The average marketable yield using soilless cultivation was 92.1%, while in-soil cultivation was only 77.0% (Maboko, Plooy, & Bertling, 2009).

## Chapter Five

### Conclusion and Recommendations

#### 5.1. Conclusion

An experimental research design (Randomized complete block design) was conducted between June to November 2020 to evaluate biomass, water, and fertilizers' use efficiency of soilless lettuce grown under two irrigation systems (surface irrigation and responsive drip irrigation). The experiment was conducted in West Bank, at the National Agriculture Research Center (NARC). In total 200 lettuce seedling was grown in soilless media. Seedlings were inserted into the Nutrient Film Technique (NFT) channel with 30 cm between each plant and 30 cm between the channels. Three replicated channels of lettuce under RDI and three under surface drip irrigation.

-Regarding the media; the study findings showed that there were statistically significant trends for calcium, K, P, N, pH, and EC levels before, during, and after the growing of the lettuce plants for both irrigation systems "surface irrigation and RDI".

The contents of Ca and N in the media increased for surface irrigation and RDI in media before, during, and after growth of the lettuce.

Regarding the efficiency of RDI on media lettuce plants grown compared to surface irrigation, the results illustrated that there were statistically significant differences in media K levels between surface

irrigation and RDI systems. Also, there were no statistically significant differences in media P, N, pH, and EC levels between surface irrigation and RDI systems. Note that the media EC levels were higher in the surface system during growth than in the RDI system.

The study showed that there were statistically significant differences in lettuce-leaf plant's Ca, K, P, and N contents before, during, and after lettuce plants were grown in both irrigation systems "surface irrigation and RDI."

Regarding the efficiency of RDI on leaf lettuce plants grown compared to surface irrigation, there were no statistically significant differences in leaf lettuce plant Ca, K, P, and N levels between surface irrigation and RDI systems. Note that the leaf plant P levels were higher in the surface system than in the RDI system.

On the other hand, the study findings showed that the total number of lettuce plants harvested from the RDI system was 90 out of 100 plants, while 66 out of 100 plants were harvested from the surface irrigation system.

The RDI system had a lower water consumption than the surface irrigation system. The RDI system's productivity was higher than that for surface irrigation system. In the same way, the productivity/ plant ratio showed that the RDI system had a higher productivity/ plant ratio than a surface irrigation system. Additionally, the amount of water use efficiency

in RDI system was elevated statistically significantly than the surface irrigation system.

Finally, fertilizer use efficiency was higher in the RDI system than the surface irrigation system.

## **5.2. Recommendations**

**Based on the results and conclusions of the study, the followings are recommended, and grouped per stakeholders:**

### **For Decision Makers**

- To adopt modern irrigation systems that save water use, such as RDI.
- To adopt cultivation systems in soilless culture and generalizing them to farmers.
- To increase farmers awareness through periodic workshops to clarify the idea of the RDI irrigation system
- To develop agricultural policies and making modern methods part of the contemporary system because of its multiple benefits.
- To adopt soilless media as an alternative for soil for growing lettuce and leafy crops.
- To registrar RDI under the ministry of agriculture as best irrigation practices and save irrigation water and fertilizers.

- To disseminate the RDI system to the farmers through more demonstration under farmer's conditions.
- To prepare guideline for the best use of RDI.
- To build capacity for the extension of soilless and RDI.

### **For Researchers and Research institutes**

- To conduct experiments on other leafy crops like spinach and arugula.
- Year-round cultivation with RDI system to check the efficiency of this system in different seasons.
- To introduce other modern technology and irrigation systems and testing them with farmers to test their efficiency.

### **For Farmers:**

- To adopt soilless system for production of leafy crops specially in summer.
- To use RDI system for irrigation soilless cultures to reduce water and realizers use and decrease cost production.

### **For Consumers:**

- To consume lettuce and other leafy crops grown under soilless system where it will be healthier.

- To encourage soilless farmers for production under soilless culture to maintain the natural resources of Palestine.
- To promote the environmentally friend products.

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**Annex 1**

**Photos during experimental setup**







كفاءة استخدام المياه والأسمدة لنباتات الخس عديمة التربة التي  
تزرع في ظل ظروف مختلفة

إعداد

إيمان تيسير جرار

إشراف

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قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في العلوم البيئية، بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس - فلسطين.

2021

ب

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## الملخص

**الخلفية:** الزراعة الخالية من التربة هي مثال على نظام الزراعة المائية الذي يزود النباتات بالمغذيات والمياه. وهذا النظام عالي الإنتاجية ويمكنه معالجة النقص في الأراضي والمياه فيما يتعلق بالطلب المتزايد على إنتاج الغذاء. ويعتبر الخس من أفضل المحاصيل لأنظمة الخالية من التربة لأنه يمكن إنتاجه في فترة قصيرة.

**الهدف:** تهدف الدراسة إلى تقييم كفاءة استخدام الكتلة الحيوية والمياه والأسمدة للخس عديم التربة المزروع تحت نظامين للري (الري السطحي والري بالتنقيط سريع الاستجابة).

**الطريقة:** تم إجراء تصميم بحث تجريبي في الفترة من يونيو إلى نوفمبر 2020. تم زراعة 200 شتلة خس على نظامي ري "100 على أنظمة الري السطحي و100 على أنظمة الري بالتنقيط السريع بالاستجابة". استخدمت الباحثة عينة عشوائية لاختيار 6 قنوات من نباتات الخس "3 ري سطحي و3 ري بالتنقيط سريع الاستجابة". تم إدخال الشتلات في قنوات تقنية الغشاء المغذي بمسافة 30 سم بين كل نبات وآخر و30 سم بين القنوات، حيث تم إجراء العديد من التحليلات الكيميائية للوسط المغذي وأوراق النبات.

**النتائج:** أظهرت نتائج الدراسة أن إجمالي عدد نباتات الخس المحصودة من نظام الري بالتنقيط سريع الاستجابة هو 90 نبتة من أصل 100 نبتة بينما تم حصاد 66 من أصل 100 نبتة من نظام الري السطحي. كان نظام الري بالتنقيط سريع الاستجابة أقل من نظام الري السطحي في استهلاك المياه. كانت إنتاجية نظام الري بالتنقيط سريع الاستجابة أعلى من نظام

الري السطحي. بالإضافة إلى ذلك، فإن كمية كفاءة استخدام المياه في نظام الري بالتنقيط سريع الاستجابة كانت مرتفعة إحصائيًا من نظام الري السطحي. وتمت زيادة كفاءة استخدام الأسمدة في نظام الري بالتنقيط سريع الاستجابة مقارنة بنظام الري السطحي.

**الخلاصة:** توجد اتجاهات ذات دلالة إحصائية في الوسط المغذي لمستويات الكالسيوم، والبوتاسيوم، والفسفور، والنيتروجين، ودرجة الحموضة، والتوصيل الكهربائي قبل وأثناء وبعد زراعة نباتات الخس لكلا نظامي الري. كما توجد فروق ذات دلالة إحصائية في مستويات الكالسيوم، والبوتاسيوم، والفسفور، والنيتروجين في نبات الخس قبل وأثناء وبعد زراعة نبات الخس في نظامي الري. كان لنظام RDI استهلاك مياه أقل من نظام الري السطحي. كانت إنتاجية نظام RDI أعلى من إنتاجية نظام الري السطحي. أظهرت نسبة الإنتاجية/النبات أن نظام RDI لديه نسبة إنتاجية / نبات أعلى من نظام الري السطحي. بالإضافة إلى ذلك، ارتفعت كفاءة استخدام المياه في نظام RDI بشكل ملحوظ إحصائيًا عن نظام الري السطحي. أخيرًا، كانت كفاءة استخدام الأسمدة أعلى في نظام RDI من نظام الري السطحي.

**الكلمات المفتاحية:** كفاءة استخدام المياه، كفاءة استخدام الأسمدة، نباتات الخس، بدون تربة، الري بالتنقيط سريع الاستجابة "RDI"، والري السطحي.

