THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Science (Sustainable Agriculture)
DEGREE

Sustainable Agriculture
FIELD

Agriculture
FACULTY

TITLE: Comparison of Hydroponic Solutions for Growing Lettuce in Nutrient Film Technique (NFT) System

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THESIS

COMPARISON OF HYDROPONIC SOLUTIONS FOR GROWING LETTUCE IN NUTRIENT FILM TECHNIQUE (NFT) SYSTEM

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A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science (Sustainable Agriculture)
Graduate School, Kasetsart University
2014

Radika Samanthi Malawwathanthri 2014: Comparison of Hydroponic Solutions for Growing Lettuce in Nutrient Film Technique (NFT) System. Master of Science (Sustainable Agriculture), Major Field: Sustainable Agriculture, Faculty of Agriculture. Thesis Advisor: Assistant Professor Sudsaisin Kaewrueng, Ph.D. 79 pages.

This study aimed at comparing two hydroponic solutions one is commonly used in Sri Lanka (solution y) and the other one is vastly used in Thailand (solution x) for growing lettuce in Nutrient Film Technique (NFT) system. In experiment one, lettuce was grown in two solutions as treatments T1 and T2 with EC and pH being maintained 1.2 mS/cm to 1.8 mS/cm and 6.0 to 6.5 during cropping cycle, respectively. In experiment two, lettuce was grown in four solutions as treatment. Treatment T1 and T2 were the same as the first experiment, while treatments T3 and T4 using the same solution as treatment T2 but with adding N as in the same amount of treatment T1 in the case of treatment T3 and half of that amount in the case of at treatment T4. In experiment two, EC was not maintained and pH level was maintained as in experiment 1. pH and EC level of the treatments, number of leaves per week, fresh yield, dry yield and N, P, K, Ca and Mg content in the upper ground biomass were observed in both experiments. In experiment one, it was found that nutrient content in the upper ground biomass and plant growth and development is better in treatment T2 than in treatment T1. K content in both treatments should be reduced and other four elements can be increased according to sufficiency nutrient level of lettuce to obtain better yield. In experiment two, plant growth and development is better in treatment T1 than in other three treatments and N content and K content in treatment T1 and K content in treatment T2 should be reduced up to suitable level which can be obtained N is 35 to 45 g/kg and K is about 55 to 62 g/kg. P content in both solutions should be increased up to suitable level that can be obtained P in upper ground biomass is 4 to 8 g/kg.

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ACKNOWLEDGEMENTS

I would like to grateful thank and deeply indebted to Assist. Prof. Dr. Sudsaisin Kaewrueng my thesis advisor for advice, encouragement and valuable suggestion for completely writing of thesis. I would sincerely like to thank Assoc. Prof. Thanya Taychasinpitak, and Assist. Prof. Somchai Anusontpornperm for their valuable comments and as my commetees. I gratefully thank Dr.C.Youngyuth for kindly providing nutrient solution and other some materials and giving some instructions for using in this research.

I would like to sincerely thank Dr. L.M.Abeywickrama in Faculty of Agriculture University of Ruhuna Sri Lanka for his help encouragement and enthusiasm during research work. I would like to greatly thank to Ms. Kanikar Phetmak and lab assistant in soil laboratory who help me to do a lab analyzes. I am heartfelt thank to my daughter who lived with me at during research time in Bangkok, my friends N.W.C.P.Lanka, Thanh Nuguyen and Phyu Thaw for their assistance for doing experiments.

This research was supported by Thailand International Development Cooperation Agency (TICA) under the Royal Thai Government.

I am especially appreciated my parents, sisters, sister-in-laws, brothers and brother-in-laws for their continuing encouragements. Finally, I am deeply appreciated to my husband and daughter who always give me heartfelt love during my graduate study and bare everything without my absence of two year period of time.

Radika Samanthi Malawwathanthri

May 2014

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LIST OF ABBRIVIATIONS

C = carbon

Ca = calcium

Ca^{2+} = calcium cation

CO_2 - = carbon dioxcide

^{O}C. = degree celcious

EC = Electrical Conductivity

Fe = ferous

H = hydrogen

H_2PO_4 = dihydrogen phosphate

K = potassium

K^+ = potassium cation

KOH = potasium hydroxide

Mg = magnesium

Mg^{2+} = mgnesium cation

mS/cm = milliSemens per centimeter

MES = 2-(N-morpholino) Ethane Sulfonic acid

NH_4 = ammonia

NH_4^+ = ammonium

N = nitrogen

NO_3 = nitrate

NFT = Nutrient Film Technique

O = oxygen

P = phospherous

ppm = parts per million

ppk = parts per thousands

S = sulpher

SO_4 = sulfate

TDS = Total Dissolved Solids

TPS = Total Plant nutrient strength

LIST OF ABBRIVIATIONS (Continued)

uS/cm = microSemens per centimeter

COMPARISON OF HYDROPONIC SOLUTIONS FOR GROWING LETTUCE IN NUTRIENT FILM TECHNIQUE (NFT) SYSTEM

INTRODUCTION

Vegetables can be grown under hydroponics as intensive agriculture. Hydroponics is a soilless culture use for green house farming. In here nutrient solutions are used to supply nutrients for crop. The physiological requirements of plants can be met without the use of soil. Plants are rooted (and thus supported) in food-safe floating, rotating trays and nutrition is provided by water-soluble nutrients. Hydroponic cultivation allows farmers easily to control the nutrient supply, by adjusting the concentration of the hydroponic nutrient solution. This factor affects the plant water and salt relations and influences plant growth and quality. (Caruso *et al*., 2011).

The hydroponics plant in system is grown in a floating, shallow water bed filled with nutrient rich water, rather than being planted directly into the ground. It does not matter where the greenhouse is located, because soil and water quality, and outdoor conditions are irrelevant. The environment is controlled for optimum results.

The plants can grow in an ideal environment, since everything can be determined, which is normally up to “mother nature.” In a completely controlled environmental agricultural system, light, temperature, water, CO_2, oxygen, pH, humidity, and nutrients are controlled.

Years of research have determined which nutrient blends to use and their combinations affect plant growth (our hydroponics formulas). This allows for greater control over plant nutrition, and therefore, increased production at low costs in a shorter growth cycle.

Plant roots are fed directly and continuously with an aqueous solution containing the correct balance of plant nutrients and introduced in micro-doses in order to provide the perfect growing conditions. Therefore, the plant is not dependent on drawing its nutrient requirements from an often-depleted soil, or wasting energy growing roots for support in the soil and reaching down to find food. Also, the plants do not suffer from the risks of inadequate rainfall and/or excessive water waste associated with irrigation or the risk of pathogens from neighboring farm contaminants.

A tightly controlled environment is created. Plants are protected from adverse and unexpected weather conditions such as heavy rain, strong winds, hailstorms, frost, snow, hail, low temperatures, high heat and excessive sunlight. They are also protected from pests and plant diseases, thus avoiding pesticides and herbicide residues.

As a result, an uninterrupted supply of hydroponics products can be made available to the market throughout the year, and can boast “local grown” 6-24 hours from the store shelf, save 70% - 90% in water and energy, and are clean, safe and green.

In modern days and also future land for cultivation will be limited because of rapid growth rate of population. Hence researchers should think about how to grow vegetable like food items using low space and without soil. Using hydroponics people can produce their own food in their balcony or any space in their home using pots, bottles, cups and utensils which are used in home.

Nowadays environmental disaster can be always seen in everywhere. Therefore people must have to be ready to face them. After disasters cultivated lands can be destroyed and food shortage can occur. In this situation hydroponics is very essential to people. Hence improving that technique is better for future.

For above reasons Hydroponics is planned to use with short term crop such as 2 month or one and a half month vegetable because research has being completed within two years.

OBJECTIVES

1. To determine the suitable hydroponic solution for growing lettuce in NFT system using hydroponic solutions named as solution x, solution y, solution z_1 and solution z_2

2. To examine the nutrient concentration and uptake in lettuce as affected by nutrients in different hydroponics solutions.

LITERATURE REVIEW

1. Hydroponics

Hydroponics is a subset of hydro culture and is a method of growing plants using mineral nutrient solutions, in water, without soil. Terrestrial plants may be grown with their roots in the mineral nutrient solution only or in an inert medium, such as perlite, gravel, mineral wool, expanded clay or coconut husk.

Researchers discovered in the 18th century that plants absorb essential mineral nutrients as inorganic ions in water. In natural conditions, soil acts as a mineral nutrient reservoir but the soil itself is not essential to plant growth. When the mineral nutrients in the soil dissolve in water, plant roots are able to absorb them. When the required mineral nutrients are introduced into a plant's water supply artificially, soil is no longer required for the plant to thrive. Almost any terrestrial plant will grow with hydroponics. Hydroponics is also a standard technique in biology research and teaching. (Caruso *et al*., 2011).

2. History of Hydroponics

The very earliest published work on growing terrestrial plants without soil was the 1627 book *Sylva Sylvarum* by Francis Bacon, printed a year after his death. Water culture became a popular research technique after that. In 1699, John Woodward published his water culture experiments with spearmint. He found that plants in less-pure water sources grew better than plants in distilled water. By 1842, a list of nine elements believed to be essential to plant growth had been compiled, and the discoveries of the German botanists Julius von Sachs and Wilhelm Knop, in the years 1859-65, resulted in a development of the technique of soilless cultivation. Growth of terrestrial plants without soil in mineral nutrient solutions was called solution culture. It quickly became a standard research and teaching technique and is still widely used today. Solution culture is now considered a type of hydroponics where there is no inert medium.

In 1929, William Frederick Gericke of the University of California at Berkeley began publicly promoting that solution culture be used for agricultural crop production. He first termed it aquaculture but later found that aquaculture was already applied to culture of aquatic organisms. Gericke created a sensation by growing tomato vines twenty-five feet high in his back yard in mineral nutrient solutions rather than soil. By analogy with the ancient Greek term for agriculture, geoponics, the science of cultivating the earth, Gericke coined the term *hydroponics* in 1937 (although he asserts that the term was suggested by W. A. Setchell, of the University of California) for the culture of plants in water (from the Greek *hydro-*, "water", and *ponos*, "labour") (Douglas, 1975).

3. Advantages

- No soil is needed for hydroponics. Crops can be grown where no suitable soil exists or where the soil is contaminated with diseases.
- Labor for tilling, cultivating, fumigating, watering and other traditional practices is largely eliminated.
- Conservation of water and nutrients is a feature of all systems. This can lead to reduction in pollution of land and streams because valuable chemicals need not to be lost.
- Maximum yield are possible, making the system economically feasible in high-density and expensive land area.
- Soil born plant diseases are more readily eradicated in closed systems which can be totally flooded with an eradicate.
- More complete control of the environment is generally a feature of the system and in greenhouse –type operations, the light, temperature, humidity and composition of the air can be manipulated.

- The amateur horticulturist can adapt a hydroponics system to home and patio-type gardens, even in high rise buildings. A hydroponics system can be clean, lightweight, and mechanized.
- It is easier to harvest
- No pesticide damage (Jones, 1997).

Today, hydroponics is an established branch of agronomy. Progress has been rapid, and results obtained in various countries have proved it to be thoroughly practical and to have very definite advantages over conventional methods of horticulture.

There are two chief merits of the soil-less cultivation of plants. First, hydroponics may potentially produce much higher crop yields. Also, hydroponics can be used in places where in-ground agriculture or gardening is not possible. (Douglas, 1975).

4. Disadvantages

- The original construction cost is great.
- Trained personnel must direct the growing operation. Knowledge of how plants grow and the principles of nutrition are important.
- Introduced soil born diseases and nematodes may be spread quickly to all beds on the same nutrient tank of a closed system.
- Most available plant verities adapted to controlled growing conditions will require research and development.
- The reaction of the plant to good or poor nutrition is unbelievably fast. The grower must observe the plants everyday (Jones, 1997).

Without soil as a buffer, any failure to the hydroponic system leads to rapid plant death. Other disadvantages include pathogen attacks such as damp-off due to Verticillium wilt caused by the high moisture levels associated with hydroponics and over watering of soil based plants. Also, many hydroponic plants require different fertilizers and containment systems. To produce the mineral wool and the fertilizers that are needed to use this method, a large amount of energy is required (Winterborne, 2005).

5. Hydroponics Techniques

The two main types of hydroponics are solution culture and medium culture. Solution culture does not use a solid medium for the roots, just the nutrient solution. The three main types of solution cultures are static solution culture, continuous-flow solution culture and aeroponics. The medium culture method has a solid medium for the roots and is named for the type of medium, e.g., sand culture, gravel culture, or rockwool culture.

There are two main variations for each medium, sub-irrigation and top irrigation. For all techniques, most hydroponic reservoirs are now built of plastic, but other materials have been used including concrete, glass, metal, vegetable solids, and wood. The containers should exclude light to prevent algae growth in the nutrient solution (Jones, 1997; Douglas, 1975; Schwarz, 1995; Hydroponics Dictionary .Com, 2008).

6. Hydroponics Systems

6.1. The Water Culture System

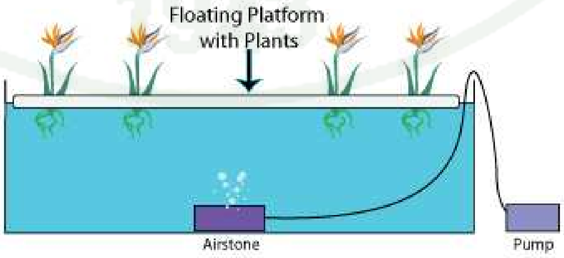


Figure 1 Water culture system

Source: Hydroponics Dictionary.Com (2008)

The Water Culture System is the simplest of all active hydroponic systems. The platform that holds the plants is usually made of Styrofoam and floats directly on the nutrient solution. An air pump supplies air to the air stone that bubbles the nutrient solution and supplies oxygen to the roots of the plants.

Water culture is the system of choice for growing leaf lettuce, which are fast growing water loving plants, making them an ideal choice for this type of hydroponic system (Jones, 1997; Douglas, 1975; Schwarz, 1995).

6.2. The Wick System

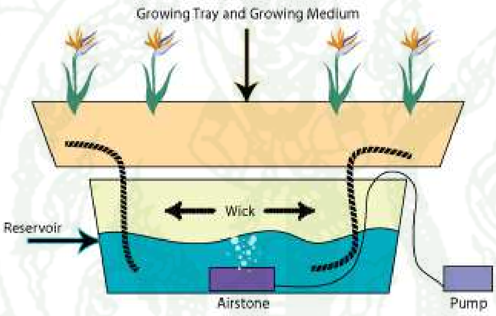


Figure 2 Wick system

Source: Hydroponics Dictionary.Com (2008)

The Wick System is by far the simplest type of hydroponic system. This is a passive system, which means there are no moving parts. The nutrient solution is drawn into the growing medium from the reservoir with a wick. This system can use a variety of growing medium. Perlite, Vermiculite, Pro-Mix and Coconut Fiber are among the most popular (Jones, 1997; Douglas 1975; Schwarz 1995; Hydroponics Dictionary.Com, 2008).

6.3. The Ebb and Flow System

Ebb and Flow works by temporarily flooding the grow tray with nutrient solution and then draining the solution back into the reservoir. This action is normally done with a submerged pump that is connected to a timer. When the timer turns the pump on nutrient solution is pumped into the grow tray. When the timer shuts the pump off the nutrient solution flows back into the reservoir.

The Timer is set to come on several times a day, depending on the size and type of plants, temperature and humidity and the type of growing medium used. The Ebb and Flow is a versatile system that can be used with a variety of growing mediums (Jones, 1997; Douglas 1975; Schwarz 1995; Hydroponics Dictionary.Com, 2008).

6.4. Drip Systems

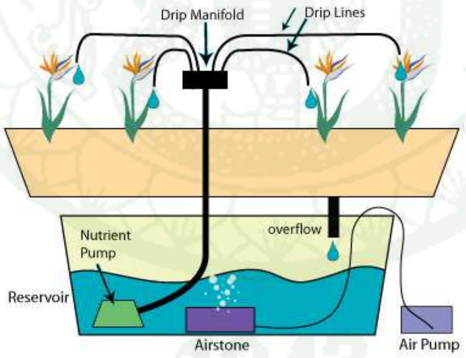


Figure 3 Drip system

Source: Hydroponics Dictionary.Com (2008)

Drip Systems are probably the most widely used type of hydroponic system in the world. Operation is simple, a timer controls a submersed pump. The timer turns the pump on and nutrient solution is dripped onto the base of each plant by a small drip line.

In a Recovery Drip System the excess nutrient solution that runs off is collected back in the reservoir for re-use. The Non-Recovery System does not collect the run off (Jones, 1997; Douglas 1975; Schwarz 1995; Hydroponics Dictionary.Com, 2008).

6.5. Nutrient Film Technique System

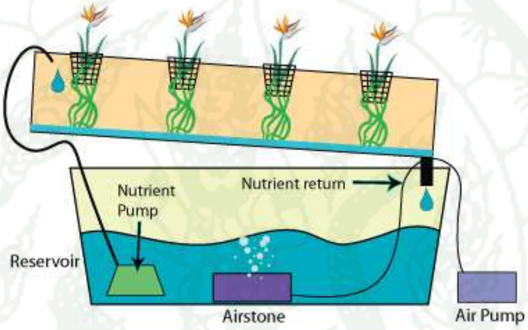


Figure 4 Nutrient film technique system

Source: Hydroponics Dictionary.Com (2008)

NFT is the kind of hydroponic system most people think of when they think about hydroponics. NFT systems have a constant flow of nutrient solution so no timer required for the submersible pump.

The nutrient solution is pumped into the growing tray (usually a tube) and flows over the roots of the plants, and then drains back into the reservoir. There is usually no growing medium used other than air, which saves the expense of replacing the growing medium after every crop. Normally the plant is supported in a small plastic basket with the roots dangling into the nutrient solution.

NFT systems are very susceptible to power outages and pump failures. The roots dry out very rapidly when the flow of nutrient solution is interrupted (Jones, 1997; Douglas 1975; Schwarz 1995; Hydroponics Dictionary.Com, 2008).

6.6. The Aeroponic System

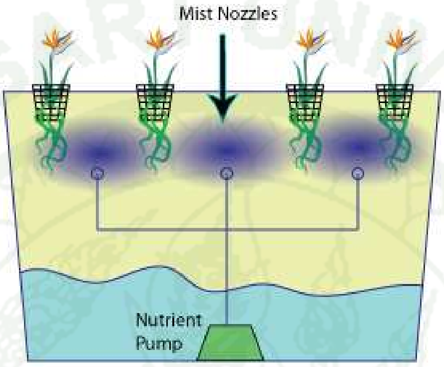


Figure 5 Aeroponic system

Source: Hydroponics Dictionary.Com (2008)

The Aeroponic System is probably the most high-tech type of hydroponic gardening. Like the N.F.T. system below the growing medium is primarily air. The roots hang in the air and are misted with nutrient solution.

The mistings are usually done every few minutes. Because the roots are exposed to the air like the NFT system, the roots will dry out rapidly if the misting cycles are interrupted (Jones, 1997; Douglas, 1975; Schwarz, 1995; Hydroponics Dictionary.Com, 2008).

7. The Major (Macro) Elements of the plants

Nine of the 16 essential elements are classified as major elements or macro elements: carbon, hydrogen, oxygen, phosphorus, potassium, calcium, magnesium and sulfur. Since the first three are obtained from carbon dioxide in the air and water from the rooting media and then combined by photosynthesis to form carbohydrates. The remaining six major elements are more important to the hydroponics grower since these elements must be present in the nutrient solution or added to a soilless medium in sufficient quantity and in the proper balance to meet the crop requirement (Jones, 1997; Schwarz, 1995).

8. The Micro Elements

Plants require considerably small amount of the micronutrients than the major elements, but the micronutrients are as critically essential as the major elements. Micronutrients are boron, chlorine, copper, iron, manganese, molybdenum and zinc(Jones, 1997; Schwarz, 1995).

In some earlier scientists suggested the establishment of nickel (Ni) as an essential element. There have been additional studies published that would confirm this finding. Normal concentration of Ni found in plants 1 mg/kg, in dry weight. If Ni is more than 50 mg/kg in dry weight it can be toxic to the plant (Jones, 1998).

In addition to above it can be said that nickel is an example of an element that was classified as beneficial but recently has been shown to be essential by researchers named as Brown, Welch, and Cary (Barker and Pilbeam, 2007).

9. Nutrient Solutions

Continuous monitoring and knowledge of the relationship between the rates of ion absorption by plants roots and the concentration of the ions to the roots is important in plant nutrition studies and when growing plants in hydroponics (Ben-Yaakovi and Ben-Asher, 1983).

Plant nutrients used in hydroponics are dissolved in the water and are mostly in inorganic and ionic form. Primary among the dissolved cations (positively charged ions) are Ca^{2+} (calcium), Mg^{2+} (magnesium), and K^+ (potassium); the major nutrient anions in nutrient solutions are NO_3^- (nitrate), SO_4^{-2}(sulfate) and H_2PO_4 (dihydrogen phosphate). Chelating agents are sometimes used to keep Fe soluble. These elements must be put in solution in water, and that such solution must be brought into contact with the plant's roots. In soilless growth good contact between roots and solution is assured (Ellis and Swaney, 1938; TPS Pty Ltd, 2002-2010).

10. Nutrient Preparations

Because of the tendency of some nutrients to combine with others and precipitate when concentrated the standard procedure is to prepare two solutions where precipitating components are kept separate. When a prepared solution is added to the nutrient water the concentrations are so low that precipitation does not cause any problems. Calcium phosphate and calcium sulphate are the main concern. Calcium is therefore kept away from phosphate and sulphate in the formulations. Never add both nutrients solutions together and then add into the water feed - valuable nutrients will precipitate and become unavailable. Ideal water temperature for total solubility of the nutrient salts is 20 to 22^0C. (TPS Pty Ltd, 2002-2010.)

11. pH Value of Solution

The acidity or alkalinity of the solution is express by pH value. In general, an excess of cation over anion leads to a decrease in pH, whereas an excess of anion over cation uptake leads to an increase in pH. For proper growth of plant pH of the nutrient solution must be controlled. pH can affect the availability of nutrients and absorption of nutrients by plant roots. pH values above 7.5 cause iron, manganese, copper, zinc and boron ions to be less available to plants and below 6 cause the solubility of phosphoric acid, calcium and magnesium to drop. pH values between 3 and 5 and temperatures above 26^OC encourage the development of fungal diseases. Ordinary most plants require a pH value of 5 to 6 for best growth. Most varieties of vegetables grow at their best in a nutrient solution having a pH between 6.0 and 6.5

and a nutrient temperature between 20 and 22^{O}C (Ellis and Swaney, 1938).

Daylight photosynthesis produces hydrogen ions which can cause the nutrient acidity to increase (lowering the pH). At dusk photosynthesis stops and the plants increase their rate of respiration and this coupled with the respiration of micro organisms and the decomposition of organic matter uses up the hydrogen ions so the acidity of the solution tends to decrease (pH rises).

In low light (overcast days or indoor growing environments) plants take up more potassium and phosphorous from the nutrient solution so the acidity increases (pH drops). In strong intense light (clear sunny days) plants take up more nitrogen from the nutrient solution so the acidity decreases (pH rises).

The addition of acids or alkalis to nutrient solutions is the most common and practical means to adjust pH, and can be easily automated. Buffers are solutions which resist pH change and are used to calibrate pH electrodes. Buffers can be added to nutrient solutions in an attempt to maintain pH stability. One such buffer is called 2-(N-morpholino) ethanesulfonic acid - abbreviated to MES. Many of the companies who claim better pH control with their 'specially' formulated nutrient solutions add MES to their mixes. It is important to remember when using MES, that after MES addition the pH is low and needs to be adjusted to required level with an alkali such as potassium hydroxide (KOH) (TPS Pty Ltd, 2002-2010).

12. Plant Nutrient Strength Requirements (EC of the solution)

For normal plant growth hydroponics nutrient solutions are in the range 0.5 to 4.5 mS/cm. Wilting, leaf scorch, bolting and other abnormalities will be experienced when conductivity levels are outside their preferred range.

Because most of the materials in water used in hydroponics are salts the mineral content of a nutrient solution is sometimes referred to as the Total Dissolved Solids (TDS) in the nutrient solution. The convention in hydroponics is to use Electrical

Conductivity (EC) as the units to measure the strength of a nutrient solution (Jones, 1997; Schwarz, 1995).

Plants tend to fall into three groups requiring a high, medium and low conductivity. Leafy greens, lettuce, beans and most herbs require a low conductivity 1.2 mS/cm in first two weeks and 1.5 to 1.8 mS/cm after 2nd week of the crop duration. (TPS Pty Ltd. 2002-2010.)

In earlier studies, investigators and growers measured the electrical conductivity of the solution and used the results as an intuitive indication of the total amount of nutrients and salts (Cooper, 1976).

Microprocessor technology scales the conductivity measurement into either milliSiemens/cm (mS/cm) or microSiemens/cm (uS/cm). Using a mathematical formula, the meters are also able to show the nutrient levels as TDS in parts per million (ppm) or parts per thousand (ppk). TDS is the concentration of a solution as the total weight of dissolved solids. (1 ppm = 1 milligram/liter and 1 ppk = 1 gram/liter) (Jones, 1997; Schwarz, 1995)

13. The Importance of Temperature Compensation

Conductivity requires mobile ions in solution, when the mobility rises because of increases in temperature the conductivity measured also rises. For every $1^{O}C$ temperature change, the conductivity of a nutrient solution will increase by around 2% (Resh, M., 1991). This temperature coefficient varies with the type of salts in the solution, the concentration of those salts and the temperature itself (TPS Pty Ltd., 2002-2010).

14. Sufficient Range for Nutrient in aerial part of lettuce

Table 1 Sufficient nutrient content in aerial part of the lettuce plant

Nutrient	Nutrient content in %	Nutrient content in ppm
N	3.5 - 4.5	35000 - 45000
P	0.4 – 0.8	4000 - 8000
K	5.5 - 6.2	55000 - 62000
Ca	2 - 2.8	20000 - 28000
Mg	0.6 - 0.8	6000 - 8000

Source: Jones (1998.)

Molynex (1988) has given the optimum, minimum and maximum some essential element concentration in the NFT nutrient solution. It is given by Table 2.

Table 2 Some essential element concentration

Essential element	Minimum (ppm)	Optimum (ppm)	Maximum (ppm)
N	50	150 - 200	300
P	20	50	200
K	50	300 - 500	800
Ca	125	150 - 300	400
Mg	25	50	100

Source: Jones (1997).

15. Growing Salad Vegetable Crops

Lettuce, endive, celery, and parsley are the most popular salad vegetables. There are three types of lettuce: loose leaf, head or semi-head, and upright. Leaf lettuce grows quickly and is the easiest type of lettuce to grow. The salad crops provide vitamins as well as needed bulk. They are usually eaten without cooking (University of Minnesota Extension, 2009).

16. Lettuce

Lettuce is a fairly hardy, cool-weather vegetable that thrives when the average daily temperature is between 60 and 70°F. It should be planted in early spring or late summer. At high temperatures, growth is stunted, the leaves may be bitter and the seedstalk forms and elongates rapidly. Some types and varieties of lettuce withstand heat better than others.There are five distinct types of lettuce: leaf (also called loose-leaf lettuce), Cos or romaine, crisphead, butterhead and stem (also called asparagus lettuce) (Ryder, 1999)

17. Growth and Development in Lettuce

The sequence of growth for lettuce can be divided into four stages: seedling, rosette, heading (not in all type) and reproductive. Within the seedling stage, there are three phases. First, in the germinating seed, the radical emerges and becomes the tap root. Then the cotyledons emerge and the enlarge. Lastly, the first true leaves are formed. The time to the emergence of the first true leaf is about two weeks.

Following the seedling stage is the rosette stage., which consists of emergence, expansion and maturation of leaves, forming either a prostrate or erect rosette. The diameter of the plant increases substantially during this stage.

Certain types of lettuce then go into the heading (hearting) stage. In butterhead and crisphead types, this consists of successive formation of cup-shaped leaves. In which earlier leaves enclose the later ones, forming a more or less spherical structure. Cos lettuce forms an upright head, in which the leaves all remain erect and barely enclose each other in the longitudinal direction. Leaf forming, in both the heading and the non-heading types, continues on the compressed stem until the plants reach harvest maturity.

Harvest maturity is followed by the reproductive stage, which occurs in three phases: stem elongation, flowering and seed development. The beginning of the flowering process takes place early in the life cycle, prior to stem elongation, but the actual expansion of the inflorescence takes place during the stem-elongation process. Stem lettuce form thicker stems and stay a little longer in that process before flowering. Flowering formation for all types takes place over a period of several weeks (Ryder, 1999).

18. Nutrient Value of Lettuce

Table 3 Nutritional values for lettuce. Values are for (grams) of edible product.

	Minerals (g)					Vitamins		Water	Fibre
	Ca	P	Fe	Na	K	A(IU)	C(g)	%	g
Crisp	22	26	1.5	7	166	470	7	95.5	0.5
Butter	35	26	1.8	7	260	1065	8	95.1	0.5
Cos	44	35	1.3	9	277	1925	22	94.9	0.7
Leaf	68	25	1.4	9	264	1900	18	94	0.7

Source: Ryder (1999)

MATERIALS AND METHODS

Materials

1. Hydroponic circulating system (NFT:- two storage tanks, PVC or any other tunnels, rubber tubes, nutrient pump, airstone)
2. Electricity
3. Vegetable seeds
4. Hydroponic fertilizers (two hydroponic solutions)
5. Plant growing trays
6. Hydroponics media (like perlite, vermiculite etc)
7. Green house cooling system
8. EC meter
9. pH meter
10. Thermometer
11. Oven

Methods

Location, Duration and Climatic Condition

In order to achieve the objective, two experiments were conducted at Department of Horticulture, Faculty of Agriculture, Kasetsart university, Bangkok, Thailand during July to November 2013 with the support of Kasetsart University and Thai International Development Cooperation Agency (TICA).

This area has a tropical wet and dry climate under the Köppen climate classification and is under the influence of the South Asian monsoon system. It experiences hot, rainy and cool seasons, although temperatures are fairly hot year-round, ranging from an average low of 20.8 °C (69.4 °F) in December to an average high of 34.9 °C (94.8 °F) in April. The rainy season begins with the arrival of the southwest monsoon around mid-May. September is the wettest month, with an average rain fall of 344.2 millimeters (13.55 in). The rainy season lasts until October, when the dry and cool northeast monsoon takes over until February. The hot season is generally dry, but also sees occasional summer storms. The surface magnitude of Bangkok's urban heat island has been measured at 2.5 °C (4.5 °F) during the day and 8.0 °C (14 °F) at night. The highest recorded temperature in Bangkok is 40.8 °C (105.4 °F) in May 1983 and the lowest recorded temperature is 9.9 °C (49.8 °F) in January 1955. (Wikimedia Foundation, Inc. 2012)

Design of the Study

This study has been conducted under green house. Lettuce (*Lactuca sativa*) was tested plant in the two experiments. There were two experiments undertaken in this study as follow. Crop duration was 40 days (6 weeks period).

In experiment one, lettuce plants were grown in NFT (Nutrient Film Technique) system under hydroponics using two nutrient solutions called solution x (solution A, B, & C) (treatment T1) vastly used in Thailand and solution y (treatment T2) commonly used in Sri Lanka which is brought from Sri Lanka.

In Experiment two also plants were grown in NFT system as in experiment 1. Lettuce was grown in four treatments named as treatment T1 (solution x), treatment T2 (solution y), treatment T3 (solution y + same amount N added as in treatment T1: solution z_1) and treatment T4 (solution y half of the N added as added in treatment T3: solution z_2).

Crop Lettuce (L)	treatment T1
	treatment T2
Crop Lettuce (L)	treatment T1
	treatment T2
	treatment T3
	treatment T4

Experiment One

In this experiment lettuce was grown with solution x (T1) and solution y (T2) for the sake of finding better solution for growing lettuce under hydroponics.

1. Experimental Preparation

1.1. Installation of NFT System

At first NFT continuous circulating system was installed by using Fresh Garden Hydroponics Centre. Length of the flow system was 3m and system had two experimental units. Air pumps were arranged for every unit to aerate the solution.

One unit had four tunnels and length of the tunnel was 3m. One tunnel had 14 holes with the 20 cm distance between two. Slop of the system was 1:22 (4.5%) and flow rate was 3 l/minute.

Figure 6 Two units of NFT hydroponics system

1.2. Preparation of Stock Solution

1.2.1. Solution x

This solution consists of three nutrient sets labeled as products A, B and C. The nutrient contents in each set are shown below.

A :- $Ca(NO_3)_2$ - 1110g

B :- KH_2PO_4 - 263g

KNO_3 - 583g

$MgSO_4.7\,H_2O$ - 564g

C :- FeDTPA - 50g

FeEDDHA - 25g

Nic spray - 50g

MnEDTA - 10g

Ammonium mollibdad - 0.5g

Nikle Sulphate - 0.3g

Nic spray is a readymade trace element mixture in Thailand and it is consist of 2% of Fe, 2% of Mo, 2% of Zn, 1.8% of Cu and 2% of B.

At first stock solution was prepared using A, B & C packets with nutrient as in powder. A, B & C were dissolved in three separate 5 liter cans and first pour some water into cans and added each nutrients into relevant cans. Then every can was shaked well and volume of each stock solution was adjusted to 5 liters mark. From this stock solution 1000 liters growing solution can be made. Hence to prepare 35 liters of growing solution 175 milliliters of stock solution was added to water separately and dissolved well.

1.2.2. Solution y

Chemical composition of this solution are given below

Common name	**g/kg**
$Ca(NO_3)_2$	500
KNO_3	225
$MgSO_4$	87.5
Anhydrous	
FeEDTA	5
ZnEDTA	1
Boric acid	0.2
MnEDTA	1
Cu EDTA	0.25
Monopotassium Phosphate	180
Sodium mollibdad	0.05

One kilogram of nutrient powdered packet should be dissolved in 500 liters water for preparing growing solution. Hence to prepare 35 liters of growing solution 70g of nutrient powdered was added to the 35 liters of water and dissolved well.

Figure 7 Prepared stock solutions

1.3. Planting Seeds

Standard hydroponic cups for NFT system were filled with seed germination media consisting of perlite and vermiculite in the ratio of 1:4 by volume. After the media was soaked with water, seeds were planted at the rate of one seed per one cup into the media at depth of ½ cm and placed into holes in system. After the tanks were filled with water and the pump were operated. Then roof of the green house was covered by the shading sheet for 48 hours for seed germination. After 5th day of the seedling stage water in tanks replaced by the 35 liter respective solutions and shading cover of green house was removed.

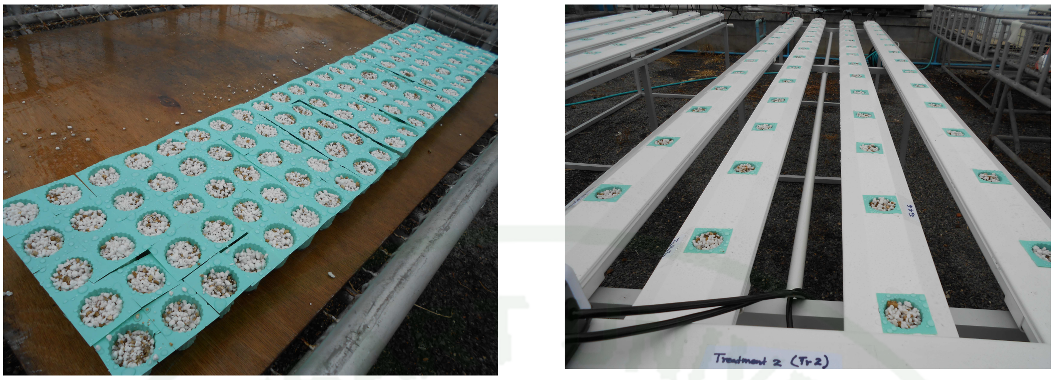
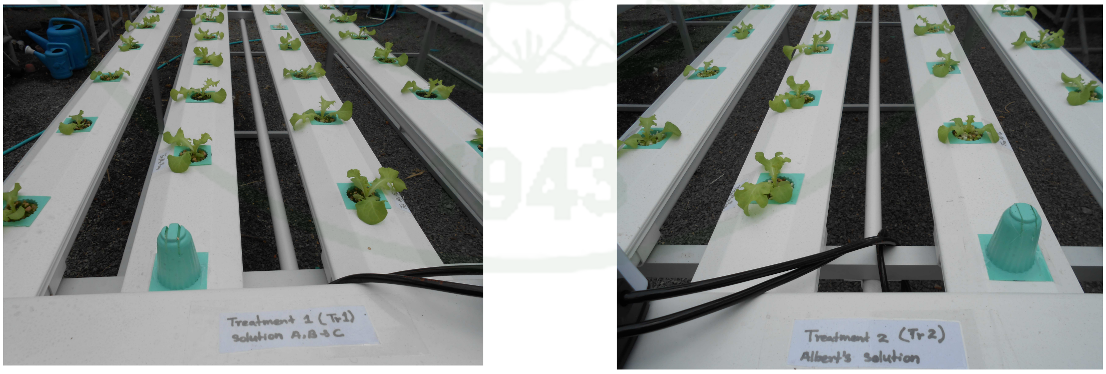


Figure 8 Cups filled with medium and after planting seeds cups in system

2. Maintaining the System with Plants

pH and EC of the solutions were maintained respectively 6.0-6.5 and 1.0-1.2 ms/cm after 3rd leaf of the plants were seen. It took nearly 11 days to appear the 3rd leaf. After that pH remained same level and EC was adjusted to 1.6-1.8 mS/cm range. Everyday pH and EC of the solutions were adjusted. During the cropping period, for adjusting the EC, 30 liters of solution x and 40 liters of solution ywere added to the relevant tank. After 40 days of the crop, plants were harvested.



Treatment T1

Treatment T2

Figure 9 Lettuce cultivation at 2nd week after planting

3. Data Recording

Following measurements were made to asses performance of the plants in different hydroponics solutions,

- pH and electric conductivity values were measured at weekly intervals, using multi-parameter PCTestr^{TM} 35 instrument. This instrument could be measured pH, EC and temperature of the solution
- Number of leaves was measured at weekly intervals from planting up to harvesting stage by counting leaf.
- N, P, K, Ca and Mg percentage of each solution were analyzed before planting and after harvesting.
- Wet weight and dry weight of the each plant were measured after harvesting
- N, P, K, Ca and Mg percentage of upper ground biomass of the each plant were analyzed after harvesting.
- N was determined by Kjeldhal method (Gallaher et al., 1976 and Jackson, 1965), P was determined by Vanadomolibdate method (Johnson and Ulrich, 1959 and Westerman, 1990) and K, Ca and Mg were determined by Atomic Absorption Spectrophotometry method (AAS) (Johnson and Ulrich, 1959 and Westerman, 1990).

4. Data Analysis

1. The data was measured carefully in the field as well as in the lab
2. The data was processed and analyzed by using SPSS/FW (Statistical Package for Social Science for Window) as completely random design.
3. Means among treatments were compared with the use of t-test with different being tested at 0.05 probability ($p<0.05$).

Experiment Two

Experiment was launched in NFT system as in experiment 1. But four treatments were used with lettuce. Treatments were named as treatment T1 (solution x), treatment T2 (solution y), treatment T3 (solution y + same amount N added as in treatment T1: solution z_1) and treatment T4 (solution y + half of the N added as in treatment T3: solutionz_2).

Figure 10 Four units of NFT hydroponics system

1. Solution Preparation

Solution x (treatmentT1) and solution y (treatment T2) were prepared as in experiment one.

Solution z_1 (T3) was made from solution y (T2) but the level of N was adjusted to the same as that in solution x by adding calculated amount of $Ca(NO_3)_2$ and KNO_3.

Solution z_2 (T4) was made from solution y supplemented with half the amount of $Ca(NO_3)_2$ and $KNO_{3\ used}$ in solution z_1.

2. Planting Seeds

Planting seeds were done as in experiment 1 and seedling stage upto 5th day of the planting was maintained as in experiment 1. After 5th day of planting, 40 litter of nutrient solutions were added in four tanks.

3. Maintaining the System with Plants

pH was maintained at 6.0-6.5 level. But in here EC was not maintained as in experiment 1. EC was considered as a recorded data. Every day water was added to the tank upto same level as in 1st day (40 liters). In this experiment hope to compare the conditions of four treatments without maintaining EC level. After 2nd week, 4th week, 5th week and between 5th and 6th week 10, 5, 5 and 15 liters of solutions was added respectively to every treatment because EC level of treatment T2 showed a less amount. After 40 days of the crop, plants were harvested.

Figure 11 End of the crop duration plants in four treatments

4. Data Recording and Analyzing

Data was recorded as in the experiment 1. Analysis of variance (ANOVA) was performed by using SPSS SPSS/FW (Statistical Package for Social Science for Window) as completely random design and means among treatments were compared using least significant difference (LSD) and different being tested at 0.05 probability ($p<0.05$).

RESULTS AND DICUSSION

Experiment One

1. Electric Conductivity of the Hydroponics Solutions

Electric conductivity (EC) of two nutrient solutions during the period of experiment is shown in Figure 12. It is evident that, EC of the both solutions were varied in the range of 1.2 mS/cm to 1.8 mS/cm. In first two weeks and last week of crop duration EC was maintained between 1.2 mS/cm to 1.4 mS/cm and middle three weeks it was maintained between 1.4 mS/cm to 1.8 mS/cm. During experimental period everyday EC was adjusted according to TPS Pty Ltd. 2002-2010. TPS Pty Ltd. 2002-2010 showed that leafy greens, lettuce, beans and most herbs require a low conductivity 1.2 mS/cm in first two weeks and 1.5 to 1.8 mS/cm in after 2nd week of the crop duration. When EC was low solution was added and when EC was high water was added to control EC level in standard range.

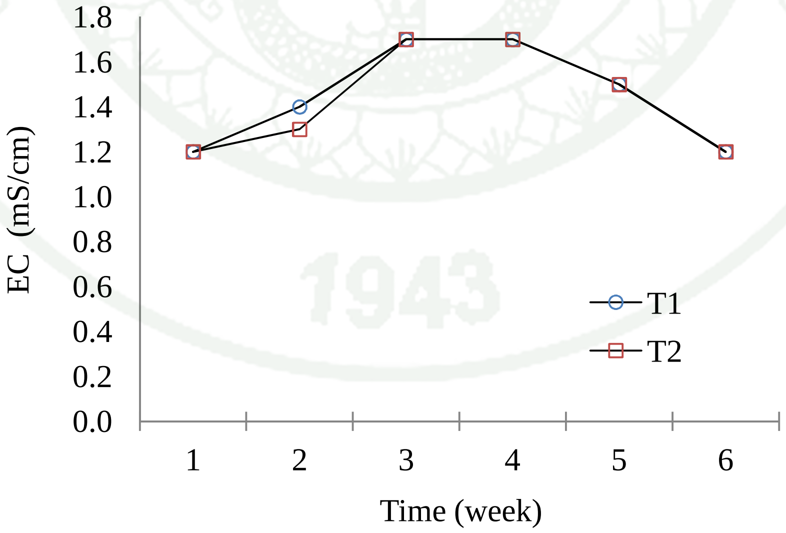


Figure 12 Records of EC values of two hydroponic solutions

2. pH of the Hydroponics Solutions

pH of two nutrient solutions during the period of experiment is shown in Figure 13. It is evident from Figure 13 that pH of the two solutions kept fairly suitable range of crop that is 6.0 to 6.5. During the cropping cycle pH was maintained to that range because Jones, 1997 and Ellis and Swaney, 1938 also reported that the pH of the nutrient solution was thought to be best when kept between 6.0 and 6.5 for most crops. When pH was high in tank pH drop down solution was added and when pH was low pH upper powder was added.

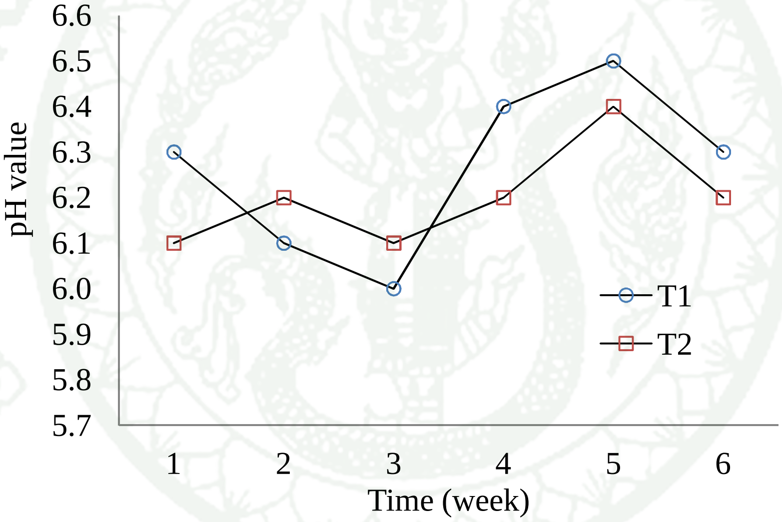


Figure 13 Weekly pH recorded of two hydroponic solutions in experiment1

3. Plant Growth and Development

1. Number of Leaves per Plant

Number of leaves produced per plant in two nutrient solutions is given in Figure 14. In first week there was no significant difference in number of leaves between two treatments but in 2nd, 3rd, 4th and 5th week there was a significant difference in number of leaves produced per plant between two treatments (Table 4).

After first week, plant grown in solution y (T2) showed a significantly high number of leaves compare to solution x (T1).

Table 4 The effect of two hydroponic solutions on number of leaves of lettuce

Treatment	1st week	2nd week	3rd week	4th week	5th week
T1	1^{a}	4.0^{a}	7.8^{a}	14.9^{a}	17.5^{a}
T2	1^{a}	3.8^{b}	8.3^{b}	17.8^{b}	20.0^{b}
t	-	3.074	3.292	12.722	14.36
F value	-	43.13	3.356	6.637	1.023

$^{a, b}$ = Significantly different ($p<0.05$).

Therefore it could be concluded that lettuce plants grown in NFT method under hydroponics using solution y is showed a better plant growth rate than solution x according to number of leaves.

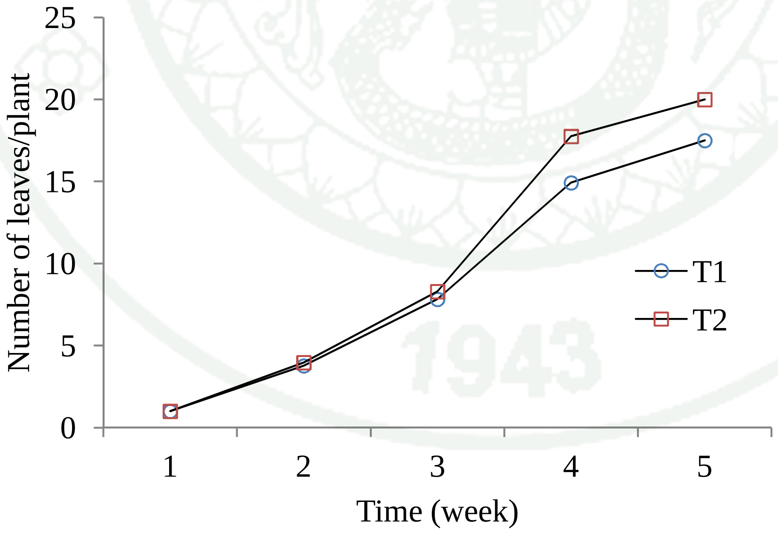


Figure 14 Number of plant leaves per plant in experiment 1

2. Fresh Yield of the Upper Ground Biomass of the Plant

Fresh yield of the upper ground biomass of the plant in two nutrient solutions are shown in Figure 15.

It is evident that there was a significant difference in fresh yield of the upper ground biomass of the plant in two solutions (Table 5). Fresh yield of the upper ground biomass of the plant in solution y was higher than fresh yield in upper ground biomass of the plant in solution x after end of the 6th week of the cropping cycle.

As given in Table 5, fresh yield of upper ground biomass in solution y was 77.67g/plant and fresh yield of upper ground biomass in solution x was 71.56g/plant.

Table 5 The effect of two hydroponic solutions on fresh yield of lettuce

Treatment	Fresh yield g/plant
T1	71.56^{a}
T2	77.67^{b}
t	2.603
Fvalue	1.693

$^{a,\,b}$ = Significantly different ($p<0.05$).

Therefore it could be supposed that growth rate and development of plant in solution y is better than plants in solution x according to fresh yield of the upper ground biomass of the plant.

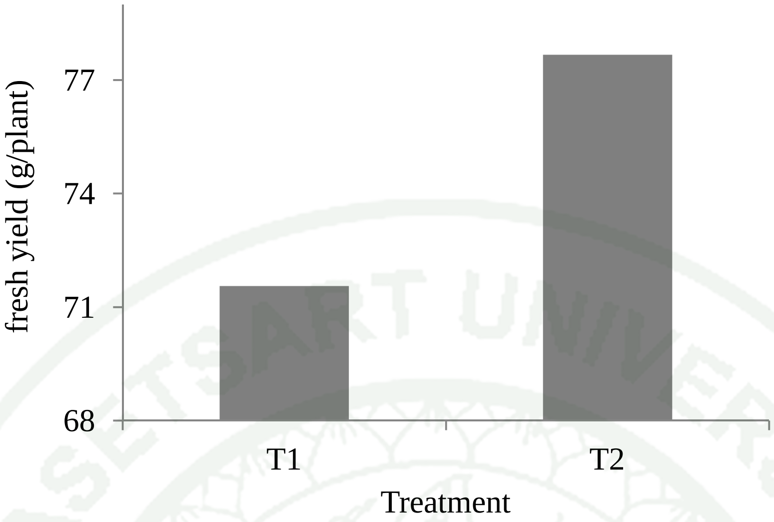


Figure 15 Fresh yield of upper ground biomass of the plant in two nutrient solutions in experiment 1

3. Dry Matter Yield of the Upper Ground Biomass of the Plant

Dry matter yield of the upper ground biomass of the plants in two nutrient solutions are shown in Figure 16.

It is evident that there was no significant difference between two nutrient solutions considering about dry matter yield of the upper ground biomass of the plant (Table 6). Dry matter yield of solution x was 2.57g/plant and dry matter yield of solution y was 2.52g/plant.

Therefore it can be concluded that plant growth and development is not differ in two nutrient solutions comparing to dry matter yield of the upper ground biomass of the plant.

Table 6 The effect of two hydroponic solutions on dry matter yield of lettuce

Treatment	Dry matter yield g/plant
T1	2.57^a
T2	2.52^a
t	2.603
Fvalue	1.693

$^{a, b}$ = Significantly different ($p<0.05$).

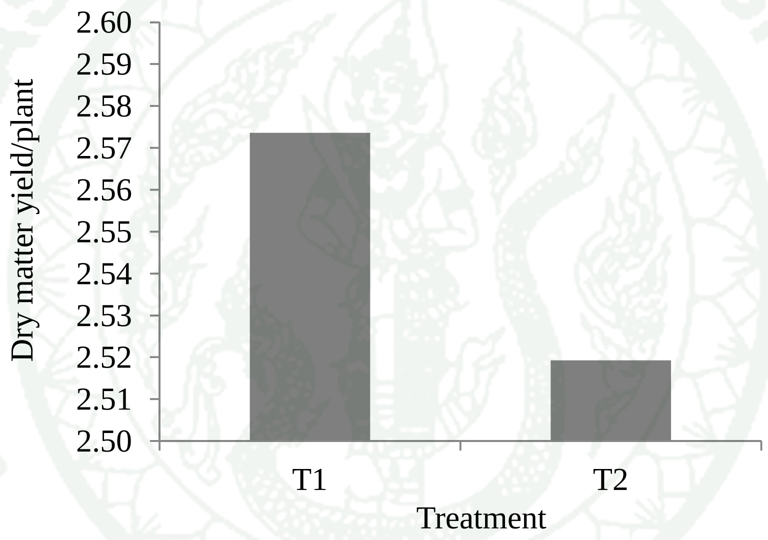


Figure 16 Dry matter yield of the upper ground biomass of the plant in two nutrient solutions in experiment 1

4. Nutrient Content in Upper Ground Biomass of the Plant

Nutrient content in upper ground biomass of the plant such as N, P, K, Ca and Mg are given in Figure 17 and Table 7.

There was no significant difference in N content in both solutions and there were significant difference between P, K, Ca and Mg content in both solutions (Table

7). According to Table 7 it can be said that P, K, Ca and Mg content is higher in solution y than in solution x.

Table 7 Nutrient content in upper ground biomass of the plant after 6th week of cropping cycle (end of the crop duration) in experiment 1

	N (g/kg)	P (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)
Solution x (T1)	39.930[a]	2.486[a]	67.678 [a]	13.295 [a]	3.713 [a]
Solution y (T2)	39.773[a]	3.859[b]	82.330 [b]	14.774 [b]	3.974 [b]

[a, b] = Significantly different ($p<0.05$).

According to Jones, 1998 sufficient range for nutrient in aerial part of lettuce was N-35 to 45 g/kg, P- 4 to 8 g/kg, K- 55 to 62 g/kg, Ca- 20 to 28 g/kg, Mg – 6 to 8 g/kg.

Considering above values it can be said that N content is in sufficiency range in both solutions but P, K, Ca and Mg contents are not in sufficiency range. While K content is higher than that of sufficiency range and P, Ca, and Mg content is lower than that of sufficiency range in both treatments. Hence it can be concluded that K content in both solution should be reduce and other four elements can be increased to get better yield than in this experiment.

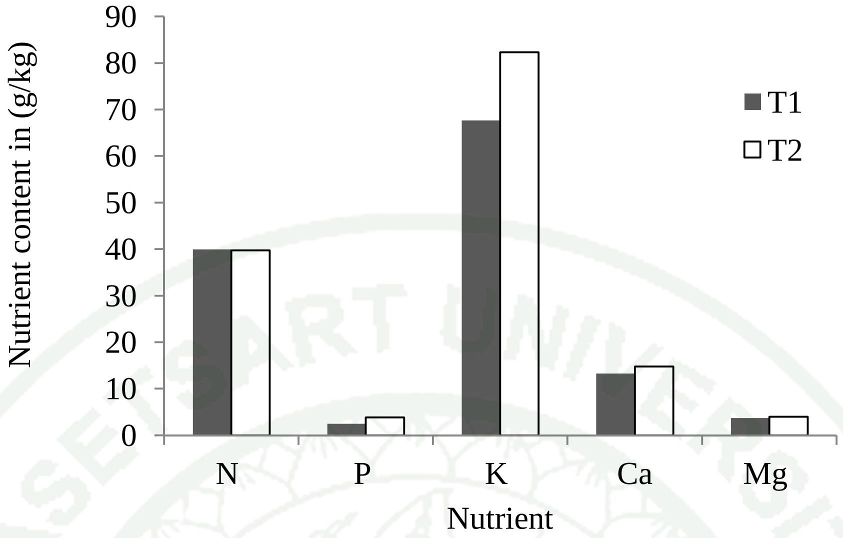


Figure 17 Nutrient content in upper ground biomass of the plant

5. Total Nutrient Uptake

Total nutrient uptake of solution in different treatments by lettuce is given in Table 8 and Figure18. Nutrient content in solution after cropping cycle (residue) of both treatments are given in Table 9. Nutrient content in both treatment before planting plants are shown in Figure 19.

According to Table 8 and Figure 18 it can be said that N and K consumption are high in solution x than in solution y but Ca, Mg and P consumption is high in solution y.

At the starting day 35 litter growing solutions were added to relevant tank for both solutions. After that in crop duration period as EC was adjusted daily, both nutrient solutions should be added to experimental tank. A 30 liters of solution x and 40 liters of solution y had been added to maintain the EC level of solutions.

Hence it can be said that more solutions have to be added to solution y than in solution x. According to analysis of nutrient content of both solutions before planting as given in Figure 19 it can be said that N content is high in solution x than in solution y.

It can be said that if EC level was not adjusted and starting nutrient amount was used for experiment, nutrient content is not enough for plants in solution y than in solution x.

Considering Above results it could be concluded that N content in solution y should be increased as in solution x for obtaining more results from solution y in experiment 1 if same amount of both solutions were used.

As shown in Figure 19 that considerable high amount of N content is in solution x than in solution y. N content is 245 ppm in solution x and 175 ppm in solution y. Although N content is high in solution x, plant growth and development is better in solution y according to number of leaves and fresh yield of the upper ground biomass of plant. Jones, 1997 described that root hairs will be almost absent when roots exposed to a high concentration of (NO_3^-) nitrate and most formulas call for the total N concentration in the nutrient solution to range from 100 to 200 ppm. Therefore it can be said that plant growth and development is lower in solution x than in solution y.

In experimental period air temperature was varied from 30^0C to 38^0C as shown in Figure 20. Hence evapotranspiration is very high in crop in that period. According to Jones, 1997 Passive mode of transport explains the high concentrations of some ions such as K^+, NO_3^-, and Cl^-. Therefore it can be said that K content is very high and N content was reached to sufficiency range in upper ground biomass of the plant in both solutions. Other thing explained in that text book if nitrate ion is the major nitrogen source in the surrounding rooting environment, intake of the K^+ is high. Hence it can be said that K consumption is high in solution x. Jones, 1998 reported that excess K reduce the Ca content also.

Table 8 Total nutrient uptake in both solutions in experiment 1

	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Solution x	408	129	417	178	8
Solution y	357	155	292	363	10

Table 9 Nutrient content in residue (tank) after cropping cycle in experiment 1

	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Solution x (T1)	47	0	18	269	106.9
Solution y (T2)	18	0	234	125	37.6

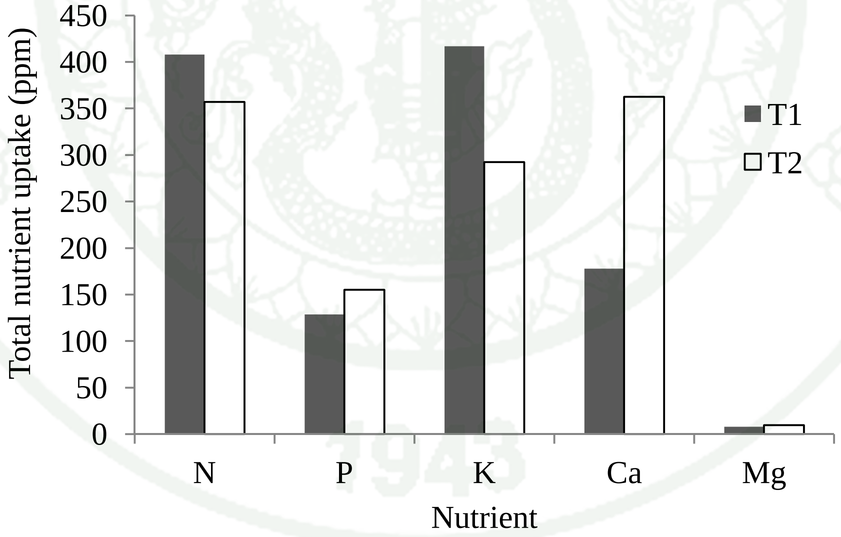


Figure 18 Total nutrient uptake in both solutions in experiment 1

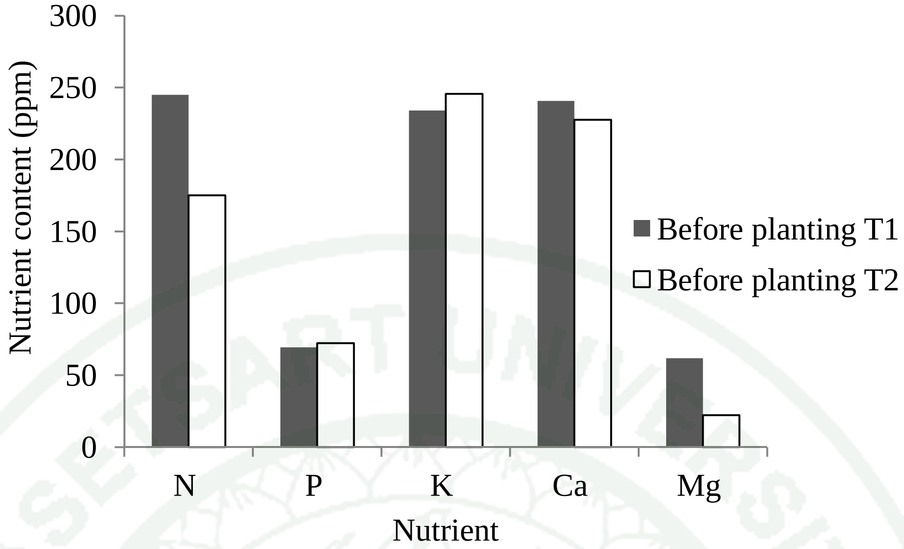


Figure 19 Nutrient content in two solutions before planting crop in experiment 1

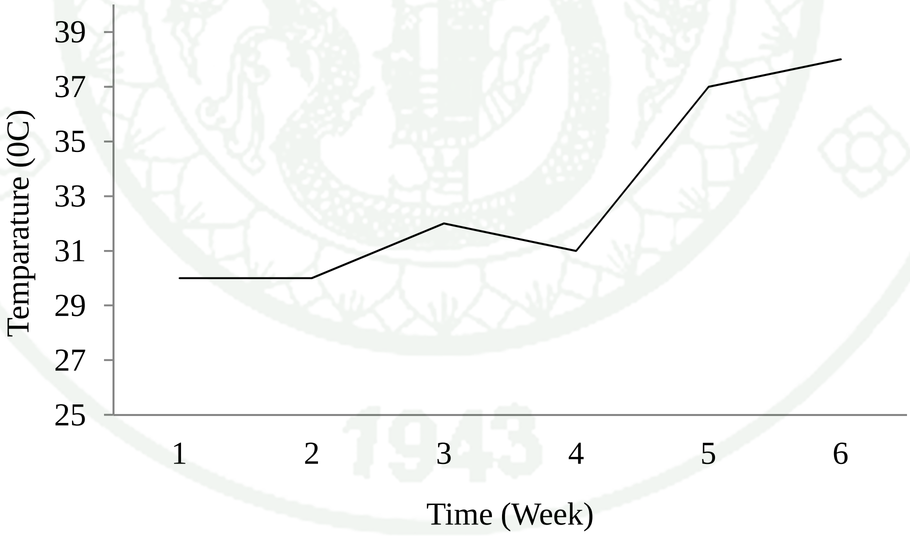


Figure 20 Air temparature in green house during cropping cycle in experiment 1

Experiment Two

1. Electrical Conductivity of Hydroponics Solutions

Electric conductivity of four treatments during period of experiment is given in Figure 21.

It is evident that, EC of four treatments varies in the range of 0.8 – 2.5 mS/cm during cropping cycle. According to Jones, 1997 and Schwarz, 1995 for normal plant growth hydroponics nutrient solutions are in the range of 0.5 to 4.5 mS/cm. Hence in four treatments EC values remained as in this range. Cooper, 1976 said that in earlier studies, investigators and growers measured the electrical conductivity of the solution and used the results as an intuitive indication of the total amount of nutrients and salts. As EC level of T1 is higher than other three treatments and EC level of treatment can be arranged as T1>T3>T4>T2, it can be said that nutrient content in each treatment can be arranged as T1>T3>T4>T2. Nutrient content of each solutions before planting can be arranged as T1>T3>T4>T2 (Figure) and hence EC of each solutions also showed high level in T1 than other three treatments and it also arranged as T1>T3>T>T2.

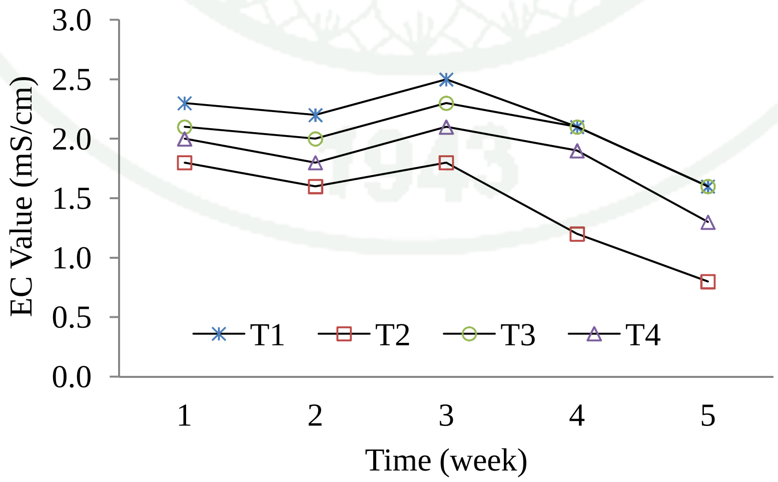


Figure 21 Changes of solution EC of each treatment in experiment 2

2. pH of the Hydroponics Solutions

pH of four treatments is shown in Figure 22.

pH of four treatments varies in the range of 6.5 – 6. During the crop duration this range was maintained because Jones, 1997 Ellis and Swaney, 1938 also reported that the pH of the nutrient solution is thought to be best when kept between 6.0 and 6.5 for most crops.

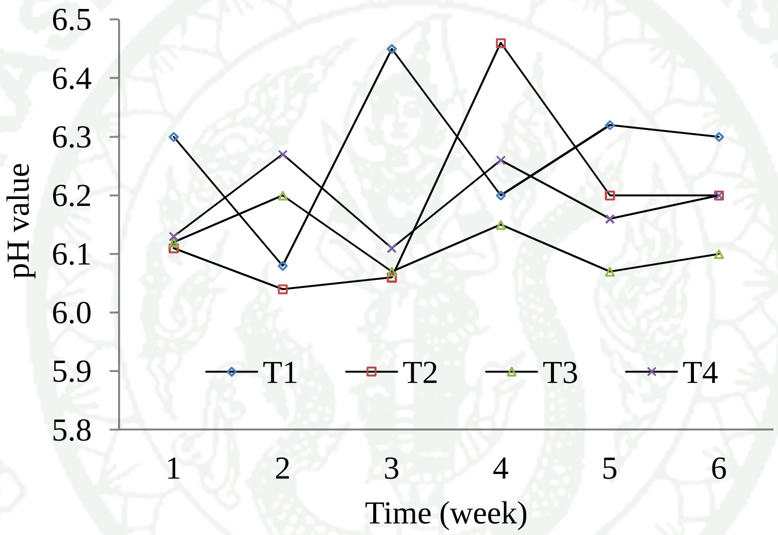


Figure 22 Changes of solution pH of each treatment in experiment 2

3. Plant Growth and Development

1. Number of Leaves per Plant

Number of leaves of plant in four treatments is illustrated on Figure 23. Upto 3rd week of transplanting number of leaves were not significantly difference in four treatments and number of leaves were significantly differed from 4th week upto harvesting stage in four treatments (Table 10).

Table 10 The effect of four hydroponic solutions on number of leaves of lettuce

Treatment	1st week	2nd week	3rd week	4th week	5th week	6th week
T1	1^a	3^a	5.95^a	10.95^a	12.95^b	24.10^a
T2	1^a	3^a	5.90^a	9.90^b	12.90^b	21.90^c
T3	1^a	3^a	5.75^a	9.25^c	13.80^a	$22.65^{c\,b}$
T4	1^a	3^a	5.85^a	9.10^c	$12.85^{a\,b}$	$23.65^{a\,b}$
Means square	0	0	0.146	14.95	4.083	18.9
F value	-	-	1.225	53.848	35.51	19.126

$^{a,\,b}$ = Significantly different ($p<0.05$).

While number of leaves in treatment T1 was significantly differed from treatment T2, treatment T3 and treatment T4 in 4th week, treatment T2 was significantly differed from treatment T3 and treatment T4. In 4th week there was no significant difference in number of leaves in treatment T3 and treatment T4 (Table 10).

In 5th week, according to number of leaves in four treatments there were significant difference in treatment T1 and treatment T3, treatment T2 and treatment T3, treatment T3 and treatment T4. There were no significant difference in treatment T1and treatment T2, treatment T1 and treatment T4, treatment T2 and treatment T4 (Table 10).

At the harvesting stage number of leaves in treatment T1 was significantly differed from treatment T2 and treatment T3. Treatment T1 was no significant difference from treatment T4. Number of leaves in treatment T2 was significantly differed from treatment T4 and not significant differed from treatment T3. There was no significant difference in number of leaves between treatment T3 and treatment T4 (Table 10).

Considering harvesting stage of the crop it can be concluded that plants grown in solution x (treatment T1) and solution z_2 (treatment T4) showed significantly high growth rate compare to other two treatments (treatment T2 (y) and treatment T3 (z_1).

Although N content was high in treatment T3 than in treatment T4 there was no significant difference between these two treatments. Jones, 1997 described that root hairs will be almost absent when roots exposed to a high concentration of (NO_3^-) nitrate and most formulas call for the total N concentration in the nutrient solution to range from 100 to 200 ppm. But N content in treatment T3 was 245 ppm and 201 ppm in treatment T4. Hence development of root hairs was reduced in treatment T3 than in treatment T4. Therefore it can be said that according to number of leaves, growth and development of plants are not difference in this two treatments.

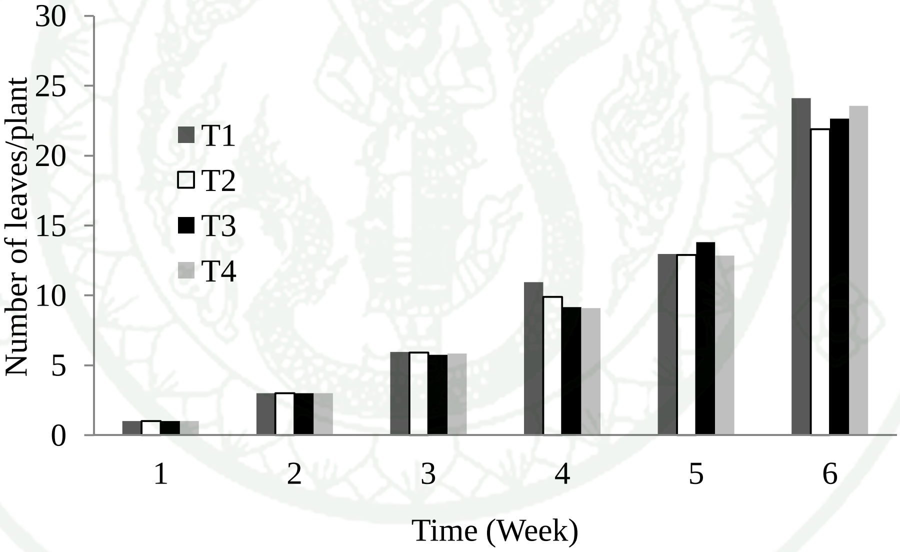


Figure 23 Number of leaves of four treatments in experiment 2

2. Fresh Yield and Dry Matter Yield of the Upper Ground Biomass of the Plant

Fresh yield and dry matter yield of the upper ground biomass of the different treatments in the experiment is shown in Figure 24.

End of the 6th week there were significant difference in fresh yield of the upper ground biomass of the plant in four treatments and there were no significant difference in dry matter yield of the upper ground biomass of the plant in four treatments (Table 11).

Table 11 The effect of four hydroponic solutions on fresh yield and dry matter yield of lettuce

Treatment	Fresh Yield (g/plant)	Dry Matter Yield (g/plant)
T1	88.1985 [a]	2.7230 [a]
T2	67.8150[b]	2.4890 [a]
T3	73.1950 [bc]	2.2410 [a]
T4	74.3974 [bc]	2.3911 [a]
Means square	1507.205	0.816
F value	8.701	1.985

[a, b] = Significantly different ($p<0.05$).

Fresh yield of the upper ground biomass of the plant in treatment T1 was showed significant difference from treatment T2, treatment T3 and treatment T4. But there was no significant differences between treatment T2 and T3, treatment T2 and T4 and treatment T3 and T4 (Table 11).

As shown in Figure 29, water uptake was greater than in treatmentT2. But considering number of leaves per plant in the harvesting stage (Figure 23) it was lowest in treatment T2. Hence fresh yield of treatment T2 showed low amount than in other three treatments. Although N content in treatment T3 was greater than in treatment T4 fresh yield was low in treatment T3 than in treatment T4 because high water uptake (Figure 29) and number of leaves at the harvesting stage (Figure 23) were high in treatment T4 than in treatment T3.

Hence it can be concluded that plants grown in treatment T1 is better for growing plants in NFT system under hydroponics than any other treatments tested in experiment according to fresh yield of the upper ground biomass of the plant. But according to dry matter yield of the upper ground biomass of the plant all treatments were shown same condition for growing plant in NFT system under hydroponics.

Considering above two parameters it can be said that number of leaves in plants is significantly high in treatment T1 and treatment T4 than in treatment T2 and treatment T3, fresh yield of the plant also high in treatment T1 than in other three treatments. Hence it can be concluded that plant growth and development is better in treatment T1 (solution x) than in any other treatment used in this experiment.

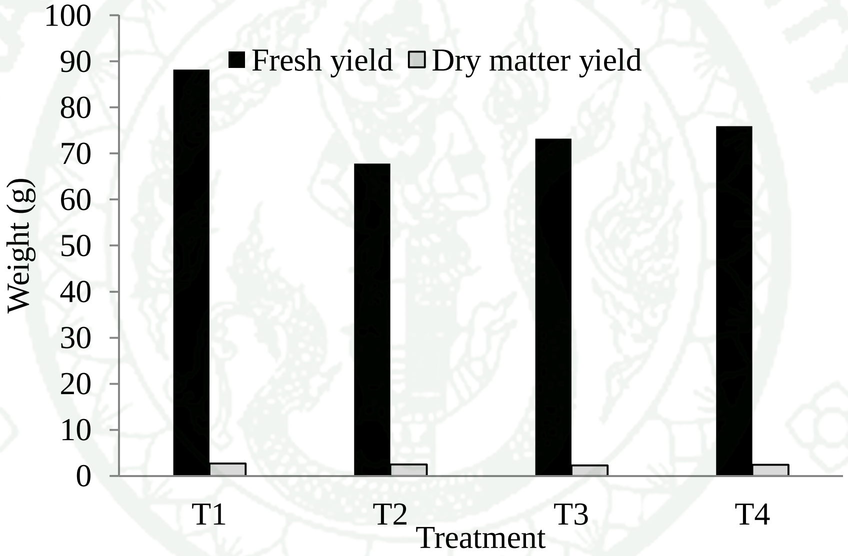


Figure 24 Fresh yield and dry matter yield of the upper ground biomass of the plant In four treatments in experiment 2

4. Nutrient Content in the Upper Ground Biomass of the Plant

N, K, P, Ca and Mg content of the upper ground biomass of the plants in different treatments are shown in Figure 25.

There were significant difference in N, P, K, and Ca in four treatments and there were no significant difference in Mg content of the upper ground biomass of the plant in each treatment (Table 12).

Table 12 The effect of four hydroponic solutions on nutrient content in upper ground biomass of lettuce

Treatment	N content g/kg	P content g/kg	K content g/kg	Ca content g/kg	Mg content g/kg
T1	49.875^{a}	2.017^{c}	107.976^{a}	18.809^{c}	7.864^{a}
T2	44.822^{b}	3.276^{b}	94.196^{c}	26.355^{a}	8.450^{a}
T3	47.097^{ab}	3.626^{a}	108.176^{ab}	23.853^{ab}	7.034^{a}
T4	45.391^{b}	3.622^{a}	106.691^{ab}	22.842^{b}	6.990^{a}
Means square	1.0128	1.1577	8.7418	1.9718	1.0477
F value	6.772	119.791	6.742	7.34	1.911

Means with the same letter are not significantly different at $P< 0.05$.

N content shows significant difference between treatment T1 and treatment T2, treatment T1 and treatment T4. But there were no significant difference between treatment T1 and treatment T3, treatment T2 and treatment T3, treatment T2 and treatment T4, treatment T3 and treatment T4 (Table 12).

It is evident that N content in treatment T1 (solution x) and treatment T3 were better than in other two treatments such as treatment T2 and treatment T4.

When considering P content in four treatments it can be said that there were significant differences between treatment T1 and treatment T2, treatment T1 and treatment T3, treatment T1 and treatment T4, treatment T2 and treatment T3, treatment T2 and treatment T4, But there was no significant difference between treatment T3 and treatment T4 (Table 12).

According to above data it can be concluded that P content in upper ground biomass of the plant is better in treatment T3 and treatment T4 than in treatment T2 and treatment T1.

K content in upper ground biomass of the plant was significantly differed in treatment T1 and treatment T2, treatment T2 and treatment T3, treatment T2 and treatment T4. But there was no significant differences between treatment T1and treatment T3, treatment T1 and treatment T4, treatment T3 and treatment T4 (Table 12).

Hence it can be concluded that K content in treatment T1, treatment T3 and treatment T4 was better than in treatment T2.

Ca content in upper ground biomass of the plant shows significant difference in treatment T1 and treatment T2, treatment T1 and treatment T3, treatment T1 and treatment T4 and treatment T2 and treatment T4. There were no significant differences between treatment T2 and treatment T3, treatment T3 and treatment T4 (Table 12).

According to above analysis it is evident that Ca content in treatment T2 and treatment T3 is better than in treatment T1 and treatment T4.

According to Jones, 1998 sufficiency range for nutrient in aerial part of lettuce is N -35 to 45 g/kg, P-4 to 8 g/kg, K-55 to 62 g/kg, Ca- 20 to 28 g/kg and Mg - 6 to 8 g/kg.

In table 12, N content of upper ground biomass of the plant in treatment T2 is in sufficiency range and other three treatments are greater than in sufficiency range. But Jones, 1998 said that NO_3 may begin to accumulate in the plant to fairly high concentrations if there is a substantial N supply in the rooting media. Hence N content is greater in treatment T1, treatment T3 and treatment T4. K content in four treatments is greater than in sufficiency range. Jones, 1998 reported that most plants absorb more

K than they need and it’s frequently referred to as luxury consumption. P content of upper ground biomass of the plant in four treatments are lower than in sufficiency range. Ca content in treatment T2 is higher than in sufficiency range and other three treatments are in sufficiency range. Mg content in treatment T2 is greater than in sufficiency range and but other three treatments are in sufficiency range.

Therefore for it can be concluded that K content and N content in treatment T1, treatment T3 and treatment T4 should be reduced while reducing K content in treatment T2. P content in four treatments should be increased.

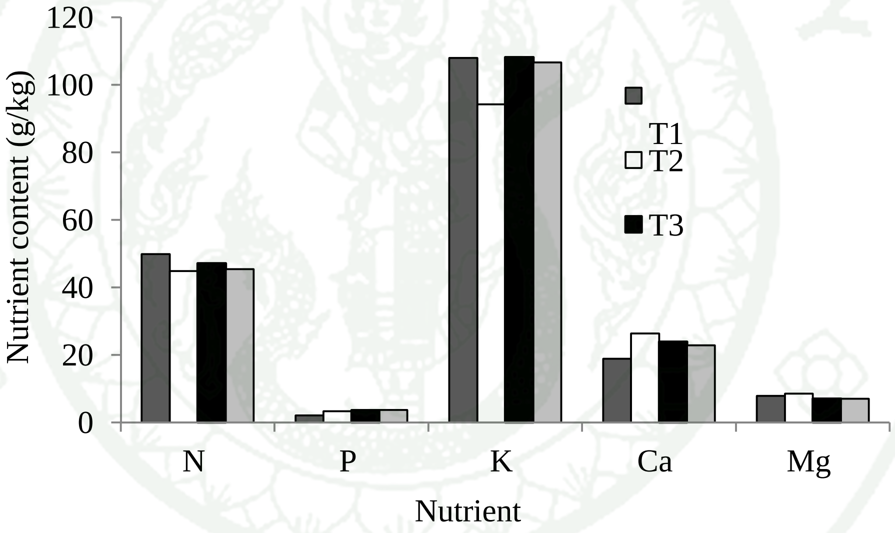


Figure 25 Nutrient content of upper ground biomass of the plant in four treatments in experiment 2.

5. Nutrient Content and water uptake of plants

Nutrient content of each treatment before planting is shown in Figure 26, total added nutrient in each treatment is shown in Figure 27, nutrient in residue after harvesting of the plant of the each treatment is shown in Figure 28 and Table 13 and water uptake of each treatment in crop duration is shown in Figure 29.

When considering nutrient content in before planting plants and total added solution it can be said that N content was similar in treatment T1 and treatment T3 and T1= T3>T4>T2. P content is in four treatment were nearly same but K content was T3>T4>T2>T1. Ca content was T1=T3>T4>T2. Mg content was nearly same in treatment T2, treatment T3 and treatment T4 but high in treatment T1 (Figure 26 and Figure 27).

As shown in Figure 28 and Table 13, N content and K content in residue after harvesting is the lowest in treatment T1 but P, Ca and Mg is lowest in treatment T2. According to EC of the solution, it shows that EC of the treatment T2 was the lowest. Hence nutrient content of the residue is also low in treatment T2. As treatment T1 is shown a high growth rate than in treatment T2 it can be said that N was more uptake by the treatment T1than in treatment T2. Hence treatment T1 residue was low in N content.

Jones, 1997, reported that passive mode of transport explains the high concentrations of some ions such as K^+, NO_3^-, and Cl^-. According to Fig.29 water uptake of each treatment was treatment T2>treatment T1> treatment T4> treatment T3. Hence passive absorption is great in treatment T2 and treatment T1 than in treatment T4 and treatment T3. Therefore it can be said that N and K uptake was greater in treatment T1 and treatment T2 than in treatment T3 and treatment T4. Hence residue of treatment T1 and treatment T2 remain low N and K content than in treatment T3 and treatment T4.

P, Ca and Mg are uptake by roots with active absorption of the root hairs. But Jones, 1998 reported that relatively high level of available of N in the surrounding the root reduce the incidence of root hair formation. Therefore it can be said that relatively low amount of the root hairs in treatment T1, treatment T3 and treatment T4 absorption of these elements are lower than in treatment T2. Hence, in residue there were more P, Ca, and Mg in treatment T1 treatment T3 and treatment T4 than in treatment T2.

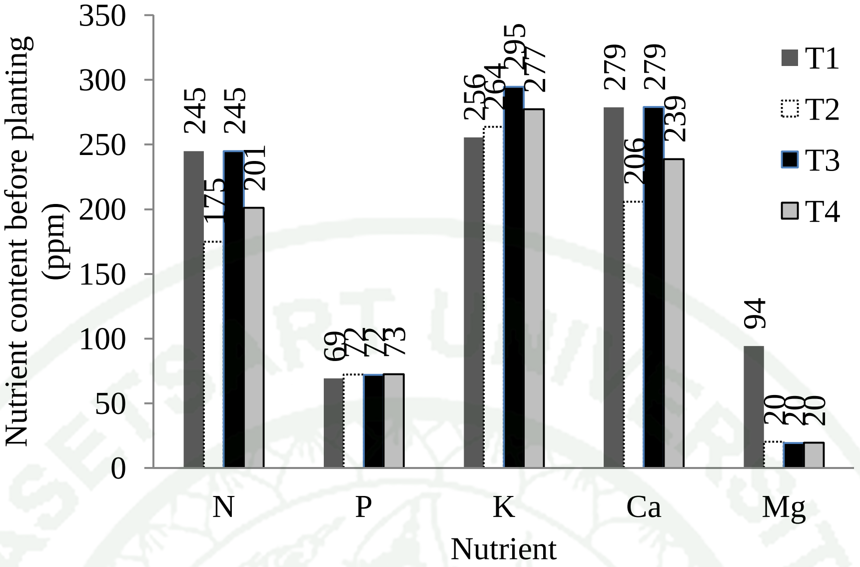


Figure 26 Nutrient content in each treatment before planting in experiment 2

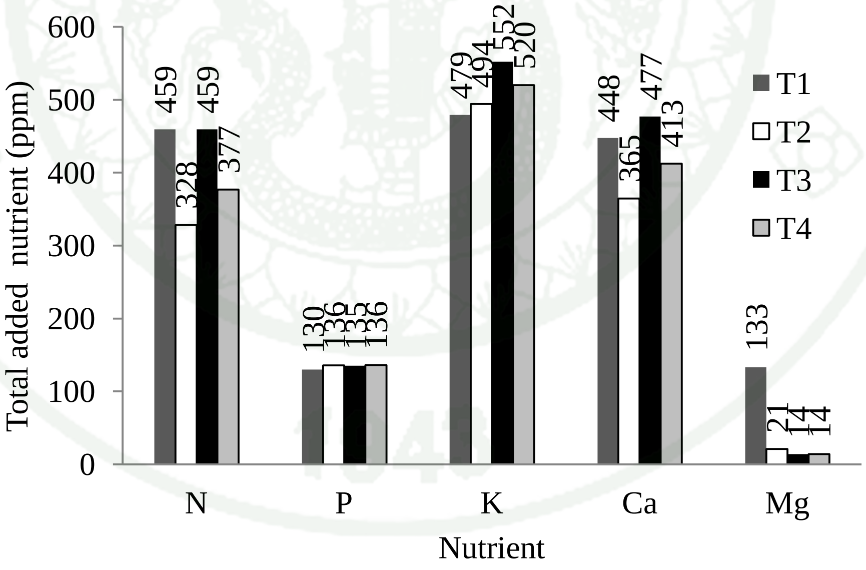


Figure 27 Total added nutrient amount in each treatment in crop duration in experiment 2

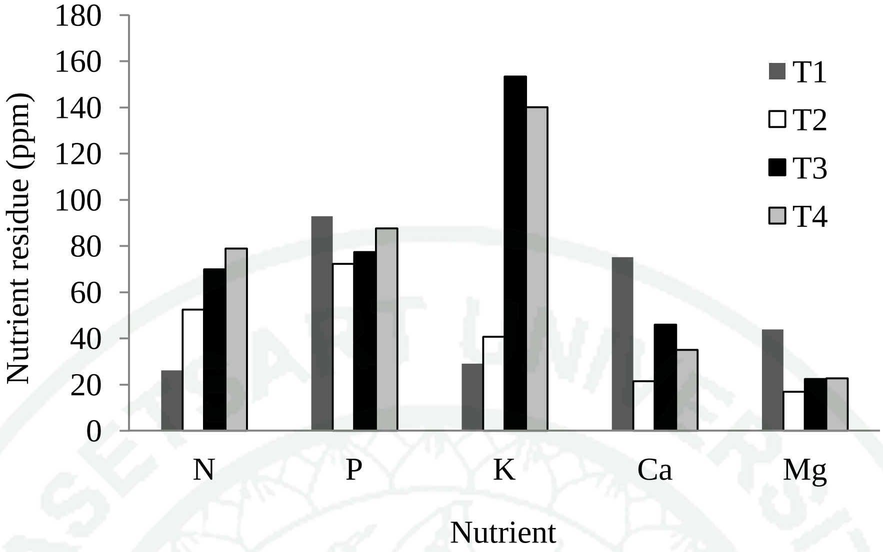


Figure 28 Nutrient residue in each treatment after harvesting in experiment 2

Table 13 Nutrient residue in each treatment after harvesting crop- experiment 2

Treatment	N(ppm)	P(ppm)	K(ppm)	Ca(ppm)	Mg(ppm)
T1	26.25	92.91	29.14	75.23	43.98
T2	52.50	72.37	40.8	21.48	16.95
T3	70.00	77.41	153.4	45.94	22.47
T4	79.00	87.68	140.09	35.11	22.81

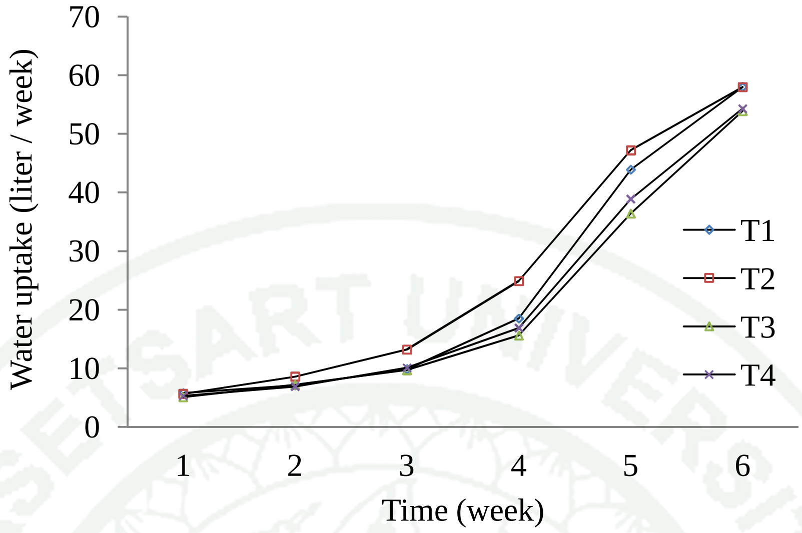


Figure 29 Water uptake of plants in each treatment during crop duration in experiment 2

CONCLUTION AND RECOMMENDATIONS

Experiment 1

1. Finally it can be concluded that although Dry matter weight is shown same condition in both solutions, solution y is better for growing lettuce in NFT system under hydroponics using maintaining the EC level of the solution than solution x.

2. According to nutrient content in upper ground biomass of the plant it can be concluded that K content in both solutions should be reduce and other four elements can be increased according to sufficiency nutrient level of lettuce to obtain better yield than in this experiment.

3. According to Nutrient consumption of experiment it can be concluded that N content of solution y should be increased as in solution x for getting same performance with same amount of solution.

Experiment 2

1. Plant growth and development of lettuce is better in solution x (Treatment T1) than in solution y (Treatment T2), solution z_1 (Treatment T3) and solution z_2 (Treatment T4) in NFT system.

2. According to nutrient content in the upper ground biomass of the plant, N content and K content in solution x and K content in solution y should be reduced up to suitable level which can be obtained N in upper ground biomass is 35000 to 45000 ppm and K is about 55000 to 62000 ppm and P content in both solutions should be increased up to suitable level that can be obtained P in upper ground biomass is 4000 to 800 ppm in NFT system.

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APENDIX

Appendix Table 1 Independent Samples Test for analysis for measuring data in two nutrient solutions – experiment 1

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
NL2nd	Equal variances assumed	47.130	.000	-3.074	110	.003	-.214	.070	-.352	-.076
	Equal variances not assumed			-3.074	80.780	.003	-.214	.070	-.353	-.076
NL3rd	Equal variances assumed	3.356	.070	-3.292	110	.001	-.482	.146	-.772	-.192
	Equal variances not assumed			-3.292	107.713	.001	-.482	.146	-.772	-.192
NL4th	Equal variances assumed	6.637	.011	-17.722	110	.000	-2.839	.160	-3.157	-2.522
	Equal variances not assumed			-17.722	102.129	.000	-2.839	.160	-3.157	-2.522
NL5th	Equal variances assumed	1.023	.314	-14.365	110	.000	-2.786	.194	-3.170	-2.401
	Equal variances not assumed			-14.365	108.384	.000	-2.786	.194	-3.170	-2.401
FW	Equal variances assumed	1.693	.196	-2.603	110	.011	-6.11143	2.34753	-10.76367	-1.45918
	Equal variances not assumed			-2.603	93.881	.011	-6.11143	2.34753	-10.77257	-1.45028

Appendix Table 1 (Continued)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
DW	Equal variances assumed	.342	.560	.434	110	.665	.05429	.12499	-.19342	.30199
	Equal variances not assumed			.434	109.406	.665	.05429	.12499	-.19343	.30201
N	Equal variances assumed	.437	.510	.176	110	.861	.01589	.09044	-.16334	.19513
	Equal variances not assumed			.176	109.536	.861	.01589	.09044	-.16335	.19514
P	Equal variances assumed	.124	.726	-24.495	110	.000	-.13734	.00561	-.14846	-.12623
	Equal variances not assumed			-24.495	109.023	.000	-.13734	.00561	-.14846	-.12623
K	Equal variances assumed	.389	.534	-9.701	110	.000	-1.46513	.15102	-1.76442	-1.16584
	Equal variances not assumed			-9.701	106.456	.000	-1.46513	.15102	-1.76453	-1.16572
Ca	Equal variances assumed	1.027	.313	-5.177	110	.000	-.14797	.02859	-.20462	-.09132
	Equal variances not assumed			-5.177	108.263	.000	-.14797	.02859	-.20463	-.09131
Mg	Equal variances assumed	.457	.500	-2.697	110	.008	-.02610	.00968	-.04528	-.00692
	Equal variances not assumed			-2.697	108.345	.008	-.02610	.00968	-.04529	-.00692

Appendix Table 2 Group statics of measuring data in two nutrient solutions in experiment 1

	Trt	N	Mean	Std. Deviation	Std. Error Mean
NL5th	T1	56	22.95	.961	.128
	t2	56	25.73	1.087	.145
FW	T1	56	71.5562	9.50616	1.27031
	t2	56	77.6677	14.77301	1.97413
DW	T1	56	2.5736	.68534	.09158
	t2	56	2.5193	.63656	.08506
N	T1	56	3.9939	.46274	.06184
	t2	56	3.9780	.49390	.06600
P	T1	56	.2486	.02823	.00377
	t2	56	.3859	.03104	.00415
K	T1	56	6.7678	.72256	.09656
	t2	56	8.2330	.86899	.11612
Ca	T1	56	1.3295	.16055	.02145
	t2	56	1.4774	.14136	.01889
Mg	T1	56	.3713	.04795	.00641
	t2	56	.3974	.05429	.00725

Appendix Table 3 One way ANOVA Statistics Descriptives Table – experiment 2

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
FW	1	20	88.1985	11.01597	2.46325	83.0429	93.3541	66.36	103.71
	2	20	67.8150	14.71345	3.29003	60.9289	74.7011	41.09	114.15
	3	20	73.1950	14.09021	3.15067	66.6006	79.7894	40.21	98.98
	4	19	74.3974	12.47471	2.86190	68.3848	80.4100	51.61	93.01
	Total	79	75.9205	14.98452	1.68589	72.5642	79.2769	40.21	114.15
DW	1	20	2.7230	.43907	.09818	2.5175	2.9285	1.83	3.66
	2	20	2.4890	.85302	.19074	2.0898	2.8882	1.44	4.83
	3	20	2.2410	.60271	.13477	1.9589	2.5231	1.36	3.20
	4	19	2.3911	.59889	.13739	2.1024	2.6797	1.23	3.48
	Total	79	2.4619	.65335	.07351	2.3156	2.6082	1.23	4.83
N	1	20	4.99E4	4925.320	1101.335	47570.08	52180.32	41125	55563
	2	20	4.48E4	2264.350	506.324	43762.35	45881.85	40688	50313
	3	20	4.71E4	4529.585	1012.846	44977.14	49216.96	38500	56438
	4	19	4.55E4	3093.171	709.622	43963.30	46945.02	40250	49875
	Total	79	4.68E4	4272.557	480.700	45872.32	47786.32	38500	56438

Appendix Table 3 (Continued)

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
P	1	20	2017.00	302.192	67.572	1875.57	2158.43	1601	2615
	2	20	3275.60	349.071	78.055	3112.23	3438.97	2789	3942
	3	20	3626.30	282.598	63.191	3494.04	3758.56	3161	4107
	4	19	3621.95	305.424	70.069	3474.74	3769.16	3140	4040
	Total	79	3129.05	733.542	82.530	2964.75	3293.36	1601	4107
K	1	20	1.08E5	8717.199	1949.225	103890.63	112050.17	95669	123983
	2	20	9.42E4	12269.448	2743.532	88453.72	99938.28	71957	111003
	3	20	1.08E5	12780.461	2857.798	102194.96	114157.84	79347	125992
	4	19	1.05E5	11344.664	2602.644	99916.36	110852.27	79146	118668
	Total	79	1.04E5	12581.250	1415.501	101095.35	106731.44	71957	125992
Ca	1	20	1.88E4	4379.205	979.220	16759.32	20858.38	10893	26356
	2	20	2.64E4	6166.144	1378.792	23469.41	29241.09	18180	40686
	3	20	2.39E4	6095.274	1362.945	21000.67	26706.03	10004	37389
	4	19	2.29E4	3505.463	804.208	21192.74	24571.89	16900	29548
	Total	79	2.30E4	5779.175	650.208	21681.65	24270.58	10004	40686

Appendix Table 3 (Continued)

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Mg	1	20	7863.75	2352.032	525.930	6762.97	8964.53	4895	13166
	2	20	8449.70	2763.660	617.973	7156.27	9743.13	4808	14469
	3	20	7033.95	1965.280	439.450	6114.17	7953.73	3830	10619
	4	19	6902.37	2204.248	505.689	5839.95	7964.78	4080	10522
	Total	79	7570.80	2381.789	267.972	7037.31	8104.29	3830	14469

Appendix Table 4 Test of homogeneity of variances – experiment 2

	Levene Statistic	df1	df2	Sig.
FW	.320	3	75	.811
DW	2.411	3	75	.073
N	4.602	3	75	.005
P	.525	3	75	.666
K	.908	3	75	.441
Ca	1.716	3	75	.171
Mg	.454	3	75	.715

Appendix Table 5 ANOVA –experiment 2

		Sum of Squares	df	Mean Square	F	Sig.
FW	Between Groups	4521.614	3	1507.205	8.701	.000
	Within Groups	12992.190	75	173.229		
	Total	17513.804	78			
DW	Between Groups	2.449	3	.816	1.985	.123
	Within Groups	30.846	75	.411		
	Total	33.295	78			
N	Between Groups	3.035E8	3	1.012E8	6.772	.000
	Within Groups	1.120E9	75	1.494E7		
	Total	1.424E9	78			
P	Between Groups	3.472E7	3	1.157E7	119.791	.000
	Within Groups	7246727.947	75	96623.039		
	Total	4.197E7	78			

Appendix Table 5 (Continued)

		Sum of Squares	df	Mean Square	F	Sig.
K	Between Groups	2.622E9	3	8.741E8	6.742	.000
	Within Groups	9.724E9	75	1.297E8		
	Total	1.235E10	78			
Ca	Between Groups	5.913E8	3	1.971E8	7.340	.000
	Within Groups	2.014E9	75	2.685E7		
	Total	2.605E9	78			
Mg	Between Groups	3.142E7	3	1.047E7	1.911	.135
	Within Groups	4.111E8	75	5480913.004		
	Total	4.425E8	78			

Appendix Table 6 Multiple comparisons – experiment 2

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
FW	LSD	1	2	20.38350*	4.16208	.000	12.0922	28.6748
			3	15.00350*	4.16208	.001	6.7122	23.2948
			4	13.80113*	4.21649	.002	5.4015	22.2008
		2	1	-20.38350*	4.16208	.000	-28.6748	-12.0922
			3	-5.38000	4.16208	.200	-13.6713	2.9113
			4	-6.58237	4.21649	.123	-14.9820	1.8173
		3	1	-15.00350*	4.16208	.001	-23.2948	-6.7122
			2	5.38000	4.16208	.200	-2.9113	13.6713
			4	-1.20237	4.21649	.776	-9.6020	7.1973
		4	1	-13.80113*	4.21649	.002	-22.2008	-5.4015
			2	6.58237	4.21649	.123	-1.8173	14.9820
			3	1.20237	4.21649	.776	-7.1973	9.6020
	Dunnett T3	1	2	20.38350*	4.10997	.000	8.9651	31.8019
			3	15.00350*	3.99929	.004	3.9046	26.1024
			4	13.80113*	3.77598	.005	3.3216	24.2807
		2	1	-20.38350*	4.10997	.000	-31.8019	-8.9651
			3	-5.38000	4.55533	.801	-17.9859	7.2259
			4	-6.58237	4.36059	.578	-18.6727	5.5079
		3	1	-15.00350*	3.99929	.004	-26.1024	-3.9046
			2	5.38000	4.55533	.801	-7.2259	17.9859
			4	-1.20237	4.25642	1.000	-12.9991	10.5944
		4	1	-13.80113*	3.77598	.005	-24.2807	-3.3216
			2	6.58237	4.36059	.578	-5.5079	18.6727
			3	1.20237	4.25642	1.000	-10.5944	12.9991

Appendix Table 6 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
DW	LSD	1	2	.23400	.20280	.252	-.1700	.6380
			3	.48200*	.20280	.020	.0780	.8860
			4	.33195	.20545	.110	-.0773	.7412
		2	1	-.23400	.20280	.252	-.6380	.1700
			3	.24800	.20280	.225	-.1560	.6520
			4	.09795	.20545	.635	-.3113	.5072
		3	1	-.48200*	.20280	.020	-.8860	-.0780
			2	-.24800	.20280	.225	-.6520	.1560
			4	-.15005	.20545	.467	-.5593	.2592
		4	1	-.33195	.20545	.110	-.7412	.0773
			2	-.09795	.20545	.635	-.5072	.3113
			3	.15005	.20545	.467	-.2592	.5593
	Dunnett T3	1	2	.23400	.21453	.850	-.3699	.8379
			3	.48200*	.16674	.038	.0184	.9456
			4	.33195	.16887	.289	-.1390	.8029
		2	1	-.23400	.21453	.850	-.8379	.3699
			3	.24800	.23355	.866	-.4019	.8979
			4	.09795	.23507	.999	-.5563	.7522
		3	1	-.48200*	.16674	.038	-.9456	-.0184
			2	-.24800	.23355	.866	-.8979	.4019
			4	-.15005	.19246	.965	-.6834	.3833
		4	1	-.33195	.16887	.289	-.8029	.1390
			2	-.09795	.23507	.999	-.7522	.5563
			3	.15005	.19246	.965	-.3833	.6834

Appendix Table 6 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
N	LSD	1	2	5053.100*	1222.227	.000	2618.30	7487.90
			3	2778.150*	1222.227	.026	343.35	5212.95
			4	4421.042*	1238.205	.001	1954.41	6887.67
		2	1	-5053.100*	1222.227	.000	-7487.90	-2618.30
			3	-2274.950	1222.227	.067	-4709.75	159.85
			4	-632.058	1238.205	.611	-3098.69	1834.57
		3	1	-2778.150*	1222.227	.026	-5212.95	-343.35
			2	2274.950	1222.227	.067	-159.85	4709.75
			4	1642.892	1238.205	.189	-823.74	4109.52
		4	1	-4421.042*	1238.205	.001	-6887.67	-1954.41
			2	632.058	1238.205	.611	-1834.57	3098.69
			3	-1642.892	1238.205	.189	-4109.52	823.74
	Dunnett T3	1	2	5053.100*	1212.148	.002	1625.78	8480.42
			3	2778.150	1496.261	.346	-1363.51	6919.81
			4	4421.042*	1310.154	.011	762.38	8079.70
		2	1	-5053.100*	1212.148	.002	-8480.42	-1625.78
			3	-2274.950	1132.352	.272	-5466.24	916.34
			4	-632.058	871.738	.975	-3063.23	1799.12
		3	1	-2778.150	1496.261	.346	-6919.81	1363.51
			2	2274.950	1132.352	.272	-916.34	5466.24
			4	1642.892	1236.697	.705	-1801.55	5087.34
		4	1	-4421.042*	1310.154	.011	-8079.70	-762.38
			2	632.058	871.738	.975	-1799.12	3063.23
			3	-1642.892	1236.697	.705	-5087.34	1801.55

Appendix Table 6 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
P	LSD	1	2	-1258.600*	98.297	.000	-1454.42	-1062.78
			3	-1609.300*	98.297	.000	-1805.12	-1413.48
			4	-1604.947*	99.582	.000	-1803.32	-1406.57
		2	1	1258.600*	98.297	.000	1062.78	1454.42
			3	-350.700*	98.297	.001	-546.52	-154.88
			4	-346.347*	99.582	.001	-544.72	-147.97
		3	1	1609.300*	98.297	.000	1413.48	1805.12
			2	350.700*	98.297	.001	154.88	546.52
			4	4.353	99.582	.965	-194.02	202.73
		4	1	1604.947*	99.582	.000	1406.57	1803.32
			2	346.347*	99.582	.001	147.97	544.72
			3	-4.353	99.582	.965	-202.73	194.02
	Dunnett T3	1	2	-1258.600*	103.240	.000	-1544.57	-972.63
			3	-1609.300*	92.515	.000	-1865.35	-1353.25
			4	-1604.947*	97.343	.000	-1874.73	-1335.17
		2	1	1258.600*	103.240	.000	972.63	1544.57
			3	-350.700*	100.427	.008	-629.20	-72.20
			4	-346.347*	104.891	.013	-637.08	-55.61
		3	1	1609.300*	92.515	.000	1353.25	1865.35
			2	350.700*	100.427	.008	72.20	629.20
			4	4.353	94.354	1.000	-257.32	266.02
		4	1	1604.947*	97.343	.000	1335.17	1874.73
			2	346.347*	104.891	.013	55.61	637.08
			3	-4.353	94.354	1.000	-266.02	257.32

Appendix Table 6 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
K	LSD	1	2	13774.400*	3600.766	.000	6601.31	20947.49
			3	-206.000	3600.766	.955	-7379.09	6967.09
			4	2586.084	3647.837	.481	-4680.78	9852.95
		2	1	-13774.400*	3600.766	.000	-20947.49	-6601.31
			3	-13980.400*	3600.766	.000	-21153.49	-6807.31
			4	-11188.316*	3647.837	.003	-18455.18	-3921.45
		3	1	206.000	3600.766	.955	-6967.09	7379.09
			2	13980.400*	3600.766	.000	6807.31	21153.49
			4	2792.084	3647.837	.446	-4474.78	10058.95
		4	1	-2586.084	3647.837	.481	-9852.95	4680.78
			2	11188.316*	3647.837	.003	3921.45	18455.18
			3	-2792.084	3647.837	.446	-10058.95	4474.78
	Dunnett T3	1	2	13774.400*	3365.479	.001	4410.59	23138.21
			3	-206.000	3459.261	1.000	-9842.96	9430.96
			4	2586.084	3251.651	.961	-6468.60	11640.76
		2	1	-13774.400*	3365.479	.001	-23138.21	-4410.59
			3	-13980.400*	3961.562	.007	-24943.07	-3017.73
			4	-11188.316*	3781.630	.031	-21666.93	-709.70
		3	1	206.000	3459.261	1.000	-9430.96	9842.96
			2	13980.400*	3961.562	.007	3017.73	24943.07
			4	2792.084	3865.329	.976	-7920.54	13504.71
		4	1	-2586.084	3251.651	.961	-11640.76	6468.60
			2	11188.316*	3781.630	.031	709.70	21666.93
			3	-2792.084	3865.329	.976	-13504.71	7920.54

Appendix Table 6 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Ca	LSD	1	2	-7546.400*	1638.642	.000	-10810.74	-4282.06
			3	-5044.500*	1638.642	.003	-8308.84	-1780.16
			4	-4073.466*	1660.063	.016	-7380.48	-766.45
		2	1	7546.400*	1638.642	.000	4282.06	10810.74
			3	2501.900	1638.642	.131	-762.44	5766.24
			4	3472.934*	1660.063	.040	165.92	6779.95
		3	1	5044.500*	1638.642	.003	1780.16	8308.84
			2	-2501.900	1638.642	.131	-5766.24	762.44
			4	971.034	1660.063	.560	-2335.98	4278.05
		4	1	4073.466*	1660.063	.016	766.45	7380.48
			2	-3472.934*	1660.063	.040	-6779.95	-165.92
			3	-971.034	1660.063	.560	-4278.05	2335.98
	Dunnett T3	1	2	-7546.400*	1691.135	.000	-12251.72	-2841.08
			3	-5044.500*	1678.240	.029	-9712.35	-376.65
			4	-4073.466*	1267.132	.016	-7589.62	-557.31
		2	1	7546.400*	1691.135	.000	2841.08	12251.72
			3	2501.900	1938.733	.731	-2862.66	7866.46
			4	3472.934	1596.189	.197	-1000.24	7946.11
		3	1	5044.500*	1678.240	.029	376.65	9712.35
			2	-2501.900	1938.733	.731	-7866.46	2862.66
			4	971.034	1582.520	.989	-3461.95	5404.02
		4	1	4073.466*	1267.132	.016	557.31	7589.62
			2	-3472.934	1596.189	.197	-7946.11	1000.24
			3	-971.034	1582.520	.989	-5404.02	3461.95

Appendix Table 6 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Mg	LSD	1	2	-585.950	740.332	.431	-2060.77	888.87
			3	829.800	740.332	.266	-645.02	2304.62
			4	961.382	750.010	.204	-532.71	2455.48
		2	1	585.950	740.332	.431	-888.87	2060.77
			3	1415.750	740.332	.060	-59.07	2890.57
			4	1547.332*	750.010	.043	53.24	3041.43
		3	1	-829.800	740.332	.266	-2304.62	645.02
			2	-1415.750	740.332	.060	-2890.57	59.07
			4	131.582	750.010	.861	-1362.51	1625.68
		4	1	-961.382	750.010	.204	-2455.48	532.71
			2	-1547.332*	750.010	.043	-3041.43	-53.24
			3	-131.582	750.010	.861	-1625.68	1362.51
	Dunnett T3	1	2	-585.950	811.476	.976	-2834.25	1662.35
			3	829.800	685.360	.782	-1069.66	2729.26
			4	961.382	729.606	.713	-1060.25	2983.01
		2	1	585.950	811.476	.976	-1662.35	2834.25
			3	1415.750	758.292	.342	-694.00	3525.50
			4	1547.332	798.506	.302	-668.57	3763.24
		3	1	-829.800	685.360	.782	-2729.26	1069.66
			2	-1415.750	758.292	.342	-3525.50	694.00
			4	131.582	669.954	1.000	-1727.44	1990.60
		4	1	-961.382	729.606	.713	-2983.01	1060.25
			2	-1547.332	798.506	.302	-3763.24	668.57
			3	-131.582	669.954	1.000	-1990.60	1727.44

Appendix Table 7 Multiple comparisons for number of leaves in experiment 2

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
NL3wk	LSD	1	2	.050	.109	.648	-.17	.27
			3	.200	.109	.071	-.02	.42
			4	.100	.109	.362	-.12	.32
		2	1	-.050	.109	.648	-.27	.17
			3	.150	.109	.173	-.07	.37
			4	.050	.109	.648	-.17	.27
		3	1	-.200	.109	.071	-.42	.02
			2	-.150	.109	.173	-.37	.07
			4	-.100	.109	.362	-.32	.12
		4	1	-.100	.109	.362	-.32	.12
			2	-.050	.109	.648	-.27	.17
			3	.100	.109	.362	-.12	.32
	Dunnett T3	1	2	.050	.085	.992	-.19	.29
			3	.200	.111	.388	-.11	.51
			4	.100	.096	.875	-.17	.37
		2	1	-.050	.085	.992	-.29	.19
			3	.150	.121	.763	-.19	.49
			4	.050	.107	.998	-.25	.35
		3	1	-.200	.111	.388	-.51	.11
			2	-.150	.121	.763	-.49	.19
			4	-.100	.129	.966	-.46	.26
		4	1	-.100	.096	.875	-.37	.17
			2	-.050	.107	.998	-.35	.25
			3	.100	.129	.966	-.26	.46

Appendix Table 7 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
NL4wk	LSD	1	2	1.050*	.167	.000	.72	1.38
			3	1.800*	.167	.000	1.47	2.13
			4	1.850*	.167	.000	1.52	2.18
		2	1	-1.050*	.167	.000	-1.38	-.72
			3	.750*	.167	.000	.42	1.08
			4	.800*	.167	.000	.47	1.13
		3	1	-1.800*	.167	.000	-2.13	-1.47
			2	-.750*	.167	.000	-1.08	-.42
			4	.050	.167	.765	-.28	.38
		4	1	-1.850*	.167	.000	-2.18	-1.52
			2	-.800*	.167	.000	-1.13	-.47
			3	-.050	.167	.765	-.38	.28
	Dunnett T3	1	2	1.050*	.085	.000	.81	1.29
			3	1.800*	.174	.000	1.30	2.30
			4	1.850*	.152	.000	1.42	2.28
		2	1	-1.050*	.085	.000	-1.29	-.81
			3	.750*	.180	.002	.24	1.26
			4	.800*	.159	.000	.35	1.25
		3	1	-1.800*	.174	.000	-2.30	-1.30
			2	-.750*	.180	.002	-1.26	-.24
			4	.050	.220	1.000	-.56	.66
		4	1	-1.850*	.152	.000	-2.28	-1.42
			2	-.800*	.159	.000	-1.25	-.35
			3	-.050	.220	1.000	-.66	.56

Appendix Table 7 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
NL5wk	LSD	1	2	.050	.106	.638	-.16	.26
			3	-.850*	.106	.000	-1.06	-.64
			4	.100	.106	.347	-.11	.31
		2	1	-.050	.106	.638	-.26	.16
			3	-.900*	.106	.000	-1.11	-.69
			4	.050	.106	.638	-.16	.26
		3	1	.850*	.106	.000	.64	1.06
			2	.900*	.106	.000	.69	1.11
			4	.950*	.106	.000	.74	1.16
		4	1	-.100	.106	.347	-.31	.11
			2	-.050	.106	.638	-.26	.16
			3	-.950*	.106	.000	-1.16	-.74
	Dunnett T3	1	2	.050	.085	.992	-.19	.29
			3	-.850*	.105	.000	-1.14	-.56
			4	.100	.096	.875	-.17	.37
		2	1	-.050	.085	.992	-.29	.19
			3	-.900*	.115	.000	-1.22	-.58
			4	.050	.107	.998	-.25	.35
		3	1	.850*	.105	.000	.56	1.14
			2	.900*	.115	.000	.58	1.22
			4	.950*	.123	.000	.61	1.29
		4	1	-.100	.096	.875	-.37	.17
			2	-.050	.107	.998	-.35	.25
			3	-.950*	.123	.000	-1.29	-.61

Appendix Table 7 (Continued)

Dependent Variable		(I) Trt	(J) Trt	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
NL6wk	LSD	1	2	2.200*	.314	.000	1.57	2.83
			3	1.450*	.314	.000	.82	2.08
			4	.550	.314	.084	-.08	1.18
		2	1	-2.200*	.314	.000	-2.83	-1.57
			3	-.750*	.314	.020	-1.38	-.12
			4	-1.650*	.314	.000	-2.28	-1.02
		3	1	-1.450*	.314	.000	-2.08	-.82
			2	.750*	.314	.020	.12	1.38
			4	-.900*	.314	.005	-1.53	-.27
		4	1	-.550	.314	.084	-1.18	.08
			2	1.650*	.314	.000	1.02	2.28
			3	.900*	.314	.005	.27	1.53
	Dunnett T3	1	2	2.200*	.279	.000	1.42	2.98
			3	1.450*	.318	.001	.56	2.34
			4	.550	.245	.167	-.13	1.23
		2	1	-2.200*	.279	.000	-2.98	-1.42
			3	-.750	.371	.259	-1.78	.28
			4	-1.650*	.311	.000	-2.51	-.79
		3	1	-1.450*	.318	.001	-2.34	-.56
			2	.750	.371	.259	-.28	1.78
			4	-.900	.346	.077	-1.86	.06
		4	1	-.550	.245	.167	-1.23	.13
			2	1.650*	.311	.000	.79	2.51
			3	.900	.346	.077	-.06	1.86

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