CULTIVATION AND MAINTENANCES TECHNIQUES OF LETTUCE (*Lactuca sativa* L.) BY VERTICAL HYDROPONICS SYSTEM

NGUYEN VAN QUY

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Agricultural Technology

at Mahasarakham University

April 2015

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The examining committee has unanimously approved this dissertation, submitted by Nguyen Van Quy, as a partial fulfillment of the requirements for the degree of doctor of philosophy in Agricultural Technology at Mahasarakham University.

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TITLE Cultivation and Maintenances Techniques of Lettuce (*Lactuca sativa* L.) by VerticalHydroponics System

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ABSTRACT

Five experiments were carried out to develop the cultivation and maintenances techniques of lettuce (*Lactuca sativa* L.) by a vertical hydroponics system. The experiments were carried out at the greenhouse, Faculty of Agronomy, Hue University, Hue city, in the centre of Viet Nam during 2012 – 2014.

The first experiment was carried out to evaluate the effect and interaction of plant densities and materials of the vertical hydroponic system on the growth, yields and quality of lettuce. Three materials (Mat, Shoddy Felt, Burlap) and four plant densities (10 x 12 cm, 12 x 14 cm, 14 x 16 cm, 16 x 16 cm) were used in this experiment. The experimental results indicated that different materials of the vertical hydroponics system had no significant effect on some parameters of lettuce growth and yield. However in comparison to weight of system, cost of system, evaporate of water /m^2, and usefulness after one season of system revealed that Mat was the best material to use for the vertical hydroponics system due to its light weight, low cost, low surface evaporation, and especially durability. In other aspects, plant density was a crucial factor affecting the growth and yield of lettuce cultivars when they were grown on the vertical hydroponics system. Lettuce with plant densities of 14 x 16 cm and 16 x 16 cm gave the highest parameters of lettuce growth, while lettuce with plant densities at 10 x 12 cm and 12 x 14 cm brought the highest yield because of large number of plants/m^2. From the above results, the plant densities of 10 x 12 cm or 12 x 14 cm was the most suitable for growing lettuce on the vertical hydroponics system to achieve high yield.

The second experiment was carried out to evaluate the effect of cultivation method on the growth, quality and yields of lettuce by the vertical hydroponics system. Three lettuce varieties (Red Rapid, Romaine, Grand Rapids Leaf) and three cultivation methods (vertical hydroponic system, hydroponic wick system, growing soil) were used in this experiment. The experimental results indicated that, different cultivation methods and lettuce varieties had significant effects on some parameters including namely lettuce growth, yield and quality. The data showed that, lettuce grown in the hydroponics wick system had the highest lettuce growth and quality, but the vertical hydroponic system was the best method for growing lettuce for yield. For lettuce varieties, the data revealed that red rapid lettuce had the highest lettuce growth, yield and quality.

The third experiment was carried out to evaluate the effect and interaction of growing media and period of irrigation on the growth, yields and quality of lettuce by the vertical hydroponic system. Three periods of irrigation (2 times, 3 times, 4 times/day) and four growing media (coconut coir, carbonized rice hull, coconut mixed carbonized rice hull, rock wool) were used in this experiment. The experimental results indicated that different growing media and the period of irrigation had a significant effect on some parameters of lettuce growth, yield and quality. Lettuce grown in coconut mix carbonized rice husk had the highest lettuce growth, yield and quality. In addition the period of irrigation of 2 times/day was the best suited for growing lettuce in vertical hydroponics system.

The fourth experiment was carried out to evaluate the effect of electrical conductivity (EC) of nutrient solution on the growth, yields and quality of lettuce by the vertical hydroponic system. Five level of electrical conductivity (EC) of nutrient solution were used in this experiment (EC = 0.5, 1.0, 1.5, 2.0, and 2.5). The experimental results concluded that, the ability to grow, yield and quality of lettuce grown in vertical hydroponic systems were significantly affected by nutrient solution concentrations (EC). The results also indicated that increasing the fertilizer concentration increased plant growth parameters, yield and quality of lettuce. The use of nutrient solution concentration of 2 mS/cm to grow lettuce in vertical hydroponic systems is considered to bring the best productivity, quality and efficiency.

The fifth experiment was carried out to evaluate the effect of compost extract on the growth, yields and quality of lettuce by the vertical hydroponic system. Six ratio of compost extract in chemical solution nutrient were used in this experiment:

1/2 compost extract + 1/2 chemical solution nutrient
1/3 compost extract + 2/3 chemical solution nutrient
1/4 compost extract + 3/4 chemical solution nutrient
1/5 compost extract + 4/5 chemical solution nutrient
% Compost extract
% Chemical nutrient solution (control).

The experimental results indicated that the addition of compost extract into the hydroponic nutrient solution had significant effects on growth, yield and quality of lettuce grown in vertical hydroponic systems. The data also shows that lettuce plant had the highest yield and quality at addition doses of 1/5 compost extract + 4/5 chemical nutrient solution. The increasing of compost extracts concentrations or 100% compost extract used in hydroponic nutrient solution will tend to decrease the lettuce yield and quality.

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List of Abbreviations

EC	Electrical conductivity
e.g.	Exempli gratia (Latin), for example
et al.	Etalli (Lain), and others
etc	Et cetera
gm	Gram
h	Hour
min	Minute
mm	Millimeter
ml	Milliliter
NFT	Nutrient Film Technique
no	Number
pH	Negative logarithm of hydrogen ion activity
PVC	Polyvinyl chloride
NAR	Net Assimilation Rate
LA	Leaf area
LAR	Leaf area ratio
LWR	Leaf Weight Ratio
SLA	Specific Leaf Area

CHAPTER 1

INTRODUCTION

1.1 Background

Hydroponics is described as a technology that allows plants to be grown in nutrient solutions with all necessary nutrient components. Whether there is a presence of inert medium such as gravel, vermiculite, rock wool, peat moss, sawdust, coir dust, coconut fiber, etc. or not, plants can still grow optimally (Carruthers, 2002). In addition, hydroponics technique is capable of providing a root environmental which can be standardized and easily controlled with simple crop management (Morgan *et al*., 1980). In comparison with soil based systems, hydroponic systems provide a more skillful control of crop production (quantity and quality). Recirculating systems of this technique also use water and fertilizers efficiently, which helps reduce environmental pollution (Heinen*et al*., 1991). As a result, hydroponic systems have been applied worldwide to produce high-value crops in glasshouses for the last 20 years (Savvas*et al*., 2002). While the horizontal hydroponic system has been used more widely and commercially for vegetables, it is popular to produce strawberries, leafy greens, edible flowers and fresh cut herbs with vertical hydroponic systems. In recent years, the latter technique has been applied for tomato as well (Tyson*et al*., 2008). The main difficulties of hydroponics are the cost of capital and energy inputs related to common production of open-field. To make the operation of the system successful, a high level of competence in plant science and technical skills is really essential. However, considerable high costs keep the production scale of hydroponic technology limited to crops of high economic value (Jensen and Collins, 1985).

As a crucial commercial vegetable crop grown all over the world in different kinds of environments, lettuce (*Lactuca sativa* L.) is produced mainly in USA, Spain, Italy, Japan and France (Ryder, 2006). Lettuce belongs to the *Composite* family, the tribe *Cichoreae* and the genus *Lactuca*. Being grown in almost all continents, this cool season leafy vegetable is primarily consumed as fresh, raw salad, vegetable apart from stem lettuce, which must be cooked before eaten (Ryder, 1986). In comparison with other vegetable crops, it ranks relatively low in terms of nutrition. In particular, it contains 95% of water and the other 5% includes various elements such as phosphorus, iron, sodium and potassium, depending on the morphological type. A higher level of ascorbic acid, vitamin A and calcium is found in leaf lettuces (Pink and Keane, 1993). Currently, lettuce is cultivated in hydroponic systems along with other vegetable crops (Stanghellini and Rasmussen, 1994,Niederweiser, 2001).

Normally, lettuce hydroponic production is carried on horizontally in greenhouses and it is really costly to construct a greenhouse. Therefore, how to increase yield per unit area within the limited volume of the greenhouse is very vital. The best solution to thoroughly take full advantage of the given greenhouse volume is building vertical hydroponic systems (Ozeker*et al*., 1999,Linsley-Noakes*et al*., 2006). According to Ozeker*et al*., (1999), it is possible to increase planting density by three times with a vertical system.

As a development of hydroponics system, vertical hydroponics enables crops to be grown on a vertical plane, instead of cultivating plants next to each other on a horizontal surface. This vertical hydroponic system brings many advantages such as giving high density production as well as saving space and water. Furthermore, this technique makes it easier for cultivation in limited areas like balconies, apartments or small farms. It is also possible to set up a vertical hydroponics system along walls and fences. Lately, because of the increasing tendency in growing plants indoors, the vertical hydroponics system has been studied and widely applied.

Although the production rate of this vertical system shows a significant improvement, there is still a serious problem of light distribution which affects the quality and quantity of the lettuce (Ozeker*et al*., 1999). How the vertical hydroponic system placed is very important because this will influence the light distribution of plants on two sides of the system. For that reason, an appropriate vertical production system needs to be developed and it is essential to find out the best method to place the vertical hydroponic system as well as the planting density within the system to create an optimal production.

Due to its high cost, the initial vertical system shows a potential unprofitability in a few production areas (Mattas *et al*., 1997). Some vertical systems do not have consistency in water distribution (Linsley-Noakes*et al*., 2006). The growing media of the hanging bag system might become compacted and flooded in the lower levels of the system. As a consequence, root can be rotten and there is a high possibility of die-off plants (Mashego, 2001). The factors of growing media, which are nutrients, aeration and moisture content, and period of irrigation also contribute important role in the vertical hydroponic system. An appropriate growing media will assist hydroponic system to improve quality and yields. The period of irrigation plays an important role in supplying nutrients and water for plants. This factor also has an effect on the efficiency of water used. After many researches and experiments, it is found out that chemical fertilizer is the best solution for hydroponic system. According to Haggag and Saber (2007), compost extract can improve the growth and quality of plants thanks to its massive amounts of enzyme vitamins, growth stimulants and micronutrients. Therefore, compost extract is becoming more and more popular in organic agriculture.

There are various types of vertical hydroponic systems being used by lettuce producers. Nevertheless, most of the systems are built using expensive, complex components and a lot of electricity, so how to set up a vertical hydroponics system with simple, compact, lightweight and low cost components is an urgent issue which needs figuring out.

Therefore, this study aims at finding basic and simple technique to build a vertical hydroponic system for lettuce cultivation. The study also examines the applicability of data obtained from this technique for growth and yield of lettuce.

1.2 Research objectives

1.2.1 To evaluate the effect and interaction of planting densities and materials of the vertical hydroponic system on the growth, yields and quality of lettuce by the vertical hydroponic system.

1.2.2 To evaluate the effect and interaction of growing media and period of irrigation on the growth, yields and quality of lettuce by the vertical hydroponic system.

1.2.3 To evaluate the effect of electrical conductivity (EC) of nutrient solution on the growth, yields and quality of lettuce by the vertical hydroponic system.

1.2.4 To evaluate the effect of compost extract on the growth, yields and quality of lettuce by the vertical hydroponic system.

1.3 Scope of research

1.3.1 The hydroponic system in experiments will use the vertical hydroponic system, which made by 3 material layers and sewn together.

1.3.2 Plant material is lettuce (*Lactuca sativa* L.) variety Red Rapid, Romaine and Grand Rapids Leaf. Seedling will be transplanted to vertical hydroponic in 2 weeks after sowing in cavity polystyrene trays, the yields will be harvested in 40 days after transplanted.

1.3.3 The formula nutrients in this experiment used the nutrient solution formulation from Ministry of Agriculture and Fishery, New Zealand.

1.3.4 The compost extract in this experiment used the compost extract produced from the earthworm compost.

1.3.5 Growing media used in this experiment were coconut coir, carbonized rice hull, and Rockwoolcollected in Viet Nam.

1.3.6 The EC level used in this experiment was from 0.0 – 2.5 mS/cm.

1.3.7 The pH level used in this experiment was from 6.0 – 6.5.

1.4 Expect result of research

The results of this study will represent a vertical hydroponic system with simplification and low cost to people. It will increase growth and yield of lettuce, and the effect of compost extract will improve the quality of lettuce productivity.

1.5 Diagram of study

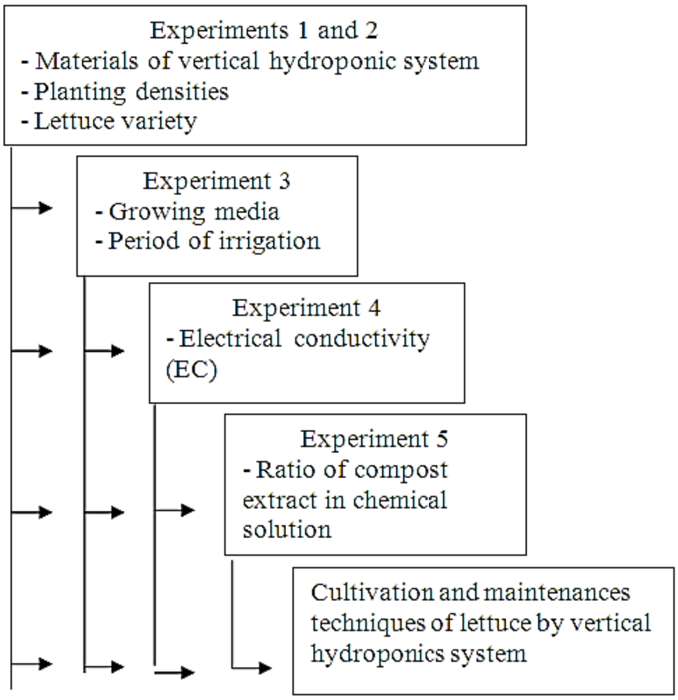

Figure 1.1 Diagram of study

1.6 Definition terms

1.6.1 The vertical hydroponics system is an improvement of hydroponics system whichproduces crops in upright or vertical rows, a method that can significantly increase plant populations. The most common vertical systems include stacked pots, stacked and sloped PVC pipes, and hanging vertical bags.

1.6.2 The nutrient solution is a mixture of chemical salts and water to provide the materials needed for plants to grow.

1.6.3 Compost extract is a liquid extract or a dissolved solution, but not simply a suspension of compost. It is made by steeping compost in water. It has been used as a fertilizer. The compost extract contains large amounts of enzyme vitamins, growth stimulants and micronutrients.

1.6.4 Growing media is simply what the roots of the plants are growing in. This can be a vast variety of materials, including rockwool, perlite, vermiculite, coconut fiber, gravel, sand or any number of other materials, even the air can be a growing medium. The growing media is an inert substance that doesn't supply any nutrition to the plants, all the nutrition comes from the nutrient solution.

1.6.5 Electrical conductivity (EC) is an index of salt concentration that informs about the total amount of salts in a solution. Hence, EC of the nutrient solution is a good indicator of the amount of fertilizer available to the plants in the root zone.

1.6.6 Lettuce (*Lactuca sativa* L.) is a cool season leafy vegetable grown in nearly all continents. Lettuce belongs to the Composite family, the tribe Cichoreae and the genus Lactuca. It is consumed mainly as fresh, raw salad vegetable with the exception of stem lettuce which is cooked before eaten

1.6.7 Leaf lettuce, the most widely adapted type, produces crisp leaves, and loosely arranged on the stalk. Nearly every garden has at least a short row of leaf lettuce, making it the most widely planted salad vegetable.

1.6.8 Cos or romaine forms an upright, elongated head. The butter head varieties are generally small, loose-heading types that have tender, soft leaves with a delicate sweet flavor. Stem lettuce forms an enlarged seeds talk that is used mainly in stewed, creamed and Chinese dishes.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydroponic vegetable production

2.1.1 Definition of hydroponics

Hydroponics is a technology that enables plants to grow and develop in a nutrient solution. To give mechanical support to the plants, this technique can use a substrate such as gravel, sand, vermiculite, rock wool, peat moss or sawdust (Jensen and Collins, 1985; Jensen, 1997). In the liquid hydroponic systems, there is no supporting medium for the plants roots, however, solid growing media supporting the plants is an essential part of aggregate hydroponic systems. Due to the fact that hydroponic systems are enclosed in a greenhouse or shade nets in most cases, temperature as well as diseases and pets are better controlled, evaporative water loss is reduced, and crops are protected against weather elements such as wind and rain.

In comparison to the growth of plants in soil, hydroponics technique isolates crops from the soil, which help prevent ordinary problems related to diseases, salinity or poor structure and drainage. While soil preparation is costly and time consuming, hydroponic systems can achieve quick turnover of crops because replanting can be easily performed in one or two-day time after harvesting. However, there are some main drawbacks of hydroponics that need to be concerned, such as cost of capital and energy inputs relative to conventional open-field production. Furthermore, a successful operation of the system requires a high level of competence in plant science and engineering skills. Also, higher costs of hydroponic technology make its application restricted to crops having high economic values (Jensen and Collins, 1985).

2.1.2 History of hydroponics

In hieroglyphs and drawings from ancient Egyptian history, it is specifically seen that farmers used hydroponic systems to grow plants in various, basic forms. This means that the practice of plants in a hydroponic system has been applied for several hundred years B.C. (Fresh Produce Hydroponics, 2002). Before the invention of the word "hydroponics", the Egyptians, Inca Indian tribes, the Aztecs, and the

Babylonians are some examples of ancient civilizations which used hydroponic system to grow plants without having any awareness of it (Deutschmann, 1998). It is likely that suspending plants in a thin soil and water mixture to provide necessary basic nutrients is the most primitive form of hydroponics.

Since the mid-1930's, hydroponics have become popular in terms of commercial use with Western Europe leading this trend (Zinnen, 1988). This commercial interest was primarily due to the scientific development of specifically designed fertilizer mixes for use in hydroponics, and commercial growers become easily accessible to these mixes subsequently. To support the development of hydroponics, there are some involvements of the use of plastics, new substrates, and researches. Using plastics was much cheaper and it also used less labor intensive production of the physical facilities (Fresh produce hydroponics, 2002). Rock wool, perlite and vermiculite were some new kinds of inert substrates used as growth substrates for plants (Niederweiser, 2001). Due to some subsequent researches, more refined hydroponic growth systems such as the Nutrient Film Technique and ebb-and-flow systems were developed and there was no need for plants to be immersed continuously in a static solution with these new systems (Harris, 1976).

2.1.3 Nutrient solution

In a hydroponic system, all the nutrient elements which are necessary for the growth of plants must be present in the circulating water. Sodium and chlorine are some of the elements presenting in the water supply with flexible proportions, however, there are some nutrient elements that needs to be added to the circulating water, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), boron (B), copper (Cu), molybdenum (Mo) and zinc (Zn) with appropriate proportions to avoid deficiency and toxicity if they are added too little or too much, respectively.

The nutrient film technique is a typical example of closed hydroponic systems, which need regular supervision and modification of the nutrient solution. Although the total salt concentration is well measured by electrical conductivity, it has no significant meaning for the concentration of the major elements and is not essentially affected by the quantity of trace elements present in the solution (Jensen and Collins, 1985). Therefore, it is vital to perform periodic chemical analyses every 2-3 weeks for major elements and every 3-4 weeks for minor elements (Graves, 1983). The most important thing is that the relative concentration of nutrients in the nutrient solution must be comparatively the same as crop uptake ratio to avoid accumulation of some nutrients and depletion of others. To maintain an appropriate balance of nutrient elements, some additions might need to be added to the solution. The proper pH level for nutrient solution should be maintained form 5.5 to 6.5 because this is the suitable range for plants to easily absorb most of the nutrient elements. Furthermore, this enables phosphates to stay in the more soluble form and the iron chelate, Fe EDTA keep associated and is therefore less liable to precipitation (Graves and Hurd, 1983).

Different from the closed systems, the nutrient solution in open systems is not recovered and recycled, but is used until depleted after being mixed. Therefore, it is not necessary to have monitoring and adjustments in open systems, however, the growing media may need to be supervised in the case of saline irrigation water or warm, high sunlight location of hydroponics facility. A sufficient amount of irrigation water must be distributed to ensure that salt does not accumulate in the growing media. This allows some drainage collected and tested periodically from the planting beds for total dissolved salts.

2.1.4 Nutritional disorders

There is no difference in cause and effect of nutritional disorders in hydroponics and field agriculture. Due to the accumulation and depletion of toxic from nutrients without monitoring, it is more likely for nutritional disorders to take place in closed systems than in open systems. In particular, excess ammonium and zinc and deficiency of potassium and calcium are major causes of nutritional disorders in hydroponic systems. To prevent various physiological disorders resulting from too much ammonium in tomatoes, no more than 10% of nitrogen is required in the ammonium form. Still, it is the best to restrict or eliminate ammonium in nutrient solution. The level of potassium in nutrient solution must be maintained above 100 ppm so that the acidity of tomato is not affected. Low level of this element can result in poor quality of fruits (Winsor and Masey, 1978). Too little calcium also causes blossom end rot in tomatoes (Nakjya, and Tayeko,1990; Nukaya*et al*., 1995; Palva et al., 1998) and tip burn on lettuce (Sherf and Macnab, 1986). In order to avoid zinc toxicity caused by the dissolution of the elements from the galvanized pipes, using plastic or other materials suitable for agriculture is a good solution. Maintaining a tight control of the components existing in the nutrient solution is a way to prevent disorders related to nutrition crops, especially in a closed system (Graves, 1983).

2.1.5 Electrical conductivity (EC) and pH of the nutrient solution

As an indicator of the concentration of salt giving information about the total amount of salt in solution, EC of the nutrient solution is a good indicator of the amount of fertilizer to give the plants in the root zone (Nemali and Iersel, 2004). When nutrients and water from the solution are absorbed by plants, there are changes in the total salt concentration, which are the EC of the solution. EC level can be measured easily, quickly, and economically so EC measurements can be performed daily by farmers. Thus, management of fertigation is currently hinged on the EC and pH control to adjust a preset nutrient solution prepared according to previous experience. Although this method is a practical one, it may lead to nutrient imbalance because EC is not an appropriate indicator of the concentration of specific ions in the solution.

The EC level from 1.5 to 2.5 mS/cm is the perfect range for soilless crops to grow. Nevertheless, salinity on crops has a specifically significant influence on the specie and cultivar (Greenway and Munns, 1980). In particular, if EC level is below 1.5 mS/cm, there might be a deficiency in nutrient whereas salinity problems are resulted from high level of EC, i.e. above 2.5 mS/cm. In addition, high input of fertilizers is also the major reason for salinity problems in greenhouse culture (Li, 2000). Moreover, there are some kinds of specific ions such as Na^+ and Cl^- causing high EC when they exist in the solution. For this reason, farmers often add fresh water into the solution to decrease EC, thus prevent the salinity problems. However, adding fresh water into the nutrient solution might make the salinity problems worse because there is presence of Na^+ and/or Cl^-in poor quality water in some regions. Therefore, it is useless to add fresh water to the nutrient solution to mitigate EC and the feasible solution for this case is to use cultivars with salinity tolerance.

In some cases, to enhance the quality of products, growers might be encouraged to use a high EC. For instance, an increase in electrical conductivity in the nutrient solution will improve the quality of flavoring and health-promoting compounds in tomatoes grown hydroponically (De Pascale *et al*., 2003; Krauss *et al*., 2007).

On the other hand, the acidity or basicity of a solution is measured by pH level, which determines the availability of essential elements for plants. As a vital parameter of controllability, the pH plays an important role in soil and soilless systems, but the correction should be performed everyday in soilless system because it has lower buffering capacity (Urrestarazu, 2004). In fertigation, pH should be maintained at a suitable level which does not damage plant roots and enable crucial nutrients to be dissolved in the nutrient solution to keep precipitation from blocking the irrigation systems and reduce nutrient availability by plants. Despite the fact that nutrient solution, pH depends on the plant. The optimum pH level that creates good conditions for some elements to be at their highest availability, is from 5.5 to 6.5 (Taiz and Zeiger, 2002). Whenever the pH of a nutrient solution strays outside the ideal, it can be corrected by chemical buffers. In particular, the addition of dilute concentrations of phosphoric or nitric acids will reduce the pH, while adding a dilute concentration of potassium hydroxide will do the opposite. Another element that can be used to regulate pH is ammonium as a source of N (5-10%).

2.1.6 Compost extract as a hydroponic nutrient solution

With the common application of compost in agriculture, the use of compost extract is becoming more and more popular in organic agriculture. Generally, when compost is soaked in water, a liquid solution form of compost containing nutrients, this solution is called compost extract. This is a new concept to some extent and there are not many researches done to find out the effectiveness of compost extract (Haggag and Saber, 2007; Hibar *et al*., 2006). Beside compost extract, compost teas are also assumed to improve the microbial activity in the soil, stimulate root as well as growth of vegetation (Hibar *et al*., 2006). After many researches and experiments, compost extract has been proved to have great contribution to higher crop yields and quality (Haggag and Saber, 2007). However, there must be more researches to verify the benefits that compost extract can bring to the hydroponics crop so that farmers will have another option when they want to increase hydroponics crop yields.

2.1.7 Disease and insect control in hydroponic systems

In terms of hydroponics growing systems, one outstanding benefit that cannot be ignored is the isolation of soil borne pathogens, especially fungi causing diseases. The spread of pathogens and insects pests mainly results from the movement of people when they go in and out of the greenhouse or through dust on the uncovered systems (Paulitz, 1997). Besides, pathogens can come from other sources like peat, and infected seed or propagation material is the origin of inoculums (Runia, 1994; Paulitz, 1997). In controlled environment installations, lacking of natural environmental checks also creates good conditions for pest populations to increase significantly. In the case of closed hydroponic system, this is a propitious environment for root diseases to spread quickly and affect all plants. To control plant pathogens in the nutrient solution, the application of ultraviolet radiation is used in the Netherlands (Runia, 1994) and in England (Jensen and Collins, 1985)

2.2 Importance of lettuce

2.2.1 Origin of lettuce

Being grown in almost all continents, lettuce (*Lactuca sativa* L.) is a cool season leafy vegetable, is primarily consumed as fresh, raw salad vegetable apart from stem lettuce, which must be cooked before eaten. Also, lettuce is said to be a substitute of tobacco in few reports (Ryder, 1986). In comparison with other vegetable crops, it ranks relatively low in terms of nutrition. In particular, it contains 95% of water with various elements such as phosphorus, iron, sodium and potassium, depending on the morphological type. A higher level of ascorbic acid, vitamin A and calcium is found in leaf lettuces (Pink and Keane, 1993).

Lettuce belongs to the family *Compositae*, the tribe *Cichoreae* and the genus *Lactuca*. There are about three hundred species that have been reported to be included in the genus *Lactuca*, although few of them are precisely documented (Ryder, 1979). De Vries (1990) later pointed that many of these names represent one specific species. Previously, nearly 100 species were identified by Lindqvist (1960), but 17 years later, Ferakova (1977) only recognized only 70 species under the genus. In this genus, seven chromosome levels are observed, 2n = 10, 16, 18, 32, 34, 36, 48.

There are some evidence paintings from Egyptian tomb shows that lettuce was grown before 4500 BC and then spread to other countries like Rome and Greece. For that reason, lettuce is said to have origin from the Mediterranean. According to Lindqvist (1960), the type of lettuce grown in ancient Egypt is morphologically described as Cos lettuce.

Cultivated lettuce is considered to proceed from *Lactucaserriola* and the significant differences observed between them have been attributed to the accumulation of mutations due to selection (De Candolle, 1959). Many proposals have been propounded to determine whether cultivated lettuce originates from hybrids between *Lactuca serriola* and other *Lactuca* species or not (Helm, 1954). The origin of cultivated lettuce is verified through three various theories which are originated from wild forms of*Lactuca sativa*, through direct descent from *Lactuca serriola*, or through hybridization between different species, including *Lactuca serriola*.

It is proved that there is a close relation and complete cross compatibility between *Lactuca serriola* and *Lactuca sativa*, so this supports the conclusions drawn on the relationship between them (De Vries, 1990), the evolution of *Lactuca sativa* is considered to result from the contribution of a second wild species (in addition to *L.serriola*) (Kesseli *et al*., 1991).

2.2.2 Morphological types

Normally, leaf shape and heading characteristics are two major criteria used to classify lettuce, though lately the classification of lettuce have also based on cropping seasons (Curtis *et al*., 1994). According to Michelmore and Eash (1986), lettuce can be divided into six broad morphological types. Crisp head cultivars have tightly folded and brittle textured leaves, large and heavy heads and they are the most extensive and preferred type grown in relatively majority of all consumer countries likes the USA. Quite small, loosely folded heads, broad, oily, crumpled leaves with various sizes, colors and appearances are some characteristics of the Butter head types. Different from the two above the leaf types do not form heads, but produce a rosette of leaves instead. This type of lettuce does not bring significant value in commercial production and it has relatively short shelf life. Cos types has typical characteristics of elongated, coarse and rough leaves with leaf-shaped heads. Similar to the Cos types, the Latin types also have loose heads and elongated leaves, whereas thickened elongated stems are commonly found in the stem types.

2.2.3 Genetics

The chromosome number of lettuce and three close wild relatives of cultivated lettuce, *Lactuca serriola*, *L.virosa* and *L.saligna*, have been determined as 2n=2x=18 (Michelmore and Eash, 1986; Ryder, 1986). According to cytogenetic studies, these four species form an effective breeding group that is reproductively isolated from the rest of the genus.

Taxonomic and genetic information available on seven wild relatives of the crop was recapitulated by Zohary (1991), including: *Lactuca aculeata*, *Lactuca altaica*, *Lactuca azerbaijanica*, *Lactuca dregeana*, *Lactuca georgica*, *Lactuca scarioloides*, *Lactuca serriola*. These seven wild relatives were depicted to be morphologically similar to cultivated lettuce. Thus, they were classified as the primary gene pool of cultivated lettuce based on morphological resemblance and interfertility among some. *L. saligna* was categorized under a secondary gene pool and *L. virosa* in a tertiary gene pool.

2.2.4 Lettuce varieties in study

2.2.4.1 Red Rapid: It is a type of Red-headed lettuce. In comparison to the green-leaf varieties, red rapid lettuce leaves provide more delicate texture and a better flavor, so it is becoming more and more popular. The red color of this type of lettuce is because of a water soluble pigment namely anthocyanin, which occurs as a metabolic product. Environment also has effects on the brightness of the red to a certain extent. While the combination of low of lower or considerably fluctuating temperatures and intense light produce optimal coloring, low exposure to sunlight and high temperatures over a relatively long period are reasons causing reduction in the intensity of the coloring. Different types of lettuce have different colors, and these colors can be controlled by external and environmental factors within a certain limit. Red salad bowl or oakleaf lettuce, feuille de chêne, is a kind of lettuce grown outdoors and harvested throughout the summer. It produces appealing leaves resembling oak foliage and delicious nutty flavor, which makes this oakleaf lettuce a fascinating type of vegetable. Because it is highly perishable, it should be stored under moderately low temperature conditions to stay fresh for one day at the most.

2.2.4.2 Romaine: It is a type of Cos or Romaine lettuces (var. longifolia). It can be recognized by long upright leaves that form a cylindrical head. They might not be named for the island of Cos, but originate from the Arabic name word for lettuce. It is said that this kind of lettuce reached Western Europe through Rome, therefore it was given the name Romaine. Due to its endurance of high temperature, Romaine lettuces are commonly grown in the Middle East. Generally, Romaine lettuce has green leaves and thick, crisp, juicy ribs. With its strong texture and sharper, pleasantly nutty flavor, it is preferred to others lettuce in terms of cooking, but it needs more washing because of its curly leaves. As the most nutritious type of the lettuces, Romaine provides an abundant source of folate, vitamins A and C, calcium, iron, and potassium. While dark green leaves provide a lot of nutrients, the paler ones have less nutrients or even nothing but fiber and water. Pertaining to the long group of lettuces, romaine lettuce grows upright and has the average height of sixteen inches, elongated leaves with rounded tips, but the shape of the heads can be rounder or more oval depending on the variety. There are differences in the color of outer and inner leaves in which they are yellowish white inside and darker outside. For older varieties, the inner part is only blanched when they are tied together, but newer types are able to self-blanch. Also, they need more time to mature and grow better with cooler weather. Contrary to head lettuce, romaine and Cos lettuces can be preserved better and more easily. With theirs slightly coarser and firmer leaves, they can be cooked as well as eaten raw with a taste quite similar to asparagus.

2.2.4.3 Grand Rapids Leaf: It is a type of loose leaf lettuces. Instead of forming a head like other types of lettuce, Grand Rapids Leaf forms a loose bunch of leaves, therefore, it is sometimes called by different names such as "cutting", "bunching", or "curled" lettuces (var. crispa). It varies in color and shape. With respect to the shape of leaves, some types have round or elongated leaves, some are intended or with unbroken margins. Similarly, the plants can range from low and bushy to upright. When the lettuces mature, they will be harvested by cut or picked one by one, and they can have different flavors such as mild, sweet, or woody. Grand Rapids Leaf lettuce can be cut completely to make just one crop through the summer. Although being a type of cutting or loose-leaf variety, Grand Rapids Leaf lettuce has a remarkable head with the shape of a compact hemispherical rosette formed by its tightly crimped tender leaves.

2.2.5 Diseases of lettuce

There are various sources of diseases such as fungi, bacteria, viruses and nematodes can affect lettuce in the field and in storage. Some typical diseases often found in lettuce are mosaic virus, big vein disease, lettuce drop by Sclerotinia species, anthracnose, downy mildew, root knot disease caused by Meloidogyne sp. Lettuce is also infected abiotic diseases like tipburn or russet spotting (Campbell, 1985). Bacterial leaf spot and head rot, corky root rot and bacterial soft rots are those belonging to bacterial diseases which can affect lettuce production economically (Patterson *et al*., 1986). *Xanthomonas campestris* pv vitians is the main agent that causes bacterial leaf spot and head rot. We can recognize this disease by circular, translucent, water soaked lesions having dark brown color. The crop will be considered to be marketable or not basing on the severity of infection. Van-Bruggen *et al*. (1989) showed that Gram negative bacterium *Rhizomonas suberifaciens* is responsible for corky root rot. This disease makes the roots look corky and causes brown banded lesions on the taproots. If the plants are seriously infected, they will become stunted, chlorotic and wilted.
A postharvest disease named bacterial soft rot primarily caused by two secondary pathogens *Erwinia carotovora* and *Pseudomonas marginalis* (Patterson *et al*., 1986). This kind of disease often occurs during the process of storage or transit. Thus, in order to restrict this epidemic, the storage temperature should be maintained close to one degree Celsius, and the crop must be harvested carefully.

2.2.6 Nutritional value of lettuce

Greater degree of ascorbic acid, vitamin A and calcium can be found in leaf lettuces (Pink and Keane, 1993). Nevertheless, the concentration of these elements also depends on the variety, growing conditions, stage of maturity, regional difference, and seasons of the year (Vanderslice and Higgs, 1991). Different analytic technique used is also a reason of different accuracy results for the same sample of lettuce (Tee and Lim, 1991).

The table 2.1 depicts the concentration of ascorbic acid, nitrate, protein and soluble sugar of lettuce on both a fresh and dry weight basis. The data covers soil and greenhouse crops, different cultivars and analysis method. Comparison of the data within the table should be made by keeping these differences in mind.

1) Ascorbic acid (vitamin C)

The changes in vitamin C content of lettuce depend on seasons (Evers, 1994). These changes have a positive correlation with the level or radiation, which means that the more radiation, the more vitamin C (Primak, 1985). However, according to Drews*et al.* (1996), an increase in the level of solar radiation causes ascorbic acid to decrease generally and the radiation affecting the vitamin C contents is altered by a head weight decline in vitamin C results in head weight enlargement.

Primak (1985) stated that when light intensity reduced from 35,000 to 6,000 lux, lettuce dry matter content and ascorbic acid content also reduced from 7.23 to 4.39% and 16.54 to 9.86 mg/100g, respectively. Increase in shade level is the reason why weight and leaf number of butter head lettuce decrease, the leaves became narrower, and ascorbic acid content decrease. There is a difference in the ascorbic acid at different time within a day, which is higher in the daytime and lower at night. This trend can be noticed more obviously on a sunny rather than on a cloudy day (Shinohara and Suzuki, 1981). As reported by Grimstad (1984), fluorescent tubes made plants produce the lowest vitamin C content and high pressure sodium lamps could help them have the highest volume of vitamin C when they are irradiated. He claimed that this was due to the higher infrared radiation (A > 750 nm) produced by the high pressure sodium lamp, not the highest photo synthetically active radiation (PAR) coming from fluorescent tubes.

Along with the continuous growth and enlargement of head size, vitamin C concentrations fall gradually (Shen *et al*., 1992). With respect to greenhouse lettuce, it decreases by 51% between the beginning and the end of the head formation stage (Drews*et al.*, 1996). The different components of outer, middle and inner leaves and their changing ratio during heading are the major causes for the change in vitamin C concentrations which presents less in middle as well as inner leaves and more in outer ones (Shen *et al*., 1992; Drews*et al*., 1996). Besides, this content decreases gradually from outer to innermost head leaves (Shen *et al*., 1992). The vitamin C content also depends significantly on various cultivars as well (Albrecht, 1993).

Comparing with 1/2 concentrations of the standard nutrient solution or more, being grown at 1/2 concentrations makes the fresh weight of lettuce reduced considerably, but causes an increase in ascorbic acid content (Shinohara*et al*., 1978;

Shinoharaand Suzuki, 1981). Shinohara*et al*. (1978) also reported that there were positive relations between the ascorbic acid and the sugar content in both lettuce and garland chrysanthemum.

According to Evers (1994), optimal nitrogen levels do not have much effect on the vitamin C content, but it will be decreased in the case of excess nitrogen. If the nitrogen supply increases from 50 to 200 kg N/ha in the field, the vitamin C will decline from 64.8 to 51.5 mg/kg (Sorensen *et al*., 1994).

Table 2.1 Concentration of ascorbic acid, nitrate, protein and Soluble sugar of lettuce on fresh weight and dry weight basis.

Traits	Ascorbic Acid	Nitrate	Protein	Soluble sugar
Fresh weight basis	mg/100g	mg/100g	mg/100g	mg/100g
Franke and Lawrenz, 1980		33 - 77.4	0.81	
Lairon *et al*., 1984			0.78 - 1.02	
Vestergaard, 1988	10		1.5	
Albrecht, 1993				
Butter crunch	22.37 ± 2.09			
Red sails	19.71 ± 3.01			
Red salad Bowl	23.66 ± 6.65			
Sorensen *et al.*, 1994	5. 15 - 6.48		- 0.7 1	1.05-1.16
Waycott and Ryder, 1994				
Salinas	3.6		0.8	
Mini-Green	3.2		1.2	
Valmaine	10.7		1.5	
Poulsen *et al.*, 1995	48-59.5			1.05-1 .25
Drews *et al.*, 1996	8 -16	16.5 - 33.3		0.7 - 0.9
Burlinghamand Milligan, 1997				
inner leaves	12		1.1	0.4
outer leaves	12		1.1	0.4
lettuce	12		1.1	0.4
Davis *et al.*, 1997				
Crisphead lettuce	6			
Butterhead lettuce	8			
Leaf lettuce	18			
Romaine lettuce	18			

Table 2.1 continued

Traits	Ascorbic Acid	Nitrate	Protein	Soluble sugar
Dry weight basis	mg/g	mg/g	%	mg/g
Frota and Tucker 1972		0.6 - 6.85		
Franke and Lawrenz, 1980			21 .32	
Subramanya *et al.*, 1980		10.4-27		
Grimstad, 1984	1.53-3.02		16.0 - 20.1	
Brunsgaard *et al.*, 1994			30.0 ±0.8	
Wheeler *et al.*, 1994			27.2 + 0.2	

2) Nitrate

The content of nitrate in lettuce changes in accordance with seasons and it decreases when radiation rises (Gysi *et al*., 1985; Evers, 1994; Drews*et al*., 1996; Primak, 1985). In addition, there is a negative correlation between nitrate and sugar, which means that high sugar content accompanies with low nitrate content (Drews*et al*., 1996).

Similar to vitamin C, nitrate concentrations in lettuce decrease gradually during its growth stage and head size increasing. The different components of outer, middle and inner leaves during heading are the major causes for the change in nitrate concentrations (Drews*et al*., 1996). It is found that there is a decline in nitrate concentration from 3,330 to 1,650 mg/kg FW between the start of head formation and the head firmness stage with greenhouse cultivars, and with field cultivars, the decreasing rate is 35% (Drews *et al*., 1996). Harvesting lettuce right after the completion of head formation can minimize its nitrate concentrations.

An increase in shade level has some specific effects on butter head lettuce such as: decrease in fresh weight and leaf number, narrower leaves, reduction in ascorbic acid and sugar contents, increasing trend in nitrate. Higher level of ascorbic acid, sugars and chlorophyll contents are found during the day, but the nitrate content has an increasing trend in the night. These propensities are more notable on a sunny day rather than on a cloudy day (Shinohara and Suzuki, 1981).

Different cultivars have different accumulation of nitrate (Gysi *et al.*, 1985; Evers, 1994). According to Drews *et al.* (1996), greenhouse cultivars have higher level of nitrate concentrations than filed cultivars do.

Evers (1994) reported that there were some factors can make the nitrate content of lettuce increase such as increasing application of N fertilizer, genotype, low light intensity, low temperature and drought, but vegetables grown in Nordic countries have lower levels of nitrate, apart from those grown under glass with supplementary lighting due to poor light condition during winter. Other researchers also find the similar results as Evers (1994).

3) Sugar

The sugar content in lettuce varies with season and it increases in accordance with increasing radiation (Grimstad, 1984; Blom-Zandstra and Lampe, 1985; Drews*et al.*, 1996). The larger head weight, the higher sugar content, thus head weight is a way to alter the radiation affecting sugar content. Sugar has a negative correlation with nitrate concentration, which is a higher sugar content often goes with lower nitrate content (Drews*et al.*, 1996). Decreasing fresh weight, leaf number, and sugar contents of butter head lettuce as well as leaf narrowing are some effects of increasing shade level on lettuce. During daytime, the sugar content is higher in comparison with night-time (Shinohara and Suzuki, 1981; Fomeyand Austin, 1988). Also, this tendency is more obvious on a sunny day rather than on a cloudy day (Shinohara and Suzuki, 1981).

Fomey and Austin (1988) reported that there is an increase in the sucrose in the cap leaf of crisphead lettuce during the day from the morning to the afternoon and it was translocate to the actively growing leaves at the end of the day. When the translocation process finishes, sucrose is converted to glucose and fructose. Because the translocation of assimilates still takes place through the night, glucose and fructose can be found more when lettuce is harvested at dawn rather than in the afternoon. Glucose, fructose and sucrose are three primary sugars contained in iceberg lettuce and accounts for 47%, 42% and 11%, respectively (Bolin and Huxsoll, 1991).

According to Blom-Zandstra and Lampe (1985), high light intensity can bring about an apparent shift from nitrate accumulation in the plant sap towards accumulation of sugar (mainly glucose) and organic acid (mainly malate).

During the head formation stage, the concentration of sugar increases by 44%, and it also rises along with the development of growth stage as well as increase in head size (Drews*et al.,* 1996). Differences in compositions of outer, middle and inner leaves and changing ratio during heading are the reasons causing these changes (Drews*et al*., 1996). Evers (1994) believed that the use of fertilizer does not have much effect on sugar content.

4) Protein

Lairon *et al.* (1984) stated that the protein concentration determined by the protein amino acids in lettuce did not present any reactions with mineral or organic nitrogen fertilizer or with the application rate used. The protein content of lettuce lies within the interval of 0.78 - 1.02% fresh matter. On the contrary, Brunsgaard *et al.,* (1994) found that when the nitrogen fertilizer levels rise from 50 to 200 kg N/ha, protein content (N×6.25) increases from 16.00 to 19.88%. Lettuce also has higher protein content if it is harvested and planted early and vice versa. A portion of non protein nitrogen, including nitrate existing in the protein content (N×6.25) represents crude protein.

5) Nitrate accumulation in vegetables

Pavlovic *et al., (*1998) stated that there were about 90% of the nitrates in human nutrition are coming from vegetables. According to FAO regulations, a normal human being should take no more than 5 mg/kg of nitrate a day. Thus, the admissible levels of nitrate for endive, spinach and lettuce that people can take have been proposed by the Dutch Government. They are 4,500 mg/kg fresh weight and 3500 mg/kg for winter grown and summer grown lettuce, respectively (Benoit and Ceustennans, 1989). The European standards from 111/98 under Belgian and Dutch climatologically conditions is 3,500 ppm NO_3 per kg fresh head lettuce weight from 1/11 to 30/4 and 2,500 from 1/5 to 31/10 (Benoit and Ceustennans, 1989).

The nitrate accumulation in leaves differs at different time of the day in which it decreases during daytime and increases at early night (Steingrover *et al.,* 1986). Carrasco and Burrage (1992) reported that Nitrate accumulation within the leaf tissue reached a peak during night time. As concluded by Steingrover *et al. (*1986), this is because the roots perform more efficiently when the night starts falling and nutrients are transported directly to the leaf blade vacuole. The increased activity of the nitrate reeducates enzyme after dawn also contributes to the nitrate accumulation (Carrasco and Burrage, 1992).

Depending on the light intensity, nitrate concentration can change at different rate. According to Scaife and Schloemer (1994), the rate of nitrate reduction increases with light up to an intensity of 320 µmol m^2/s.

The nitrate concentration in vegetables occurs differently between plant parts. Petioles are those having the highest concentration (Maynard and Barker, 1979, Pavlovic *et al.,* 1998), whereas lower concentration is found in roots, leaf lamina, fruit or grain, and flower parts (Maynard and Barker, 1979). Blom-Zandstra and Eenink (1986) stated that the concentration rose at the beginning, but it decreased when plants become older.

Beside the part of a nitrogen source to help synthetize amino acids (McCall and Willumsen, 1998), nitrate also plays a role as an intracellular osmoticum (Smirnoff and Stewart, 1985; McCall and Willumsen, 1998). Vacuoles are considered to be the largest storage pool for nitrate (Martinoia *et al.,* 1981; Granstedt and Huffaker, 1982; Steingrover*et al.,* 1986). While Granstedt and Huffaker (1982) believed that vacuoles of green barley could hold 58% of the total cellular nitrate, Martinoia *et al.* (1981) reported that there were 99% of the cellular nitrate in barley leaf vacuoles. When there are some conditions which are not propitious for the photosynthesis process, nitrate is responsible for replacing organic compounds such as carbohydrates and organic acids in the cell sap. A decline in demand for nitrate resulting from the availability of organic solutes and carbohydrates in the leaves causes the nitrate uptake activity to decrease (Blom-Zandstra and Lampe, 1985; Steingrover *et al.,* 1986). Blom-Zandstra *et al. (*1988) found out that the higher nitrate concentration, the lower concentration of organic acids and sugars. This inverse relation is very close between sugars and nitrate contents (r^2=0.99) and photosynthetic rate and nitrate content (r^2=0.79) (Behr and Wiebe, 1992).

Nitrate accumulated in fully developed leaves is assimilated into organic nitrogen (Smirnoff and Stewart, 1985). The vacuole is the place storing almost all cellular nitrates, whereas only nitrate in the cytoplasmic pool and in the xylem flow is readily available for reduction (Shaner and Boyer, 1976). Solomonson and Barber (1990) reported that the performance of nitrate assimilation consumed about 25% the energy of photosynthesis.

2.2.7 Factors affecting growth and productivity of lettuce

1) Planting density

Population or plant density is one of the vital elements that have effects on yield and quality of lettuce. Different plant densities often results in different lettuce yield and distance between plants have specific impacts on average fresh weight, number of heads, and yield at harvest (Adu-Sankode, 1980; El-Shal *et al*., 1986; Eyisok *et al*., 1996). Maximum yield can be harvested with appropriate plant spacing, but the yield and even quality will decrease if too high or too low spacing is applied (Kobryn, 1987). The optimal plant spacing for lettuce, which is available in many documents and materials such as books, annual reports and journals, is generally from 20 to 45 cm between plants and 30 to 50 cm between rows (Bose and Som, 1986; Rahman *et al*., 1997; Rashid, 1999).

A field experiment was carried out by Moniruzzaman (2006) to find out how plant spacing influences lettuce. He used with three levels (40×20, 40×30 and 40×40 cm) in his tests and he discovered that the yield and yield components of lettuce are affected considerably by the lettuce plant spacing. As a result, the closet spacing (40×20 cm) and medium spacing (40×30 cm) gave the highest fresh yield of lettuce during both years.

Many experiments were also conducted on some lettuce cultivars including Cos romaine, Batavia green, Webb's wonderful and Great lakes. The result is that higher yields, higher average head weight per plant and greater number of heads were obtained from a closer spacing of 30.48×22.86 cm compared with others, such as 30.48×33.02 and 30.48×38.1 cm (Adu-Sarkodie, 1980).

Nurzynska-Wierdak (2008) reported that the row spacing 20-30 cm was applied for the leaf lettuce in field cultivation and the use of this spacing also depended on different cultivars. There is a fact that an appropriate plant density will determine the quantity and quality of lettuce yield. Among three lettuce plant density (30×30 cm, 30×20 cm and 20×20 cm) used in his experiment, the lowest density (20×20 cm) gave the highest total yield as well as marketable yield.

From May to June 2008 in South Africa, Maboko*et al*. (2009) performed an experiment in relation to lettuce hydroponic product with five spacing variations which are 10×20 (50 plants/m^2), 10×25 (40 plants/m^2), 15×20 (30 plants/ m^2), 20×20 (25 plants/ m^2) and 20×25 (20 plants/m^2). An important interplay was found between and cultivar with respect to leaf, fresh and dry mass, whereas different spacing leads to the same reaction for all cultivars on other yield parameters. Plant population impacted greatly on many aspects of plants, namely plant height, fresh and dry leaf mass, leaf area and leaf number/m^2, with significantly higher values of all variables at the closest spacing (50 plants/m^2). It was revealed that there is a distinguishable increase in and yield components of leafy lettuce when the plant population increased, and the highest yield was obtained from all cultivars at a spacing of 50 plants/m^2.

During the period from December 2000 to August 200, there were researches carried out to investigate how spacing affected growth and yield of head lettuce on highland at Pangda Royal Project, Samerng district, Chiang Mai province, Thailand. It was found that growth and yield of lettuce were affected greatly, especially in winter, summer and rainy season. Among different spacing, 45×60 and 60×60 cm are those that produced the highest number of leaves, head size and weight, given that there were 2 or 3 rows in each bed. However, if the plants were grown with 3 or 4 rows per bed, they gave the highest yield at 25×25 and 30×30 cm (Noree, 2002).

The optimal planting density for lettuce was examined by performing a field study with three distinct spacing of 15, 20 and 25 cm in Jordan in 2000 and 2001. The final outcomes indicated that plant spacing greatly affected some aspects like vegetative and yield components, but the highest values were obtained from the spacing of 20 cm, followed by 25 cm then 15 cm (Abu-Rayyan, 2004).

2) Temperature

Temperature is one of the primary determinants deciding the growth rate of lettuce during seedling emergence and the early growth period (Bierhuizen *et al.*, 1973; Scaife, 1973; Gray and Morris, 1978). According to Wurr and Fellows (1984), the mean temperature associates considerably with head weight up to 42 days from emergence. They also stated that leaf growth, head formation and head weight of drilled crops totally depended on the temperatures during the early growth period.

Wien (1997) reported that the temperature of the growing point was also a factor deciding the growth rate of lettuce, and this organ is located close to the soil surface. Therefore, it is believed that the relation between the growth rate of lettuce and soil temperature can be closer than that and air temperature (Scaife, 1973; Wurr *et al.*, 1981). For instance, the plant growth has a close relationship with root zone temperatures in the NFT system (Takano, 1988). According to Ikeda and Osawa (1984), root temperature has direct effects on plant through growth respiration, water absorption, water movement, transpiration and ion uptake processes of lettuce. Researchers have proved that lowering root temperatures is a way which enables headed lettuce to grow and develop successfully in tropical regions (Lee and Cheong, 1996; Jie and Kong, 1998a; 1998b, Thompson *et al.*, 1998). The growth of lettuce grown in NFT is also stimulated by the increased temperatures of nutrient solution during spring (Mongeau and Stewart, 1984) and winter. Mongeau and Stewart (1984) reported that the restriction of air temperature to production was a condition which helped they see the most apparent beneficial effects of solution temperature.

On the other hand, head formation of iceberg lettuce is proved to be affected more positively by night air temperature than soil temperature (Maaswinkel and Welles, 1987). Also, root temperature only has minor effects on plant size (Hicklenton and Wolynetz, 1987). Head lettuce quality is impacted by temperature as well. According to Zink and Yamaguchi (1962), the interval of temperature from 51 to 67^0 F (10.6- 19.4^0 C) is the most suitable range that can produce good quality lettuce during head formation.

Hicklenton and Wolynetz (1987) have reported that day and night temperatures do not show any remarkable interaction effects between them. While, a rise of day temperature from 12^0C to 19.5^0C leads to increases in fresh and dry leaf weight and leaf area at final harvest, there is just little effect resulting from an increase in night temperature from 5^0 C to 14^0C. In comparison to to 7^0 C and 13^0 C, 18^0 C is the optimum night temperature for growing lettuce and producing the highest yield, given that day temperature are kept at 20^0C (Knavel, 1981). On the other hand, Glenn (1984) stated that the relation between daytime air temperatures and growth was slightly positively correlated, while the night temperature had a relatively negative correlation. He set the greenhouse temperatures in his experiment at 14^0 C and 25^0 C at corresponding night and day, but the thermostat settings are often not relevant to the actual temperatures.

3) Light condition

In general, as the sole source of illumination, light is considered to be the most crucial variable in heated greenhouses depending on natural radiation (Klapwijk, 1979). Os (1984) stated that natural radiation levels were potential rate limiting for lettuce growth anywhere in the world. In the latter stage of growth, the plant growth is affected more by radiation compared to temperature after self shading of leaf and hearing occur in lettuce (Bierhuizen *et al.*, 1973, Gray and Morris, 1978). According to Wurr *et al.* (1987), head weight at maturity has a greatly crucial positive correlation with total solar radiation in the period 7 and 10 days before 50% hearting. Therefore, the relative growth rate of lettuce and solar radiation are positively correlated either at hearting and post-hearting (Wurr and Fellows, 1991).

Sanchez *et al.* (1989) reported that light saturation point for photosynthesis of crisphead lettuce in the heading phase could achieve 800µmol s^{-1} m^{-2} and a decrease in the irradiance at which the plants were grown led to a decrease in the maximum net CO_2 assimilation rate. The radiation levels also have specific effects on the water uptake of lettuce (Voogt, 1988).

Growing Romaine lettuce under full sunlight is proven to give better results, whereas it is better to grow leaf lettuce in reduced light. This is because Romain lettuce has the habit to grow upright to protect the growing point of the plant while leaf lettuce exposes its growing point (Foley, 1965). Sanchez *et al.* (1989) also indicated the importance of light as continuous shading from thinning to harvest reduced crop growth approximately in direct proportion to the reduction in irradiance. Similarly, Maaswinkel and Welles (1987) found that continuous shading of a thermal screen led to a reduction of the head weight.

The application of additional light has brought many benefits. Schlagnhaufer *et al.* (1987) reported that fresh weight of 'Grand Rapids' increased up to 770% and that of 'Etus' increased to 241% under continuous supplementary lighting. Similarly, Gaudreau *et al.* (1994) discovered that continuous supplementary lighting of 100 µmol s^{-1} m^{-2} brought more obvious effects on plants during months having low levels of natural light. In particular, biomass accumulation (=<270%), head firmness and tip bum incidence with shorter production cycles (=<30%) were increased under this supplementary lighting rather than natural light. High pressure sodium lamp is the most useful light source for fresh and dry weight of lettuce at equal photosynthetic photon flux (PPF) against other sources (Koontz *et al.*, 1987, Ito, 1989). According to Ito (1989), 280 µE s^{-1} m^{-2} is said to be the best-case PPF density in case of 14-hour photoperiod.

4) Mineral nutrient

In lettuce, total nutrient uptake detected fromchanges in nutrient solution conductivity during the day is the same as that during the night (Huett, 1994). According to Heinen *et al.* (1991), there is a similarity in shape between the relative growth rate and the relative cumulative uptake of nitrogen, potassium, B, Zn and Cl (and to a lesser extent of calcium, magnesium and S). Along with the gradual growth of plants, the uptake activity of phosphorus reduces, but the uptake of Fe, Mn and Na increases.

4.1) Nitrogen

Among various nutrients taken up by the plant, nitrogen and potassium are the dominant ones, and the head was the major sink for lettuce. As in the case of 11 M m^{-3} nitrogen level, the highest ratios of nutrients are found to present in lettuce head to the whole plant, while the application of 2 and 36 M m^{-3} nitrogen level gives the lowest ratios. During the last week of the growth period, there is a remobilization of nitrogen and potassium from outer leaves and stem of lettuce to the head.

After transplanting, the nitrogen uptake rate of lettuce reaches its highest level in the sixth week and then drops quickly (Huett and Dettmann, 1992). On the other hand, Van Goor *et al.* (1988) reported that the uptake rate of nitrogen (daily uptake per plant) by lettuce kept increasing significantly (partly exponentially) during the growing period and that rate remained unchanged at the end. The maximum uptake rate of nitrogen, phosphorus and potassium presents in over 70% ofthe above ground dry weight accumulating during the last few weeks of the crop cycle.

When more nitrogen fertilizer is applied, the yield of lettuce will increase at first and then either stay unchanged or decline. As in experiments of Greenwood *et al.* (1980), they found that 170 kg N/ha gave the optimum yield in the field. In terms of peat, further application of nitrogen enhances the yield and the proportion of heated lettuce until the peat contained 60 mg N/l. (Adams *et al.*, 1978). Nitrogen does not take into effect much over the range 60 - 250 mg N/l.

The temperature has specific impacts towards the rate of nitrogen uptake and the nitrogen content of the leaves (Winsor and Adams, 1987). In particular, plants grown in cooler soil have higher levels of nitrogen than those grown in warmer soil and youngest leaves always contain the most nitrogen. High temperature stimulates the uptake of both ammonium and nitrate though the response is greater with nitrate (Frota and Tucker, 1972).

Young plants always have the highest level of nitrogen concentration and it decreases gradually when plants get older. Also, nitrogen concentrationis found to be highest in young leaves and lowest in the outer leaves (Knavel, 1981). As reported by several workers, the nitrogen content correlating to optimum yield was 1.92% N in the midribs of the wrapper leaves and about 5.1% N in the laminae, while it was 4.1% N, 5% N and 5.4 - 5.7% N in the leaves (Knavel, 1981).

The concentration of nitrogen in the leaf tissue does not really have a sensitive relationship with yield and it is restricted as a diagnostic parameter for lettuce (Sanchez *et al.*, 1988). According to Greenwood *et al.* (1980), the yield of a range of crops, including lettuce will increase by 10% when the level of nitrogen in the plant increases by 0.1%.

4.2) Phosphorus

In last 2 weeks of the growth period, the uptake of phosphorus still keeps increasing continuously (Huett and Dettmann, 1992). Temple-Smith and Menary (1977) reported that plants would produce the maximum yield at a mean rate of phosphate absorption of 8.4 µM phosphate per gram (0.026 µg/g) root fresh weight per day.

36 days after sowing, the phosphorus in the plants can make up 60% of the variation in plant dry weight, while % N may account for only 12% (regression analysis) (Costigan, 1984). According to leaf analysis, phosphorus is generally the most limiting nutrient. Therefore, Sanchez *et al.* (1990) concluded that the phosphorus concentration in leaf tissue was below the critical level of 0.43 % whenever fertilizer is deficient. The definition of critical level can be understood as the nutrient concentration in the tissue related to a 10% reduction in yield. There is a possible relationship between responses to phosphorus and the availability of phosphorus in the soil in which the research was carried out (Costigan and Heaviside, 1988).

In regards with lettuce grown in soil, the higher level of phosphorus applied, the more phosphorus content of the leaves, and the phosphorus level decreases as the plants grow older (Zink and Yamaguchi, 1962). In comparison with older leaves, younger ones contain more phosphorus (Knavel, 1974). The concentration of phosphorus in the younger leaves doubles that in leaf laminate, and the phosphorus of the latter still even exceeds the content contained in the midribs.

Lettuce seedlings can grow at the expense of phosphorus stored in the seed during the first 11 days. However, as the growth curves for the various phosphorus treatments of Scaife and Smith (1973) showed a separation at about 4 days from emergence, it meant that lettuce seedlings were sensitive to lack of phosphorus. In the research of Berry and Carey (1971), the critical concentrations of phosphorus in lettuce seedlings for the conductive, lamina and root tissue on a dry weight basis were 780, 600, 580 ppm soluble PO_4, respectively. It was 0.44% at the six to eight leaf stages in the study of Sanchez *et al.* (1988). As suggested by Adams and Winsor (1984), the yield of lettuce and the phosphorus content of the leaves have a close correlation, up to 0.6% phosphorus can be found in lettuce leaves. Similarly, Scaife and Smith (1973) also have the same conclusion that the optimum phosphorus concentration used for lettuce should be 0.6%. The phosphorus percentage in the dry matter of lettuce also has another helpful function which is detecting deficiencies.

4.3) Potassium

Zink and Yamaguchi (1962) reported that nitrogen, phosphorus, potassium, calcium, magnesium, and sodium uptake curves had the same shape as dry matter production curve. More than 70% uptake of plant nutrients was absorbed in twenty-one days before the first harvest.

After transplanting, the potassium uptake rate of lettuce reached its highest level in 6 weeks time and then fell quickly (Huett and Dettmann, 1992). The ratio of potassium: nitrogen was about 2:1, whereas there was a remobilization of nitrogen and potassium from the outer leaves and stem of lettuce to the head over the last period of the growth stage.

Accordingto Van Goor *et al.* (1988), there are changes in nutrient ratios in the plant over time. In particular, the ratio of potassium : nitrogen in lettuce falls greatly from about 1.3 to about 0.50 during the growth period There is also a considerable decrease of the calcium : potassium ratio from about 0.5 to 0.05. The calcium: potassium ratio decreases at the end of the growing period as well because of low evaporation after the onset of head formation, especially in the younger leaves.

For crops grown in soil, an increase in the levels of potassium fertilizer leads to an increase in the uptake of potassium by the crop, but in a diminishing returns manner (Greenwood *et al.*, 1980). Thus, Berry and Carey (1971) concluded that the yield of lettuce had a positive correlation with potassium supply, which meant higher potassium supply resulted in higher lettuce yield, however, potassium supply exceeding 2 mM/l would not bring any further increase in yield. Bres and Weston (1992) suggested that 150 mg/l was the appropriate level of potassium in the nutrient solution for efficient production of NT lettuce. According to Greenwood *et al. (*1980), potassium fertilizer does not have much effect on the quality of lettuce, whereas the percentage potassium at harvest plays an important role as a useful indicator that help identify which crop growth is restricted by lack of potassium.

In the research of Zink and Yamaguchi (1962), although there was no general trend observed, the potassium content rose and fell throughout the growth of the crop. According to Barta and Tibbitts (1991), the highest potassium concentrations can be found in the leaf apex and it decreases towards the base and also decreases from the midrib to the margin. The critical concentrations of potassium in the conductive, lamina and root tissue are 2, 1.8, and 1.3%, respectively (Berry and Carey, 1971), it is 15-22 mM/l in petiole sap from young expanding leaves and 5.6% at the six to eight leaf stage. Knavel (1981) stated that a good growth often had relation to high concentrations of potassium (9-10%) in leaf dry matter. Disregarding the cool or warm soil condition of plant growth, there must be sufficient potassium supplies for 9 - 10% leaf concentrations. Knavel (1974) found the oldest leaves were those containing the highest cation potassium.

The applications of fertilizer considerably impacts the mineral composition of the plants, especially potassium, phosphorus and magnesium contents. Whenever there is an increase in the potassium content of the plant, there is always a change in the opposite direction of the magnesium content and vice versa. Although malnutrition diagnosis for potassium deficiency may be based on leaf analysis, it is not suitable for an excess of potassium.

The potassium deficiency can be recognized through some symptoms such as stunted growth, yellowing of the leaf-edges of the older leaves, which turn necrotic later on. If the deficiency becomes serious, there will be yellow spots near the tips of the older leaves. After that, these spots spread and coalesce, and may turn brown ultimately (Winsor and Adams, 1987).

2.3 Vertical hydroponic systems

Vertical hydroponic systems are considered to be a feasible alternative for growing vegetables, crops, or plants which have small size such as strawberry and lettuce. These hydroponic systems are especially suitable for small-scale growers with their small, inexpensive protective structure and they farmers can get many benefits from this technique given that technical operation can be simplified. There are several different vertical systems ranging from horizontal NFT troughs staked above each other to small containers arranged vertically. Cheap containers made from PVC plastic tubes, which are divided into a number of pockets can be found in many stores. Cable or beam is used to suspend these tubes, thus this kind of arrangement can create up to eight planting positions on both sides (Hutton, 1999).

In vertical hydroponic systems, plants are grown in upright or vertical rows, which can considerably increase plant populations. There are some typical vertical systems, namely stacked pots, stacked and sloped PVC pipes, and hanging vertical bags. However, the competition for light and space may cause plants to grow and develop differently, despite that fact that plant population is enhanced greatly. It is popular to use vertical systems for producing strawberries, leafy greens, edible flowers and fresh-cut herbs. Lately, this technique has been developed and applied for tomato as well (Tyson*et al.*, 2008)

Vertical production systems were developed 30 years ago in Italy (Linsley-Noakes *et al.*, 2006). By rising the planting density to many times compare to what would normally be grown in a single layer system, the greenhouse space can be taken full advantage absolutely and this is also the main purpose of vertical production systems (Linsley-Noakes *et al.,* 2006; Morgan, 2006). Ozeker *et al*. (1999) stated that vertical systems could enable plant density to be increased 3 times compared with conventional systems. The application of vertical systems is appropriately applied for the production of strawberry because this kind of plant has shallow canopy and small leaf area, unlike other crops like tomato. Vertical systems can help produce high yield of strawberries, but light intensity must be ensured to be maintained sufficiently. Thus the commercial production of strawberries has been widely used in higher light climates such as Florida in the USA and Australia due to its especially high success rate. To have good production, maintaining good light levels is very crucial, those produced out of season, and light is an indispensable factor that cannot be ignored in vertical systems (Morgan, 2006). In order to avoid weight loads on the greenhouse construction, substrates used in a vertical bag system are suggested have a low bulk density. The substrate must also be well aerated (El-Behairy *et al.*, 2001b).

2.3.1 Advantages

Due to better energy utilization and more efficient use of the greenhouse volume, soilless vertical production systems are becoming more and more popular, and these systems also bring higher yields per unit area compared to conventional methods (Paraskevopoulou- Paroussi and Paroussis,1995). With Vertical systems, working height for plant maintenance and harvesting becomes really convenient for growers. Using moveable stacks, it is easy to planted stock in and out of cold storage for successive greenhouse crops (Morgan, 2006).

Durner (1999) reported that lower light intensities in the lower rows in vertical systems made the yield plant decrease. Because of this limitation, there are also decreases in the leaf numbers, fresh and dry plant weight, as well as the number of crowns plant (Paraskevopoulou-Paroussi and Paroussis, 1995).

A vertical system might be costly to be built, although there is a total possibility that the system will not generate any profits in some production areas (Mattas *et al.*, 1997). According to Linsley-Noakes *et al.* (2006), the water distribution is not equally allocated in some vertical systems. In terms of hanging bag system, it has an outstanding drawback which is that the growing media would become compacted and flooded in the lower levels of the system, which causes root rot and a high percentage of plants that die off. However, many improvements have been made in modern vertical systems (Morgan, 2006).

2.3.2 Developing models of vertical hydroponic system.

The high capital cost per square meter of protective environment structures in the vertical layer systems make them only suitable for crops with small plants like strawberry and lettuce. These hydroponic systems are especially suitable for small-scale growers with their small, inexpensive protective structure and they farmers can get many benefits from this technique given that technical operation can be simplified. There are several different vertical systems ranging from horizontal NFT troughs staked above each other to small containers arranged vertically. Inexpensive containers made from PVC plastic tubes, which are divided into a number of pockets can be purchased in many stores. Cable or beam is used to suspend these tubes, thus this kind of arrangement can create up to eight planting positions on both sides (Hutton, 1999).

2.3.2.1 Hydroponic hanging vertical plastic columns:

The vertical hydroponic system consisted non-transparent white plastic tubes with several pockets that are designed to hold plants and these pockets are filled with appropriate substrate and supplied with nutrient solution. With the length of 1.7m and diameter of 300 mm, a plastic tube is capable of carrying sixteen pockets. There are eight pockets suspended over a cable and spaced 200 mm apart on each side of the tube, and small drainage opening at the bottom of each growing pocket. Through these openings, nutrient solution can drain from the highest pocket to the lowest one. In closed system, the excess nutrient solution will be collected for recycling, but it is drained to waste in the open system. A micro drip tube is used to deliver nutrient solution to the top pocket (Figure 2.1).

2.3.2.2 Hydroponic vertical plastic columns

Vertical columns are made of milky polyethylene film with the height of 120cm and a diameter of 16cm and new or used perlite fed at 1.20×0.66 m (1.265 columns/m^2) is filled in these columns. Plants were planted at 4 orientation sites (E, W, N, S), 18 plants/column (22.7 plants/m2) (Figure 2.2).

Figure 2.1 Hydroponic hanging vertical plastic columns

Source: https://www.pinterest.com/gsfloralgirl/vertical-gardening/

Figure 2.2 Hydroponic vertical plastic columns

Source: http://bookcoverimgs.com/hydroponic-home-food-gardens/

2.3.2.3 Hydro stackers vertical system:

In order to save areas for floor space, hydro stackers is designed intelligently and this hydro stackers verticalsystem still allows crops to grow optimally, including strawberries (Figure 2.3).

Figure 2.3 Hydro stackers vertical system

Source: http://joanrcookson.tumblr.com/page/11

2.3.2.4 Vertical hydroponics nutrient film technique (N.F.T) system

When vertical hydroponics is mentioned, the vertical hydroponic system is the kind that almost all people think of. In vertical N.F.T. systems, a constant flow of nutrient solution is established, thus there is no need for the submersible pump at given specific time. 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.

Vertical N.F.T. systems do not use any growing medium apart from air, which is an advantage because there is no need to replace costly growing medium after every crop. Generally, the plant is supported in a small plastic basket with the roots dangling into the nutrient solution. If there is any interruption towards nutrient solution, the roots will become dry at a very quick rate and vertical N.F.T. systems are very sensitive to power outages and pump failures like this (Figure 2.4).

Figure 2.4Vertical hydroponics nutrient film technique (N.F.T) system

Source:http://saigonthuycanh.com.vn/vn/products.aspx?subid=1

2.3.3 Materials to make vertical hydroponics system

Burlap

Burlap is a woven cloth created from jute, hemp or flax fibers. These plants are not known for their silky or cottony textures, so the result is a coarse fabric with a large weave pattern and natural beige coloring. Burlap is often used to form storage bags for grains, potatoes and other bulky materials. These bags can be imprinted with rudimentary logos or trademarks to help identify their contents. The actual meaning of the word is a bit of a mystery, but some sources also refer to it as Hessian cloth.

Figure 2.5 Burlap created from jute

Cloth made of burlap is also used in the formation of linoleum floor covering. Much like steel rebar in concrete, it reinforces the linoleum and gives it some linear structure. A form of this material may also be found in the underside of carpeting, providing a base for the individual fibers. Some designers may also use burlap panels as wall coverings, since they can hold paint and have distinctive textures.

Burlap has not received quite the same level of respect as its cousin canvas, but it can be used for similar purposes. Tote bags made of this fabric often replace paper or plastic as an ecological choice for grocery packing. Burlap is also biodegradable, which means all of those potato and apple sacks should eventually disintegrate without harm to the environment. Using jute and hemp fibers also keeps these alternative industries economically viable (Pollick, 2003).

Shoddy felt

Shoddy is the name given to an inferior woollen yarn made by shredding scraps of woollen rags into fibres, grinding them and then mixing them with small amounts of new wool. The object was to manufacture a cheap cloth which could be made into products and clothes. It was also known as Rag-Wool. An even finer shredding process produced what was called Mungo.

Shoddy was first made in Batley, Yorkshire, by, it is believed, Benjamin Law, and its production quickly spread to surrounding textile towns in the area.

The collection of the rags for this process started in streets all over Britain by rag dealers or rag and bone men as they became more commonly known. The rags were sorted, and any seams, or parts of the rag not suitable, were left to rot and then sold onto to farmers to manure crops. Or they were used for bedding or stuffing.

The remaining wool rags were then sent to the shoddy mills for processing. For several decades shipments of rags even arrived from continental Europe.

Figure 2.6 Shoddy made by shredding scraps of woollen rags into fibres

The rags were again sorted before the shredding process. This shredding created a very fine dust, which again, was used for manure on the fields. But the fine dust also caused health problems for many of the shoddy workers who breathed in the fine dust. It was known as 'shoddy fever'.

During the manufacturing process not all of the shoddy could be used as it was too short to spin. This was packed up in bales and sent off to Kent to be used as manure on the hop fields.

After spining the coarse cloth was sold on. In the mid-Victorian period the US and Canada was a large export market for the cloth. One common use of the material was for army uniforms and blankets (Jubb, 2014).

Mat

A mat is a textile floor covering consisting of an upper layer of "pile" attached to a backing. The pile is generally either made from wool or a man made fibre such as polypropylene, nylon or polyester and usually consists of twisted tufts which are often heat-treated to maintain their structure, which serves a range of purposes including:

Providing a regular or flat surface, such as a mousepad.

Protecting that which is beneath the mat, such as a place mat or the matting used in archival framing and preservation of documents and paintings.

Protecting that which is above the mat, such as a wrestling or gymnastics mat, or an anti-vibration mat.

Changing the state of that which passes above it, such as a doormat attracting dirt from shoes.

Figure 2.7 Mat made from polypropylene

Nylon is the most common material for construction of mat. Both nylon 6 and nylon 6-6 are used. Nylon can be dyed topically or dyed in a molten state (solution dying). Nylon can be printed easily and has excellent wear characteristics. In carpets nylon tends to stain easily because it possesses dye sites on the fibre. These dye sites need to be filled in order to give nylon any type of stain resistance. As nylon is petroleum-based it varies in price with the price of oil.

Polypropylene is used to produce mat because it is inexpensive. It is difficult to dye and does not wear as well as wool or nylon. Polypropylene is commonly used to construct berber mat. In this case, polypropylene is commonly referred to as olefin. Large looped olefin berber mat are usually only suited for light domestic use and tend to mat down quickly. Berber mat with smaller loops tend to be more resilient and retain their new appearance longer than large looped berber styles. Commercial grade level-loop mat have very small loops, and commercial grade cut-pile styles are well constructed. When made with polypropylene these styles wear very well, making them very suitable for areas with heavy foot traffic such as offices. Polypropylene mat are known to have good stain resistance but not against oil based agents. If a stain does set, it can be difficult to clean. Commercial grade carpets can be glued directly to the floor or installed over a 1/4" thick, 8-pound density padding. Outdoor grass mat are usually made from polypropylene (Wikimedia Foundation, 2014).

2.4 Hydroponics wick system

Wick Systems are the most basic form of hydroponics and are incredibly easy to set up. They are a great introduction for beginners or students looking to learn the basic principles of hydroponics without having to deal with the complex mechanisms of other systems.

Wick Systems are passive, meaning they have no moving parts. This makes them easier and cheaper to maintain than active systems such as Ebb and Flow, but they also have the drawback of being less efficient and not well equipped for high-maintenance plants, or large plants that consume a lot of water. The best plants to use in this system are fast growing lettuces or herbs. Herbs such as rosemary that don’t require a lot of water such are the best choices, while thirsty plants such as tomatoes would not do well.

The way a Wick System works is similar to the Lettuce Raft Method because the roots are always in contact with water. The difference is that a Wick System uses two or more wicks to deliver water from the reservoir to the roots via capillary action, while in a lettuce raft the roots are submerged in the reservoir itself.

One of the biggest drawbacks of Wick Systems is that they cannot handle very thirsty plants such as tomatoes. The best plants to use in Wick Systems are fast growing lettuces as well as herbs. Herbs such as rosemary that do not require very much water are the very best choices.

There are four main components in a Wick System- the grow tray, reservoir, wick and aeration system

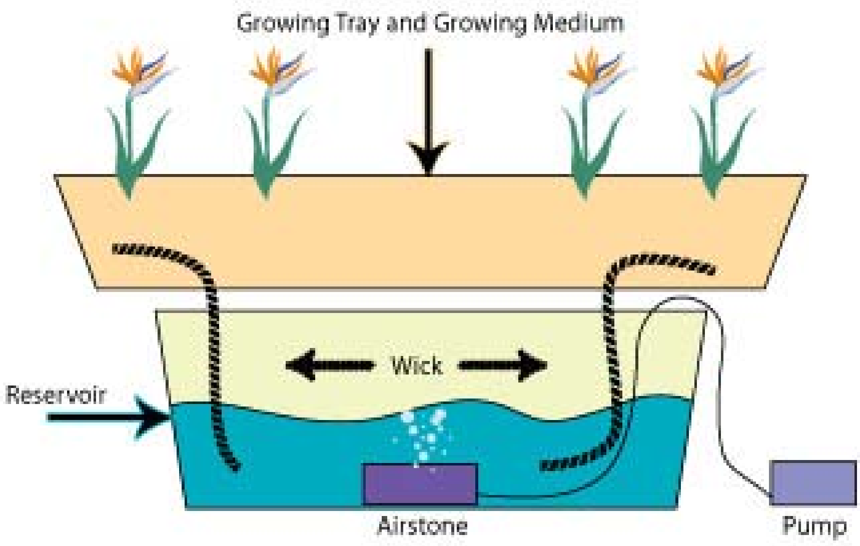

Figure 2.8 Hydroponics wick system

2.4.1 The Grow Tray

The grow tray in a Wick System differs from other hydro set ups in that it does not use net pots to hold the growing medium. The growing medium fills up the entire tray, with seedlings transplanted directly into it. The best kind of growing medium to use in this system is one that will not drain too fast and will utilize the capillary action of the wick most effectively. Vermiculite, perlite and soilless mixes are all good choices, they have good wicking abilities but will not become soggy like traditional soil.z

2.4.2 The Reservoir

The reservoir is much the same as in any other system. It is a large container of fertilized water that sits below the grow tray and supplies water and nutrients to the plants. The water in the reservoir must be refreshed every week or so, because the strength of the nutrients diminishes as the plants absorb them.

2.4.3 The Aeration System

The most common aeration system is an air stone and pump. The air stone, much like those found in home aquariums, is placed in the water and connected to an air pump outside the reservoir. The pump pushes air through the stone, which blows out tiny bubbles to distribute oxygen through the water.

It is essential to the health of the plants that their roots are oxygenated. In traditional gardening and active hydro systems, this is accomplished partially by letting the roots dry out in between watering. Active systems also use air stones to oxygenate the water, but in a Wick set-up the aeration system is especially important because the roots never have a chance to dry out completely.

2.4.4 The Wicks

The reservoir is connected to the grow try by two or more wicks. The wicks utilize capillary action to transport nutrient solution into the growing medium and to the roots of the plants. The easiest wick to use is cotton rope, but after a while it can be susceptible to mold or rot. If you plan on using the system for extended periods of time, make sure to check the rope periodically. Alternatively, nylon rope is very effective and does not mold or rot.

The wicks are inserted into the grow tray through small holes. You may want to add either a rubber connector or make sure the holes are slightly smaller than the wicks to prevent any grow media from falling through the holes.

The number of wicks used depends on a number of factors – the total system size, plants used, growing medium, and wick material will all have an effect. A good rule of thumb is to use one wick per plant, and make sure the tip of the wicks is placed near the roots. For water-hungry plants and large systems, two wicks per plant may be necessary.

If you were setting up a Wick System in the classroom, a fun experiment would be to test different types of rope to see which has the best wicking ability. Just stick the ends into a cup or bowl of colored liquid and measure how fast and how much liquid each sucks up. Washing the rope can have a significant impact on its wicking ability, so make sure to test all of your wicks both washed and unwashed and compare the difference. Depending on your results, you can decide how many and which type of wick your system will need to be effective (Roberto, 2003).

CHAPTER 3

MATERIALS AND METHODS

This study will be conducted in attempt to open up a new line of approach to increase the outcome of lettuce (*Latuca sativa* L.) by vertical hydroponic system. The whole study will divide into 4 experiments including, (1) Adapting a vertical hydroponic system for lettuce production to small scale farming situations. (2) The effect of growing media and period of irrigation on the growth, quality and yields of lettuce by vertical hydroponic system. (3) The effect of electrical conductivity (EC) on the growth, quality and yields of lettuce by vertical hydroponic system. (4) The effect of the ratio of compost tea in chemical solution on the growth, quality and yields of lettuce by vertical hydroponic system.

3.1 Materials

3.1.1 Preparation of seedling

The process of preparation of seedling of lettuce (*Latuca sativa* L.) was: (1) Fill the seed trays with seed starter. Watering the seed starter unit it is moist. (2) Sprinkle three to four seeds in each seed tray and cover them with ¼ inch of seed starter. The seedling will transplant after 2 weeks after sowing. (3) Place the seed trays in the nursery room. Keep the seed starter moist at all time. (4) The seedling will be ready for transplant when they are 3-5 inches tall.

3.1.2 Preparation of vertical hydroponic system

The vertical hydroponics system used in the experiments including four modules (Figure 3.1):

Module growing plants (1): That was made from 3 material layers and sewn together. Cut on either side to make small pockets. In each pocket contained growing media. Seedlings were transplanted into the pockets. There are 288 - 400 pockets in a vertical hydroponics system.

Module irrigation and nutrition supply (2): Including the nutrition and water container, pump and drip irrigation system. Drip irrigation system was installed above the module growing plants to irrigation water and nutrients to the plants, under the module growing plant has been fitted up with a PVC pipe to collect the excess water and nutrients from the modulus growing plants.

Module period of irrigation controller (3): Comprises a timer to control the period of irrigation.

Module frame to hang the hydroponics system (4): That was made by iron, wood or bamboo to hang the vertical hydroponics system on the vertical space.

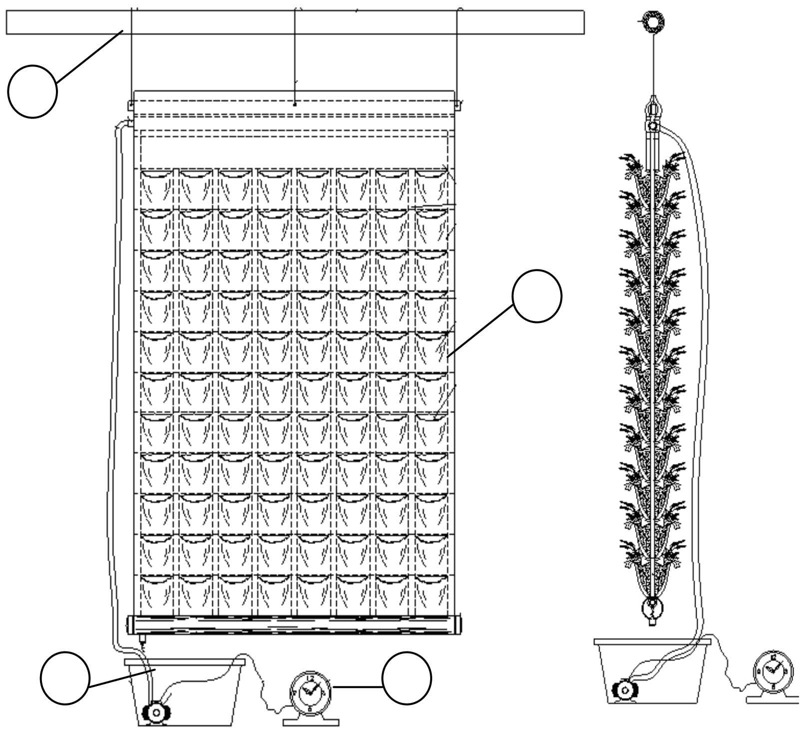

Figure 3.1 Vertical hydroponic system design

3.1.3 Preparation of nutrient Solution

The Nutrient solution in this study is from Ministry of Agriculture and Fishery, New Zealand for lettuce solution (Tregidga *et al*., 1986). The stock solutions are as follows:

Stock solution A. 10 liters consist of:

Calcium nitrate	$Ca(N0_3)_2.4\ H_2O$	1737.333	gm
Chelated iron	FeNa EDTA	105.173	gm

Stock solution B: 10 liters consists of:

Potassium nitrate	$KN0_3$	451.467	gm
Magnesium sulphate	$MgS0_4.7H_2O$	662.133	gm
Potassium dihydrogen phosphate	KH_2P0_4	362.667	gm
Manganous sulphate	$MnS0_4.2H_20$	8.205	gm
Boric acid	H_3B0_3	2.285	gm
Copper sulphate	$CuS0_4.5H_20$	0.367	gm
Ammonium molybdate	$(NH_4)_6M_70_{24}.4H_2O$	0.123	gm
Zinc sulphate	$ZnS0_4.7H_20$	0.411	gm

3.2 Experimental design

3.2.1 Experiment 1: Effect of planting densities and materials of vertical hydroponic system on the growth, quality and yields of Lettuce by vertical hydroponic system.

Locality

The experiment was carried out at the greenhouse, Faculty of Agronomy, Hue University, Hue city, in the centre of Viet Nam during March to May, 2012.

Cultivation Practices

Grand Rapids Leaf variety was used in this experiment. Lettuce seeds were wrapped in damp cloth overnight before sowing. Then the planting trays were filled with growing media, and 2-3 seeds are sown in each planting hole of the trays. These trays are then placed in the greenhouse with shade of black mesh, regular watering was done to keep moist until the germination of lettuce seeds. Lettuce seedlings would be planted in the vertical hydroponic system after 2 weeks, as they reached a height of 3-5 cm.

Preparing the vertical hydroponics system:

12 vertical hydroponics systems were readily established for the experiments, including 4 vertical hydroponics systems made of Burlap, 4 vertical hydroponics systems made of Mat, and the other four made of Shoddy Felt. Each vertical hydroponics system was divided into 4 parts having different planting bag sizes which were: 10×12, 12×14, 14×16 and 16×16 cm. The vertical hydroponics system was suspended 0.2 m above the ground in the North-South direction to take full advantage of sunlight. The spacing between 2 vertical hydroponic systems was 1m. Spacing between 2 replications was 1m. The experimental area is 4×8 m. A tank of water and nutrients with a capacity of 500 liters and a pump with 150 W would be installed to provide water and nutrients to the plant. The period of irrigation took 15 minutes each.

Transplanting:

Growing media including carbonized rice hull and coconut coir with a 1:1 ratio were placed into planting bags to prepare for growing new lettuce seedlings. After 2 weeks of sowing lettuce seeds, healthy and uniform lettuce seedlings were chosen to transplant into planting pockets in the vertical hydroponics system.

Caring:

The system set the pump to run 3 times a day to water the plants at 6:00 am, 12:00 am, and 6:00 pm. It took15 minutesper session of watering. In order to provide fertilizer for plants, hydroponic nutrient solution from Ministry of Agriculture and Fishery was used to mix with water and EC of hydroponic solution was maintained at 1.5 to 2.0 mS/cm. The pH was maintained at 6.0 to 6.5. Watering and adjusting EC and pH level were checked daily in accordance with given standards. The concentration was achieved by adding to tap water all the major and minor nutrients in equal proportions until the required concentration was achieved. Potassium hydroxide (KOH) and Phosphoric acid (H_3PO_4) were used to raise and lower the pH, respectively. pH and EC of the nutrient solution will be measured daily with a handheld device 'HANNA' pH and EC meter.

Treatments and Experimental design

The experiment was laid out in 3×4 split plot design with 4 replications (block). Each block contained three equal sized main plots, which were divided into 4 subplots. Analysis was done with materials of the vertical hydroponic system as the main plot factor, planting density as the subplot factor. Data was analyzed using STATISTIX version 8.0. Least Significant Difference (LSD) was calculated at a 5% level to compare the treatment means.

The main plots are:

A1: Vertical hydroponic system made of Burlap

A2: Vertical hydroponic system made of Shoddy Felt

A3: Vertical hydroponic system made of Mat

The sub plots are:

B1: Spacing: 10×12 cm (400 plants/m^2)

B2: Spacing: 12×14 cm (288 plants/m^2)

B3: Spacing: 14×16 cm (224 plants/m^2)

B4: Spacing: 16×16 cm (192 plants/m^2)

Data collected

1) Vertical hydroponics system data: weight of the system (kg), cost of the system (USD), evaporate water /m^2 system/12 hours (liters), time of use were determined

2) The lettuce data: the height of plant (cm), the number of leaves/plant (leaves), the plant diameter (cm), the total fresh weight (gm), the total dry weight (gm), the leaf area (LA), and the yield/unit were determined.

3.2.2 Experiment 2: Effect of cultivate method on the growth, quality and yields of Lettuce

Locality

The experiment was carried out at the greenhouse, Faculty of Agronomy, Hue University, Hue city, in the center of Viet Nam during June to August, 2012.

Cultivation Practices

Three lettuce varieties used in this experiment were the Rapid Red, Grand Rapids Leaf and Romaine. Seeds of lettuce were wrapped in a damp cloth overnight before sowing. After filling the planting tray was with growing media, 2-3 seeds are sown in each planting hole of the tray. The trays are then placed in the greenhouse under shade of black mesh, and watered to keep moist until the germination of lettuce seeds. The lettuce seedlings would be transplanting in soil, hydroponic wick system, and vertical hydroponic system after 2 weeks, when they had a height of 3-5 cm.

Preparing the vertical hydroponics system:

Four vertical hydroponics systems were prepared for experiment. The vertical hydroponic system was made of Mat with the size of 1.3×2 m, planting density of 10×12 cm (400 plants / m^2). Each vertical hydroponics system was divided into 3 parts to plant 3 different lettuce varieties. The vertical hydroponics system was suspended 0.2 m above the ground in the direction north-south to absorb optimally sunlight. The spacing between two vertical hydroponic systems was 1m. Spacing between 2 replications was 1m. A tank of water and nutrients with a capacity of 500 liters and a pump with 150 W would be installed to provide water and nutrients to the plant. The time of irrigation would set at 6.00 am, 12.00 am, and 6.00 pm. The period of irrigation would take 15 minutes per each.

Preparing wick hydroponic system:

The system consists of three parts: (1) a plastic bucket containing water and nutrients with a capacity of 15 liters of water, (2) a Styrofoam box containing growing media having three dimensions (length x width x height) 60 x 40 x 15 cm, (3) a wick system connecting the water container and the growing media container which delivers water and nutrients to growing media. Growing media consist of carbonized rice hull and coconut coir which are added to the Styrofoam box, and seedlings or seeds will be planted in this growing media. The planting density is 10 x 20 cm (50 plants/ m^2).

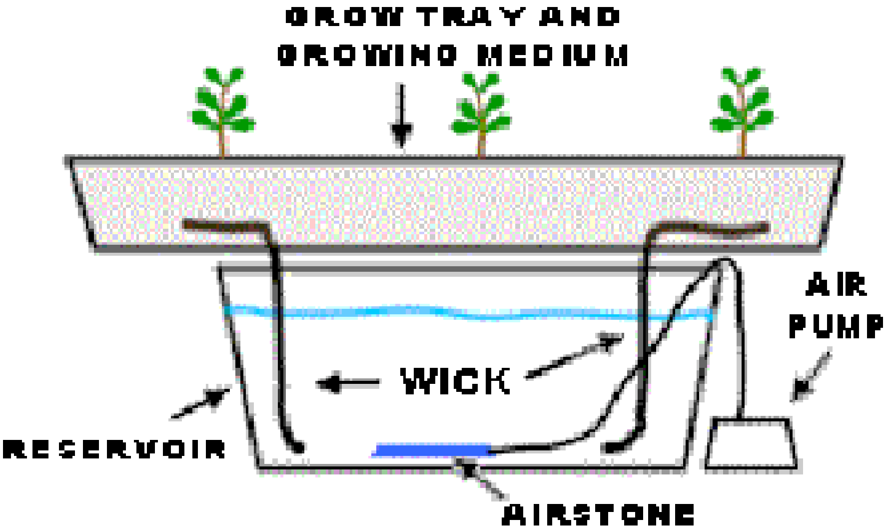

Figure 3.2 Hydroponics wick system design

Transplanting:

Growing media consisting of carbonized rice hull and coconut coir with a ratio of 1:1 was put in the vertical hydroponics system and hydroponic wick system to prepare for the lettuce seedlings planting. After 2 weeks of sowing lettuce, healthy and uniform seedlings were chosen for transplanting into the vertical hydroponics system, hydroponic wick system and soil.

Caring:

For hydroponics systems:

Vertical hydroponic system: The pump was set to run 3 times a day to water the plants at 6:00 am, 12:00 am, and 6:00 pm. It takes 15 minutes per watering session.

Hydroponic wick system: The water in the container is checked regularly. Water and nutrient solution are added to all the containers when they are about to run out. The wick system will automatically take up water and nutrient for plants on the principle of osmosis.

To provide fertilizer for crops, hydroponic nutrient solution from Ministry of Agriculture and Fishery was used to mix with water, and EC of hydroponic solution was maintained at 1.5 to 2.0 mS/cm. The pH was maintained at 6.0 to 6.5. Checking water for plants and adjusting EC and pH in accordance with the standard were done daily. The concentration was achieved by adding to tap water all the major and minor nutrients in equal proportions until the required concentration was achieved. Potassium hydroxide (KOH) and Phosphoric acid (H_3P0_4) were used to raise and lower the pH respectively. pH and EC of the nutrient solution will be measured daily with a handheld ‘HANNA’ pH and EC meter.

Treatments and Experimental design

The experiment was laid out in 3×3 split plot design with 4 replications. Cultivation method was chosen as the main plots, and lettuce varieties were the sub plots. Data was analyzed using STATISTIX version 8.0 (Statistix, 2007). Least Significant Difference (LSD) was calculated at 5% level to compare the treatment means.

The main plots were:

A1: Lettuce growing in vertical hydroponic system

A2: Lettuce growing in hydroponic wick system

A3: Lettuce growing in soil

The sub plots were:

B1: Lettuce variety Red Rapid

B2: Lettuce variety Romaine

B3:Lettuce variety Grand Rapids Leaf

Data collected

Each experimental unit selected 10 plants to collect data. The following data were recorded for assessments of

1. The height of plant (cm), the number of leaves/plant (leaves), the plant diameter (cm), the total fresh weight (gm), the total dry weight (gm), the chlorophyll content of leave, the leaf area (LA), and the yield/unit will be determined.

2. Ascorbic acid determination (vitamin C), nitrate determination, color of leave, shelf life, and sensory evaluate were determined

3.2.3 Experiment 3: Effect of growing media and period of irrigation on growth, quality and yields of Lettuce by vertical hydroponic system.

Locality

The experiment was carried out at the greenhouse, Faculty of Agronomy, Hue University, Hue city, in the center of Viet Nam during September – November, 2012.

Cultivation Practices

Rapid Red lettuce varieties were used in this experiment. Lettuce seeds were wrapped in a damp cloth overnight before sowing. After filling the planting tray with growing media, 2-3 seeds are sown in each planting hole in the tray. The trays are then placed in the greenhouse under shade of black mesh, and watered to keep moist until the germination of lettuce seeds. The lettuce seedlings would be transplanted into the vertical hydroponic system after 2 weeks, when they had a height of 3-5 cm.

Preparing the hydroponics system:

12 vertical hydroponics systems were prepared for experiments. The vertical hydroponic system was made of Mat with the size of 1.3x2 m, planting density of 10x12 cm (400 plants/m^2). Each vertical hydroponics system was divided into four parts to put four different kinds of growing media. The vertical hydroponics system was suspended 0.2 m above the ground in the direction North-South to absorb optimally sunlight. The spacing between two vertical hydroponic systems was 1m. The spacing between 2 replications was 1m. A water container with a capacity of 20 liters and a pump having power of 25W inside the container are installed under each vertical hydroponics system to deliver water and nutrient solution to the plants.

Transplanting:

Growing media was filled into pockets in the vertical hydroponics system to prepare for the lettuce seedlings planting. After 2 weeks of sowing lettuce, healthy and uniform seedlings are chosen for transplanting into the vertical hydroponics system.

Caring:

Number of water and nutrient solution pumping times depends on each experimental formula. It takes 15 minutes per watering session. The water in the container is checked regularly. Water and nutrient solution are added to all the containers when they are about to run out.

To provide fertilizer for crops, hydroponic nutrient solution from Ministry of Agriculture and Fishery was used to mix with water, and EC of hydroponic solution was maintained at 1.5 to 2.0 mS/cm. The pH was maintained at 6.0 to 6.5. Checking water for plants and adjusting EC and pH were done daily in accordance with the standard. The concentration was achieved by adding to tap water all the major and minor nutrients in equal proportions until the required concentration was achieved. Potassium hydroxide (KOH) and Phosphoric acid (H3P04) were used to raise and lower the pH respectively. pH and EC of the nutrient solution will be measured daily with a handheld 'HANNA' pH and EC meter.

Treatments and Experimental design

The experiment was laid out in 3×4 split plot design with 4 replications. Period of irrigation was chosen as the main plots, and growing media were the sub plots. Data was analyzed using STATISTIX version 8.0 (Statistix, 2007). Least Significant Difference (LSD) was calculated at 5% level to compare the treatment means.

The main plots are:

A1: Period of irrigation at 7 am and 5 pm.

A2: Period of irrigationat 6 am, 12 am and 6 pm.

A3: Period of irrigation at 6 am, 10 am, 2 pm and 6 pm.

The sub plots are:

B1: Use coconut coir as growing media

B2: Use carbonized rice hull as growing media.

B3: Use coconut and carbonized rice hull (ration 1:1) as growing media.

B4: Use rock wool as growing media.

Data collected

Each experimental unit selected 10 plants to collect data. The following data were recorded for assessments of

1. The height of plant (cm), the number of leaves/plant (leaves), the plant diameter (cm), the total fresh weight (gm), the total dry weight (gm), the color of leave, the chlorophyll content of leave, the leaf area (LA), the yield/unit will be determined.

2. Ascorbic acid determination (vitamin C), nitrate determination, color of leave, shelf life, sensory evaluate, antioxidant will be determined

3.2.4 Experiment 4: Effect of Electrical Conductivity (EC) on the growth, quality and yields of Lettuce by vertical hydroponic system.

Locality

The experiment was carried out at the greenhouse, Faculty of Agronomy, Hue University, Hue city, in the center of Viet Nam during February to April, 2013.

Cultivation Practices

Rapid Red lettuce varieties were used in this experiment. Lettuce seeds were wrapped in a damp cloth overnight before sowing. After filling the planting tray with growing media, 2-3 seeds are sown in each planting hole in the tray. The trays are then placed in the greenhouse under shade of black mesh, and watered to keep moist until the germination of lettuce seeds. The lettuce seedlings would be transplanted into soil, hydroponic wick system, and vertical hydroponic system after 2 weeks, when they had a height of 3-5 cm.

Preparing the hydroponics system:

20 vertical hydroponic systems were prepared for experiments. The vertical hydroponic system was made of Mat with the size of 1.3×2 m, planting density of 10×12 cm (400 plants/m^2). The vertical hydroponics system was suspended 0.2 m above the ground in the direction North-South to absorb optimally sunlight. The spacing between two vertical hydroponic systems was 1m. The spacing between 2 replications was 1m. A water container with a capacity of 30 liters and a pump having power of 25W inside the container are installed under each vertical hydroponics system to deliver water and nutrient solution to the plants. The period of irrigation is set at 6.00 am, 10.00 am, 2pm, and 6.00 pm. It will take 15 minutes per irrigation session.

Transplanting:

Growing media containing carbonized rice hull and coconut coir with a ratio of 1:1 was put in planting pockets in the vertical hydroponics system to prepare for the lettuce seedlings planting. After 2 weeks of sowing lettuce, healthy and uniform seedlings are chosen for transplanting into the vertical hydroponics system.

Caring:

The pump is set to run 4 times a day to water the plants at 6.00 am, 10.00 am, 2 pm and 6.00 pm. It takes 15 minutes per watering session. The water in the container is checked regularly. Water and nutrient solution are added to all the containers when they are about to run out.

To provide fertilizer for crops, hydroponic nutrient solution from Ministry of Agriculture and Fishery was used to mix with water, and EC of hydroponic solution was maintained as available experimental formula. The pH was maintained at 6.0 to 6.5. Checking water for plants and adjusting EC and pH were done daily in accordance with the standard. The concentration was achieved by adding to tap water all the major and minor nutrients in equal proportions until the required concentration was achieved. Potassium hydroxide (KOH) and Phosphoric acid (H_3P0_4) were used to raise and lower the pH, respectively. pH and EC of the nutrient solution will be measured daily with a handheld ‘HANNA’ pH and EC meter.

Treatments and Experimental design

The experiment will conduct with 5 treatments and 4 replications in Randomized Complete Block (RCB) design. Data was analyzed using STATISTIX version 8.0 (Statistix, 2007). Least Significant Difference (LSD) was calculated at a 5% level to compare the treatment means.

Treatment 1: EC = 0.5 mS/cm

Treatment 2: EC = 1.0 mS/cm

Treatment 3: EC = 1.5 mS/cm

Treatment 4: EC = 2.0 mS/cm

Treatment 5: EC = 2.5 mS/cm (control)

Data collected

Each experimental unit selected 10 plants to collect data. The following data were recorded for assessments of

1. The height of plant (cm), the number of leaves/plant (leaves), the plant diameter (cm), the total fresh weight (gm), the total dry weight (gm), the color of leave, the chlorophyll content of leave, the leaf area (LA), the yield/unit will be determined.

2. Ascorbic acid determination (vitamin C), nitrate determination, color of leave, shelf life, sensory evaluate, antioxidant will be determined

3.2.5 Experiment 5: Effect of the ratio of compost extract in chemical solution nutrient on growth, quality and yields of Lettuce by vertical hydroponic system.

Locality

The experiment was carried out at the greenhouse, Faculty of Agronomy, Hue University, Hue city, in the centre of Viet Nam during February to May, 2013

Cultivation Practices

Rapid Red lettuce varieties were used in this experiment. Lettuce seeds were wrapped in a damp cloth overnight before sowing. After filling the planting tray with growing media, 2-3 seeds are sown in each planting hole in the tray. The trays are then placed in the greenhouse under shade of black mesh, and watered to keep moist until the germination of lettuce seeds. The lettuce seedlings would be transplanted into the vertical hydroponic system after 2 weeks, when they reached the height of 3-5 cm.

Preparing the hydroponics system:

24 vertical hydroponics systems were prepared for experimenting. The vertical hydroponic system was made of Mat with the size of 1.3×2 m, planting density is 10×12 cm (400 plants/m^2). The vertical hydroponics system was suspended 0.2 m above the ground in the direction North-South to absorb optimally sunlight. The spacing between two vertical hydroponic systems was 1m. The spacing between 2 replications was 1m. A water container with a capacity of 30 liters and a pump having power of 25W are installed under each vertical hydroponics system to deliver water and nutrient solution to the plants. The period of irrigation will set with the timer at 6.00 am, 10.00 am, 2pm, and 6.00 pm. The period of irrigation will take 15 minutes per each.

Transplanting:

Growing media containing carbonized rice hull and coconut coir with a ratio of 1:1 was put in planting bags of the vertical hydroponics system to prepare for the lettuce seedlings planting. After 2 weeks of sowing lettuce, healthy and uniform seedlings are chosen for transplanting into the vertical hydroponics system.

Caring:

The pump is set to run 4 times a day to water the plants at 6.00 am, 10.00 am, 2.00 pm and 6.00 pm. It takes 15 minutes per watering session. The water in the container is checked regularly. Water and nutrient solution are added to all the containers when they are about to run out.

To provide fertilizer for crops, compost extract made from earthworm compost and hydroponic nutrient solution from Ministry of Agriculture and Fishery was used to mix with water, and EC of hydroponic solution was maintained at 2 – 2.5 mS/cm. The pH was maintained at 6.0 to 6.5. Checking water for plants and adjusting EC and pH were done daily in accordance with the standard. The concentration was achieved by adding to tap water all the major and minor nutrients in equal proportions until the required concentration was achieved. Potassium hydroxide (KOH) and Phosphoric acid (H3P04) were used to raise and lower the pH, respectively. pH and EC of the nutrient solution will be measured daily with a handheld ‘HANNA’ pH and EC meter.

Treatments and Experimental design

The experiment will conduct with 6 treatments and 4 replications in Randomized Complete Block (RCB) design. Data was analyzed using STATISTIX version 8.0 (Statistix, 2007). Least Significant Difference (LSD) was calculated at a5% level to compare the treatment means.

Treatment 1: 1/2 compost extract + 1/2 chemical solution nutrient

Treatment 2: 1/3 compost extract + 2/3 chemical solution nutrient

Treatment 3: 1/4 compost extract + 3/4 chemical solution nutrient

Treatment 4: 1/5 compost extract + 4/5 chemical solution nutrient

Treatment 5: Compost extract

Treatment 6: Chemical nutrient solution (control)

Data collected

Each experimental unit selected 10 plants to collection data. The following data were recorded for assessments of

1. The height of plant (cm), the number of leaves/plant (leaves), the plant diameter (cm), the shoot and root fresh weight (gm), the shoot and root dry weight (gm), the color of leave, the chlorophyll content of leave, the leaf area (LA), the yield/unit will be determined.

2. Ascorbic acid determination (vitamin C), nitrate determination, color of leave, shelf life, sensory evaluate, antioxidant will be determined.

3.3 Data collection method and analysis.

3.3.1 Data of vertical hydroponics system.

3.3.1.1 Weight of the system (kg): After completing all the vertical hydroponics systems, which were made of different materials, appropriate scale was used to determine the weight of each system.

3.3.1.2 Cost of the system (USD): Price of the vertical hydroponics system is the total expenses of all the materials used to create different types of vertical hydroponics system.

3.3.1.3 Evaporate water/m^2 system/12 hours (liters): After completing the 3 different types of hanging gardens in terms of materials, each of them was suspended on by one and planting pockets were then filled with growing media. At 6 o'clock in the morning, the pump was used to pump water to wet the substrate in the planting bags. Then at 9 o'clock am, 10 liters of water were pumped to the gardens to make the bags wet. The excess water flowing down was determined. The amount of water evaporated was calculated by taking the initial 10 liters subtracts the excess water running down. This was repeated at 12 pm, 15 pm and 18 pm Evaporate water /m^2 system/12 hours were calculated by adding the amount of water evaporated at the time of 9 am, 12 pm, 15 pm and 18 pm

3.3.1.4 Time of use: After each season, pull the vertical hydroponics system made from different materials to determine which ones can be used for the next planting season.

Table 3.1 The detail of time use of materials to make vertical hydroponics system

Time of use	**Detail**
Good	Material was not tear when pulled by hand
Rotten	Material was tear when pulled by hand

3.3.2 Data of lettuce growth and yield.

Each experimental unit selected 10 plants to collect data. The following data were recorded for assessments of:

3.3.2.1 The height of the plant (cm): The data will be collected weekly from 10 plants/experimental unit. Use cm ruler to measure from base the highest position of the lettuce plant.

3.3.2.2 The number of leaves / plant (leaves): The data will be collected weekly from 10 plants / experimental unit. After each count, use a red marker to mark the leaf which is at the highest position of the tree. On the next count, we just need to count from the one adjacent to the marked leaf to the tip. Total number of leaves of lettuce is calculated by adding the number of leaves in all counts.

3.3.2.3 The plant diameter (cm): The data will be collected weekly from 10 plants/experimental unit. Use a ruler to measure the position having largest diameter.

3.3.2.4 The total fresh weight (gm): Shoot and root fresh weight at final harvest will be recorded from 3 plants per plot. Use electronic scale to weigh the fresh weight immediately after harvesting.

3.3.2.5 The total dry weight (gm): Shoot and root dry weight at final harvest will be recorded from 3 plants per plot. Once harvested, the plants are dried at the temperature of 105^0C until they reach constant weight. Use the electronic scale to weigh the dry weight.

3.3.2.6 Leaf area: 3 lettuces are taken from each plot. All the leaves/plants are cut, then weighed and we have b (g). 1 dm^2 of leaves is also weighed and we have a (g). Leaf/tree area was calculated using the formula:

$$S = b/a\ (dm^2)$$

Leaf /plant area is calculated during lettuce harvest period.

3.3.2.7 Leaf area index: was calculated by multiplying the leaf/tree area with the number of plants per m^2.

3.3.2.8 Total yield/m^2: was determined by weigh all ettuce plants/m^2atthe harvesting period.

3.3.2.9 Total yield/ha: was determined by multiplying the total yield/m^2 with 10000 m^2.

3.3.2.10 Chlorophyll content: was analyzed as described by Arnon (1949)

3.3.2.11 Leaf color: was determined on the leaf surface with a Hunter Lab Model No. SP60, X-Rite – USA. CIE color values L* (black = -100 and white = +100), a* (greenness), b* (yellowness). Each experimental unit selected 10 leaves to collect leaf color. The leaves is placed between the clamps of Hunter Lab, readthe L*, a*, and b*value ondisplay screen of Hunter Lab

3.3.3 Data of lettuce quality

3.3.3.1 Ascorbic acid determination (vitamin C):The method used for ascorbic acid determination was the 2,6-dichlorophenolindophenol spectrometric method after extraction with xylene, following the procedure of ISO 6557/2 (Anonymous, 1984).

3.3.3.2 Vitamin A content: was determined using High Performance Liquid Chromatography (HPLC).

3.3.3.3 Nitrate determination:Nitrate concentration was determined by selective electrode method (Bedwell *et al.,* 1995).

3.3.3.4 Shelf life: After the fresh weight determinations, 3 heads from each plot were packed in plastic bag. They were kept in a controlled temperature room at 25^0 C. The fresh weight of 3 heads was measured every day to determine the loss of 10% fresh weight would occur in which day (Ryall and Lipton, 1979).

3.3.3.5 Sensory evaluate: Fresh lettuce from all treatments was washed and prepared. The prepared lettuce was placed in identical dishes tagged with codes signifying the treatments (Food and Agriculture Organization (FAO), 2000).
This helped in avoiding bias preferences of panelists. The salad was not dressed in order to prevent bias preferences or dislikes of panelists due to flavor and/or taste of dressing (FAO, 2000). The panelist number was 30. There were 15 females and 15 males that did the organoleptic tastes. The panelists were aged between 18 and 25 years.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Effect of plant densities and materials of vertical hydroponic system on the growth and yields of lettuce by vertical hydroponic system

4.1.1 Weight of the system, cost of the system, evaporates water/m^2, and usableness after one season of system

The study found materials to make the vertical hydroponics system having lightweight, low cost, less water evaporates and sustainable use characteristics. This will make it easier for users to approach vertical hydroponics system, and bring higher economic efficiency for growers. The indicators such as weight of system, the cost of system, evaporate water/m^2 are measured before planting, except for the usableness after one season of system is measured after a crop harvested. The study results are shown in the following table:

Table 4.1 Weight of system, cost of the system, evaporate water /m^2 system,and usable after one season of different materials of the vertical hydroponics system

Treatments	Weight of system(kg)	Cost of system(USD)	Evaporate water /m^2 system/hour(ml)	Usable after one season
Mat	3.2	16.6	70.8	Good
Burlap	5.6	15.0	160.8	Rotten
Shoddy Felt	4.7	21.4	139.2	Good

The study results showed that Mat was the lowest of weight of system and evaporate water/m^2 system. The cost of the system was 16.6 USD/system on average. After one season, the unstableness was good. Burlap was the material having the lowest cost of system (15.5 USD/system). But it had the highest weight and evaporates water/m^2 system, and the system was rotten and unable to use after one season. Shoddy

Felt was the material having average weight of system and evaporate water/m^2/system, but its cost was very high (21.4 USD/system). This material was usable after one season.

The result showed that Mat was the most suitable material for vertical hydroponics system in terms of low cost, light weight, less water evaporation, and especially long time use.

4.1.2 Stem length

Plant height, which is an indicator of the growth condition (good or bad), is measured every five days, and growers begin measuring from the 25th day after planting. The study results are shown in table 4.2. The recorded data in table 4.2 showed that different materials of the vertical hydroponics system had no effect on stem length of lettuce through the period of plant growth. Lettuce plants in harvest stage reached the height from 19.49 to 20.18 cm. This difference was less relatively and not significant statistically. These indicated that the material of vertical hydroponics had no important role in stem length of lettuce.

The study results also indicated that plant densities of 10×12 cm tended to be more suitable for development of stem length of lettuce. The differences among different planting densities were less relatively and not significant statistically. Therefore, growers can choose a planting density of 10×12 cm to get the highest number of plants per unit area. The results of this study are not consistent with the results of the research carried out by Moniruzzaman (2006), who found that lettuce height would decrease as planting density increased, but it was as the findings of Firoz *et al.* (2009). Firoz (2009) conducted experiments at two lettuce densities which are 50×30 and 50×45 cm. The results showed there was no significant difference in lettuce height between these two planting densities.

4.1.3 Number of leaves, plant diameter, leaf area and leaf area index

The different materials of the vertical hydroponics system had no effect on the number of leaves, plant diameter, leaf area and leaf area index of lettuce, while the different plant densities and the interaction between materials and plant densities had a significant effect. The results from table 4.3 revealed that plant densities of 14×16 cm and 16×16 cm gave the highest number of leaves, plant diameter and leaf area of lettuce. However, the leaf area index of lettuce was the highest with a planting density of 10×12 cm. This suggests that the materials used to make the vertical hydroponics system are not the factors affecting the number of leaves, plant diameter, leaf area and leaf area index. The experiment indicated that plant density is an important factor that impacts

Table 4.2 Stem length of lettuce after planting with different materials of vertical hydroponics system and plant densities

Factor	Stem length (cm) after planting (days)				
	25	30	35	40	45
Materials					
Mat	7.25	10.84	14.88	18.17	19.68
Burlap	7.31	11.42	15.23	18.28	20.18
Shoddy Felt	7.07	11.02	14.82	17.67	19.49
F-test	ns	ns	ns	ns	ns
CV%	9.22	9.99	8.19	8.89	6.26
Plant densities					
10 x 12 cm	7.16	11.23	15.06	18.16	20.15
12 x 14 cm	7.15	10.83	15.08	18.28	19.70
14 x 16 cm	7.35	11.18	14.72	17.80	19.51
16 x 16 cm	7.19	11.13	15.07	17.91	19.76
F-test	ns	ns	ns	ns	ns
CV%	9.02	9.65	8.03	8.67	14.97
Materials x Plant densities					
Mat 10 x 12 cm	7.25	11.27	15.23	19.21	21.06
Mat 12 x 14 cm	6.53	10.23	14.65	17.90	19.30
Mat 14 x 16 cm	7.97	11.13	15.05	17.96	19.71
Mat 16 x 16 cm	7.27	10.72	14.59	17.60	18.64
Burlap 10 x 12 cm	7.49	11.19	14.71	17.51	19.68
Burlap 12 x 14 cm	7.25	11.53	15.73	19.57	20.61
Burlap 14 x 16 cm	7.07	11.63	14.93	17.80	19.68
Burlap 16 x 16 cm	7.44	11.35	15.55	18.22	20.74
Shoddy Felt 10 x 12 cm	6.73	11.22	15.23	17.75	19.72

Table 4.2 continued

Factor	Stem length (cm) after planting (days)				
	25	30	35	40	45
Shoddy Felt 12 x 14 cm	7.66	10.74	14.84	17.36	19.19
Shoddy Felt 14 x 16 cm	7.01	10.79	14.17	17.64	19.14
Shoddy Felt 16 x 16 cm	6.86	11.32	15.04	17.90	19.89
F-test	ns	ns	ns	ns	ns
CV%	11.49	10.01	7.93	8.61	9.24

ns = non significant

these indicators. How planting density affects the number of leaves, plant diameter, leaf area and leaf area index are represented as follows:

When planting density reduces, the number of leaves, leaf area and plant diameter tend to increase and peak at planting densities of 14×16 cm and 16×16 cm. This is similar to the findings of Moniruzzaman (2006). He conducted experiments with different densities, including 40×20, 40×30 and 40×40 cm and had found that a decline in planting density resulted in an increase in the number of leaves and maximum length of the leaf. The rise of these indicators is due to the low planting density. Lettuce needs plenty of space to grow and absorb more sunlight.

When planting density was increased from 10×12 to 12×14 cm, lettuce tended to increase the number of leaves, leaf area and plant diameter. But as planting density increased from 12×14 to 14×16 cm and 16×16 cm, the difference in these indicators was not really significant. This suggests that planting density of 12×14 cm provides sufficient space the development and sunlight absorption of lettuce.

On the contrary, when the planting density decreased, leaf area index decreased as well. This was due to less plant per m^2 at lower plant density.

4.1.4 Total fresh weight, total dry weight, and yield

The recorded data in table 4.4 shows that different materials of the vertical hydroponics system have no significant effect on total fresh weight, total dry weight and total yield of lettuce. This shows that the materials of the vertical hydroponics system are not an important factor impacting the performance indicators of lettuce.

The data in Table 4.4 also shows that different plant densities have a significant effect on total fresh weight, total dry weight and total yield. Effect of planting density on these indicators is shown as follows.

Plants treated with plant densities at 14×16 cm and 16×16 cm gave the highest total fresh weight and total dry weight ranged from 14.89 - 15.05 g/plant and 0.88 – 1.01 g/plant, respectively. This result indicates that at low planting density, lettuce develops and weighs more than those grow in high density planting. The reason is that, lettuce has more space to grow and absorb sunlight in the low planting density. This is consistent with findings of Moniruzzaman (2006), who reported that the increased density of lettuce grown from 40×20 to 40×30 and 40×40 caused the fresh weight of lettuce

Table 4.3 Number of leaves, plant diameter, leaf area and leaf area index of lettuce growing at different materials of the vertical hydroponics system and plant densities

Treatment	Number of leaves(leaves)	Plant diameter(cm)	Leaf area (m^2)	Leaf area index (m^2 leaf/m^2 land)
Materials				
Mat	18.49	19.11	0.097	13.02
Burlap	18.21	19.16	0.104	13.91
Shoddy Felt	18.28	18.46	0.105	14.08
F-test	ns	ns	ns	ns
CV%	5.10	10.22	14.5	19.23

Table 4.3 continued

Treatment	Number of leaves(leaves)	Plant diameter(cm)	Leaf area (m^2)	Leaf area index (m^2 leaf/m^2 land)
Plant densities				
10 x 12 cm	17.26[b]	16.99[b]	0.084[c]	16.87[a]
12 x 14 cm	18.54[a]	18.14[b]	0.101[b]	14.58[b]
14 x 16 cm	18.51[a]	19.89[a]	0.108[ab]	12.11[c]
16 x 16 cm	19.01[a]	20.64[a]	0.116[a]	11.12[c]
F-test	**	**	**	**
CV%	3.55	6.50	8.68	8.96
Materials x Plant densities				
Mat 10 x 12 cm	17.24[b]	16.55[g]	0.079[e]	15.86[abc]
Mat 12 x 14 cm	18.34[ab]	18.62[defg]	0.098[bcd]	14.21[c]
Mat 14 x 16 cm	19.13[a]	20.37[abc]	0.101[bc]	11.31[e]
Mat 16 x 16 cm	19.25[a]	20.91[ab]	0.111[ab]	10.68[e]
Burlap 10 x 12 cm	17.29[b]	17.06[g]	0.084[de]	16.86[ab]
Burlap 12 x 14 cm	18.59[a]	18.04[efg]	0.103[abc]	14.88[bc]
Burlap 14 x 16 cm	18.17[ab]	20.02[abcd]	0.112[ab]	12.58[de]
Burlap 16 x 16 cm	18.80[a]	21.52[a]	0.117[a]	11.29[e]
Shoddy Felt 10 x 12 cm	17.26[b]	17.34[fg]	0.089[cde]	17.86[a]
Shoddy Felt 12 x 14 cm	18.66[a]	17.74[efg]	0.102[bc]	14.64[c]
Shoddy Felt 14 x 16 cm	18.25[ab]	19.28[bcde]	0.111[ab]	12.43[de]
Shoddy Felt 16 x 16 cm	18.96[a]	19.48[bcde]	0.118[a]	11.39[e]
F-test	**	**	**	**
CV%	5.38	9.88	14.13	18.44

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

to increase to 200.5, 288.5 and 315.2 g/plant, and made dry weight increase to 5.33, 7.48 and 8.24 g/plant, respectively. When Fatma *et al.*(2010) carried out experiments on different planting densities for strawberries, they have also shown that fresh weight and dry weight of plants with low planting density were higher than those with high density planting.

Contrary to total weight/plant, the treatments with high planting density gave a higher total yield than those with low planting density. The treatment achieving the highest total yield was at planting density of 10×12 cm, with total yield of 50.2 tons/ha. Despite of low total weight/plant, treatments with high planting density, but the formula having high planting density had higher number of trees/ha than those having low planting density. These study results are also consistent with the findings of Moniruzzaman (2006). In his research findings, he also pointed out that low planting density of lettuce resulted in higher total weight/plant, but it was lower in treatments having high planting density.

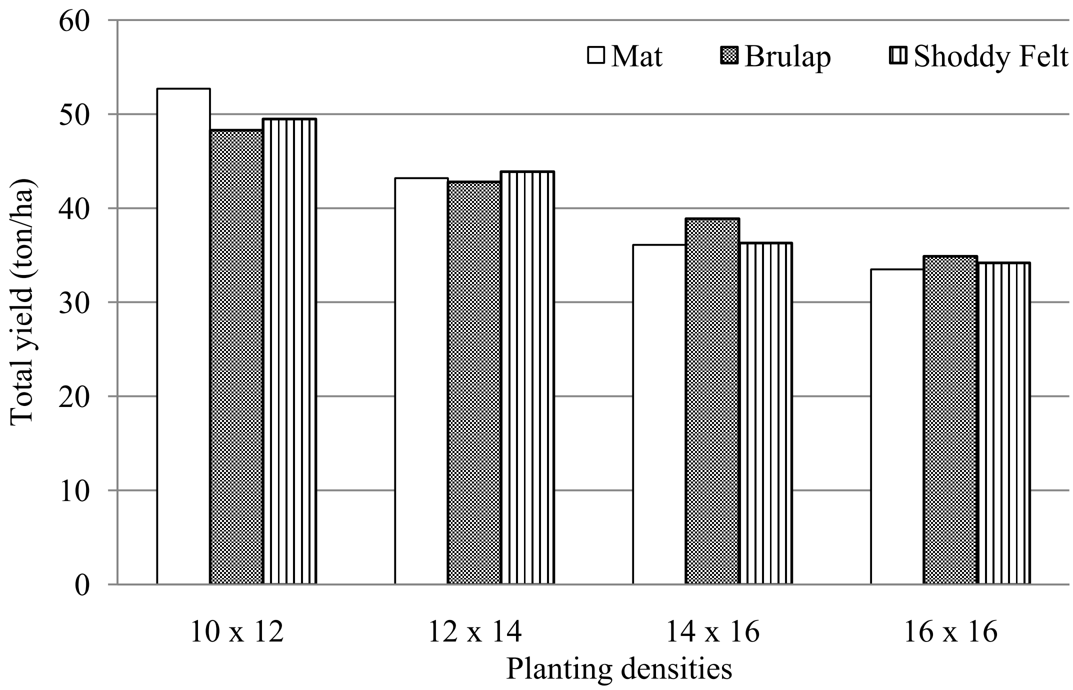

Figure 4.1 Effect of different materials of vertical hydroponics system and plant densities on lettuce total yield

Table 4.4 Total fresh weight, total dry weight and total yield of lettuce growing at different materials of the vertical hydroponics system and plant densities

Treatment	Total fresh weight (gm/plant)	Total dry weight (gm/plant)	Total yield $/m^2$ (kg)	Total yield /ha (ton)
Materials				
Mat	13.61	0.91	4.14	41.1
Burlap	14.21	0.95	4.12	41.2
Shoddy Felt	13.75	0.87	4.10	41.0
F-test	ns	ns	ns	ns
CV%	13.64	20.15	17.25	17.25
Plant densities				
10 x 12 cm	11.88^{c}	0.75^{b}	5.02^{a}	50.2
12 x 14 cm	13.60^{b}	0.88^{ab}	4.33^{b}	43.3
14 x 16 cm	14.89^{ab}	1.01^{a}	3.71^{c}	37.1
16 x 16 cm	15.05^{a}	1.01^{a}	3.42^{d}	34.2
F-test	**	*	**	**
CV%	9.78	16.87	6.38	6.38
Materials x Plant densities				
Mat 10 x 12 cm	12.19^{cde}	0.78	5.27^{a}	52.7
Mat 12 x 14 cm	13.66^{abcde}	0.83	4.32^{cd}	43.2
Mat 14 x 16 cm	14.11^{abcd}	0.98	3.61^{ef}	36.1
Mat 16 x 16 cm	14.48^{abc}	1.04	3.35^{f}	33.5
Burlap 10 x 12 cm	11.41^{e}	0.79	4.83^{ab}	48.3
Burlap 12 x 14 cm	13.53^{bcde}	0.91	4.28^{cd}	42.8
Burlap 14 x 16 cm	16.04^{a}	1.05	3.89^{de}	38.9
Burlap 16 x 16 cm	15.84^{ab}	1.04	3.49^{ef}	34.9
Shoddy Felt 10 x 12 cm	12.06^{de}	0.69	4.95^{a}	49.5
Shoddy Felt 12 x 14 cm	13.60^{bcde}	0.89	4.39^{bc}	43.9
Shoddy Felt 14 x 16 cm	14.53^{abc}	0.97	3.63^{ef}	36.3
Shoddy Felt 16 x 16 cm	14.83^{ab}	0.93	3.42^{f}	34.2
F-test	*	ns	**	**
CV%	13.09	20.0	16.45	16.45

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

All above data indicated that, different materials of the vertical hydroponics system had no significant effect on some parameters of lettuce growth and yield. This indicates that all three kinds of material, Mat, Burlap, and Shoddy Felt can be used to build vertical hydroponics systems for growing lettuce. In comparison to weight of system, cost of system, evaporates water /m^2,and usableness after one season of system, however, revealed that Mat was the best material to use for the vertical hydroponics system due to its light weight, low cost, low surface evaporation, and especially durability.

Different planting densities had a significant effect on some parameters of lettuce growth and yield. This shows that planting density is a crucial factor affecting the growth and yield of lettuce cultivars when they are grown on vertical hydroponics system. Lettuce with planting densities at 14×16 cm and 16×16 cm gave the highest parameters of lettuce growth, while lettuce with planting densities at 10×12 cm and 12×14 cm brought the highest yield because of large number of plants/m^2. From the above results, the plating densities of 10×12 cm or 12×14 cm is the most suitable for growing lettuce on the vertical hydroponics system to achieve high yield.

4.2 The effect of varieties and cultivation method on the growth, quality and yields of Lettuce by vertical hydroponics system

4.2.1 Stem length

Plant height is an indicator showing the growth ability of lettuce plant. This indicator depends on lettuce varieties and cultivation techniques. Study results about height of three lettuces grown on 3 different methods are shown in Table 4.5.

The recorded data in table 4.5 showed that both of different cultivate methods and varieties had effect on stem length of lettuce through the period of plant growth. This again confirms that cultivate methods and varieties are the important criteria deciding the height of lettuce.

Lettuce grown in hydroponic wick system had the highest stem length at 25, 30, 35, 40 and 45 days after planting. At the time of 45 days after planting, plant height of lettuce grown in the hydroponic wick system reached 21.5 cm. Lettuce grown in soil reached the rank of number two with plant height at harvest of 20.7 cm. Lettuce grown in

Table 4.5 Stem length of lettuce after planting at different cultivation methods and lettuce varieties

Factor	Stem length (cm) after planting (days)				
	25	30	35	40	45
Cultivate method					
Vertical hydroponic system	6.6^{b}	9.3^{b}	13.3^{c}	17.5^{c}	19.4^{c}
Hydroponic wick system	7.3^{a}	10.8^{a}	16.0^{a}	19.8^{a}	21.5^{a}
Growing in soil	6.0^{c}	9.5^{b}	14.8^{b}	18.3^{b}	20.7^{b}
F-test	**	**	**	**	**
CV%	9.32	10.27	8.74	6.34	5.73
Lettuce variety					
Red Rapid	6.9^{a}	10.4^{a}	15.3^{a}	19.0^{a}	21.3^{a}
Romaine	6.3^{b}	9.3^{b}	13.9^{b}	18.2^{b}	19.5^{c}
Grand Rapids Leaf	6.8^{a}	10.0^{a}	14.9^{a}	18.4^{b}	20.8^{b}
F-test	*	**	**	*	**
CV%	7.52	12.42	10.55	8.20	7.45
Cultivate method x variety					
Vertical system x Red Rapid	6.9^{bcd}	10.3^{bc}	14.8^{bcd}	18.6^{bc}	21.1^{b}
Vertical system x Romaine	6.3^{de}	7.8e	11.2^{e}	15.9^{d}	17.2^{d}
Vertical system x Grand Rapids	6.7^{bcde}	9.8ab	14.0^{d}	18.1^{c}	19.9^{c}
Wick system x Red Rapid	7.7^{a}	10.6ab	15.8^{ab}	20.1^{a}	22.0^{a}
Wick system x Romaine	7.1^{abc}	11.2a	16.2^{a}	20.3^{a}	21.3^{ab}
Wick system x Grand Rapids	7.2^{ab}	10.6ab	16.1^{a}	19.1^{b}	21.0^{b}
Growing in soil x Red Rapid	6.1^{ef}	10.2bc	15.3^{abc}	18.4b^{c}	20.8^{b}
Growing in soil x Romaine	5.5^{f}	8.8d	14.4^{cd}	18.3^{bc}	19.9^{c}
Growing in soil x Grand Rapids	6.4^{cde}	9.5cd	14.7^{bcd}	18.1^{bc}	21.3^{ab}
F-test	**	**	**	**	**
CV%	10.59	11.00	10.61	7.10	6.91

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = P ≤ 0.01, * = P ≤ 0.05, ns = non significant

the vertical hydroponic system had the lowest height of just 19.4 cm. The reason causing lettuce grown in the vertical hydroponic system to have lower height than the other methods is high planting density. Besides, the vertical system also makes lettuce to receive low and uneven light, which restricts the development of lettuce height. Durner (1999) and Paraskevopoulou-Paroussi and Paroussis (1995) also reported that, due to low light intensity and uniform light distribution, lettuce grown in the vertical hydroponic system usually had lower height some other development indicators than crops grown on the horizontal plane.

For lettuce varieties joining in the experiment, Rapid Red variety had the highest stem length with plant height of 21.3 cm, followed by Grand Rapids Leaf (20.8 cm) and Romaine variety (19.5 cm). The results from Table 1 also revealed that the interaction between cultivation and lettuce varieties had a highly significant effect on lettuce stem length. Among In particular, Red Rapid and Romaine varieties grown in the hydroponics wick system had the highest stem length. Plant height at harvest reach 21.3-22.0 cm. Grand Rapids variety grown in soil was also relatively high, they reached 21.3 cm at harvest stage.

4.2.2 Number of leaves, plant diameter, leaf area and leaf area index

Different cultivation methods, lettuce varieties and interaction between cultivation and lettuce varieties had a significant effect on the number of leaves, plant diameter, leaf area and leaf area index of lettuce. Red lettuce variety had the highest results in terms of the above indicators compared to other varieties, followed by Romaine variety and Grand Rapids Leaf variety.

In regard to the factor of cultivation method, there are relatively large differences in the number of leaves, plant diameter, leaf area and leaf area index of lettuce between different planting methods. This suggests planting method is a decisive factor to the indicators of lettuce. Lettuce grown in the hydroponic wick system had the highest number of leaves, plant diameter and leaf area. However, the leaf area index of lettuce was the highest for the vertical hydroponic system because of the highest number of plants/m^2. In his study, Johannes Jacobus de Villiers, (2008) also pointed out that, due to the limitations of light and development space, crops grown in the vertical hydroponic system usually had lower number of leaves, plant diameter, leaf area and leaf area index than plants grown on land or on other horizontal planes. However, the vertical hydroponic system had higher leaf area index and yield per unit area because there were more plants per unit area.

Table 4.6 Number of leaves, plant diameter, leaf area and leaf area index of lettuce growing at different cultivation methods and lettuce varieties

Factor	Number of leaves (leaf)	Plant diameter (cm)	Leaf area (m^2)	Leaf area index (m^2 leaf/m^2 land)
Cultivate method				
Vertical hydroponic system	15.54^{c}	14.70^{c}	0.074^{c}	11.89^{a}
Hydroponic wick system	19.99^{a}	19.00^{a}	0.108^{a}	5.40^{b}
Growing in soil	17.47^{b}	18.39^{b}	0.093^{b}	2.32^{c}
F-test	**	**	**	**
CV%	11.46	10.86	18.53	50.75
Lettuce variety				
Red Rapid	18.67^{a}	17.66^{a}	0.098^{a}	7.25^{a}
Romaine	16.40^{c}	17.03^{b}	0.083^{b}	5.52^{b}
Grand Rapids Leaf	17.92^{b}	17.40^{ab}	0.094^{a}	6.84^{a}
F-test	**	*	**	**
CV%	10.73	6.54	20.57	34,63
Cultivate method x variety				
Vertical system x Red Rapid	16.87^{c}	15.63^{d}	0.086^{cd}	13.76^{a}
Vertical system x Romaine	13.87^{e}	13.30^{e}	0.058^{e}	9.23^{b}
Vertical system x Grand Rapids	15.90^{d}	15.17^{d}	0.079^{d}	12.69^{a}
Wick system x Red Rapid	20.47^{a}	18.97^{ab}	0.111^{a}	5.55^{c}
Wick system x Romaine	18.83^{b}	19.87^{a}	0.103^{ab}	5.17^{c}
Wick system x Grand Rapids	20.67^{a}	18.17^{bc}	0.110^{a}	5.48^{c}
Growing in soil x Red Rapid	18.67^{b}	18.37^{bc}	0.097^{abc}	2.43^{d}
Growing in soil x Romaine	16.50^{cd}	17.93^{c}	0.087^{cd}	2.18^{d}
Growing in soil x Grand Rapids	17.20^{c}	18.87^{b}	0.094^{bcd}	2.35^{d}
F-test	**	**	*	**
CV%	12.32	12.24	19.06	65.19

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

The interaction data between cultivating method and lettuce varieties showed that three varieties of lettuce had the highest number of leaves, plant diameter and leaf area when they grown in the hydroponic wick system. But the leaf area index was the highest when those varieties were grown in the vertical hydroponics system.

4.2.3 Total fresh weight, total dry weight, and yield

Productivity is the end result that lettuce growers want to achieve. Beside lettuce varieties, the productivity also depends on the method of cultivation and other farming techniques. Results of productivity of three lettuces grown with three different methods are shown in Table 4.7.

The recorded data in table 4.7 showed that, there was a highly significant effect of cultivation method, lettuce varieties and interaction between cultivation and lettuce varieties on lettuce yield. The recorded data in table 4.7 also showed that lettuce grown in the vertical hydroponics system had the lowest total fresh weight and total dry weight, but the highest total yield because of the highest number of plants/m^2. Lettuce grown in hydroponic wick system had the highest total fresh weight and total dry weight. In the final result, lettuce yield in the vertical hydroponics system was 24.1 tons/ha, in the hydroponic wick system was 10.6 tons/ha, and in soil was 4.8 tons/ha. This again confirms that lettuce grown in the vertical hydroponics system has the highest yield due to its large number of plants per unit area, although this system has lower development indicators than others. According to Durner (1999), the yield/plant decreases on the lower part of the vertical system due to lower light intensity. Leaf number, fresh and dry plant weight, as well as the number of crowns/plant also decreases in the vertical system (Paraskevopoulou-Paroussi and Paroussis, 1995). But Ozeker *et al*. (1999) pointed out that planting density could be increased three times with vertical systems compared to conventional systems, thus the vertical system can be used to grow crops having small size such as lettuce, strawberries with the aim of improving productivity per unit area. In his experiments, Mashego (2001) also showed that lettuce often had higher number of plants per unit area when they were grown in the vertical hydroponic system, which led to higher productivity per unit area. D.C. Mashego (2001) also reported that the lettuce grown in the upper position of the

Table 4.7 Total fresh weight, total dry weight and total yield of lettuce growing at different cultivation methods and lettuce varieties

Treatment	Total fresh weight (g/plant)	Total dry weight (g/plant)	Total yield/m^2 (kg)	Total yield/ha (ton)
Cultivate method				
Vertical hydroponic system	15.06^{c}	0.92^{c}	2.41^{a}	24.1
Hydroponic wick system	21.12^{a}	1.09^{a}	1.06^{b}	10.6
Growing in soil	19.23^{b}	1.01^{b}	0.48^{c}	4.8
F-test	**	**	**	**
CV%	16.67	8.79	42.75	42.75
Lettuce variety				
Red Rapid	18.59^{b}	1.01^{ab}	1.35^{a}	13.5
Romaine	19.29^{a}	1.05^{a}	1.31^{b}	13.1
Grand Rapids Leaf	17.54^{c}	0.96^{c}	1.28^{b}	12.8
F-test	**	**	**	**
CV%	13.19	8.20	9.45	9.45
Cultivate method x variety				
Vertical system x Red Rapid	15.93^{e}	0.97^{bcd}	2.55^{a}	25.5
Vertical system x Romaine	14.13^{f}	0.87^{d}	2.26^{c}	22.6
Vertical system x Grand Rapids	15.10^{e}	0.92^{cd}	2.42^{b}	24.2
Wick system x Red Rapid	20.63^{b}	1.07^{b}	1.03^{e}	10.3
Wick system x Romaine	23.17^{a}	1.22^{a}	1.16^{d}	11.6
Wick system x Grand Rapids	19.57^{c}	0.98^{bc}	0.98^{e}	9.8
Growing in soil x Red Rapid	19.20^{c}	0.99^{bc}	0.48^{f}	4.8
Growing in soil x Romaine	20.53^{b}	1.05^{b}	0.51^{f}	5.1
Growing in soil x Grand Rapids	17.97^{d}	0.97^{bcd}	0.45^{f}	4.5
F-test	**	**	**	**
CV%	15.57	10.72	62.99	62.99

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

vertical hydroponic system tended to develop and weigh more than those in the lower position.

With respect to lettuce varieties, Red Rapid and Romaine varieties had higher lettuce yield in comparison with the Grand Rapids Leaf variety. In the final result, Red Rapid variety achieved a yield of 13.5 tons/ha. Romaine variety reached 13.1 tons/ha, and Grand Rapids Leaf variety reached 12.8 tons/ha.

Data on interaction between two factors showed that Romaine variety grown on wick system had the highest total plant weight. But the total yield was the highest for Red Rapid lettuce grown in the vertical hydroponics system. In general, all the lettuce varieties have higher total yield when they are grown in the vertical hydroponic system, and it is the lowest when lettuce is grown in soil. The Data on interaction between two factors showed more in figure 4.2.

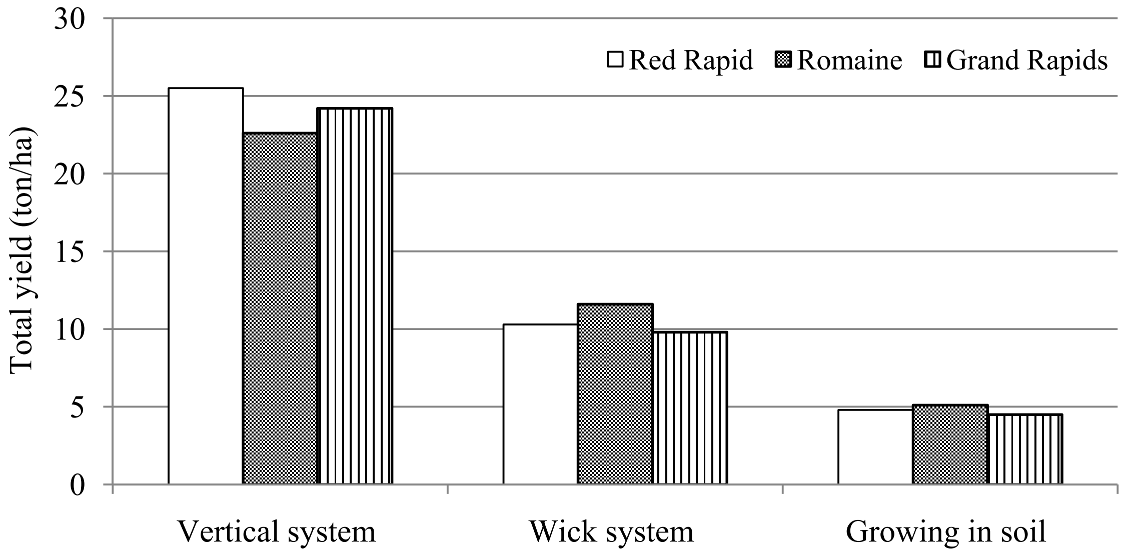

Figure 4.2 Effect of varieties on lettuce total yield/ha grown in three production systems

4.2.4 Ascorbic acid (vitamin C), Vitamin A, nitrate determination and shelf life

Ascorbic acid determination (vitamin C): Ascorbic acid is a sugar acid and there is a positive correlation between ascorbic acid and sugar content in lettuce. In the result of this experiment, cultivation method, lettuce variety and interaction between cultivation method and lettuce variety had a significant effect on vitamin C of lettuce. Romaine lettuce had the highest vitamin C in competition with Red Rapid and Grand Rapids Leaf lettuce. This result is similar to the one of Mou and Ryder(2004). They found that Romaine lettuce had higher vitamin C than other lettuce varieties. Data competition between cultivation methods showed that lettuce grown in the hydroponics wick system had higher vitamin C than other cultivation methods (19.16 mg/100g). This might be related to the high leaf area of lettuce grown in the hydroponics wick system. Ascorbic acid content in lettuce leaves increases under strong light conditions and decreases under weak light or shaded conditions (Hulewicz and Kalbarczyk, 1976; Shinohara and Suzuki, 1981). The increased photosynthetic area and sugar supply might have contributed to the higher vitamin C content in lettuce head. This is also the cause of relatively low vitamin C content (16.79 mg/100 g) of the lettuce varieties when they are grown on vertical hydroponic system.

Vitamin A: Different cultivation method, lettuce varieties and interaction between cultivation and lettuce varieties had a significant effect on vitamin A of lettuce. The Red rapid lettuce had the highest vitamin A in competition with other lettuce varieties and it had the highest vitamin A when it was grown in the hydroponics wick system.

Shelf life: Lettuce grown in the vertical hydroponic system had the time of 10% fresh weight loss lower than other cultivation methods. In terms of lettuce varieties, the data showed that Romaine lettuce had the highest the time of 10% fresh weight loss, and it was highest when lettuce was grown in the hydroponic wick system or in soil.

Nitrate accumulation: At both locations, the interactive effect of Cultivate method and Lettuce variety at harvest (6 weeks after transplanting) on the nitrate accumulation of lettuce heads was highly significant (Table 4.8). The highest nitrate accumulation in lettuce heads was found with lettuce grown in soil while the lowest values were observed with lettuce grown in the vertical hydroponics system. This was because lettuce grown in soil had a lower density than those grown in hydroponic systems. This might be related to the competition effect of higher population. This result agrees with those of Al-Bahash *et al.* (1985) and Esiyok *et al.*(1996) who reported that lower planting density gave the highest nitrate content compared to higher densities. With reference to lettuce varieties, Grand Rapids Leaf had the lowest nitrate accumulation in competition with other varieties.

Table 4.8 Ascorbic acid (vitamin C), Vitamin A, nitrate determination and shelf life of lettuce growing at different cultivation methods and lettuce varieties

Treatment	Vitamin C (mg/100g)	Vitamin A (mg/100 g)	Nitrate accumulation (mg/kg)	Shelf life (day)
Cultivate method				
Vertical hydroponic system	16.79[b]	2.37[b]	638.89[c]	3.22[b]
Hydroponic wick system	19.16[a]	2.58[a]	763.78[b]	3.89[a]
Growing in soil	16.36[b]	2.50[a]	835.11[a]	4.22[a]
F-test	**	**	**	**
CV%	14.32	16.76	13.63	16.78
Lettuce variety				
Red Rapid	16.91[b]	3.11[a]	793.00[a]	3.67[b]
Romaine	19.96[a]	2.53[b]	817.56[a]	4.67[a]
Grand Rapids Leaf	15.43[c]	1.80[c]	627.22[b]	3.00[c]
F-test	**	**	**	**
CV%	12.78	19.85	16.45	23.52
Cultivate method x variety				
Vertical system x Red Rapid	16.17[c]	2.90[c]	681.67[c]	3.33[c]
Vertical system x Romaine	19.20[b]	2.47[d]	675.33[cd]	4.00[bc]
Vertical system x Grand Rapids	15.00[de]	1.73[e]	559.67[e]	2.33[d]
Wick system x Red Rapid	18.73[b]	3.33[a]	792.00[b]	3.67[c]
Wick system x Romaine	21.87[a]	2.57[d]	868.00[a]	4.67[ab]
Wick system x Grand Rapids	16.87[c]	1.83[e]	631.33[d]	3.33[c]
Growing in soil x Red Rapid	15.83[cd]	3.10[b]	905.33[a]	4.00[bc]
Growing in soil x Romaine	18.80[b]	2.57[d]	909.33[a]	5.33[a]
Growing in soil x Grand Rapids	14.43[e]	1.83[e]	690.67[c]	3.33[c]
F-test	**	**	**	**
CV%	13.50	22.6	16.65	24.71

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

4.2.5 Sensory evaluation

To determine whether there was any significant taste of lettuce growing at different cultivation method and lettuce varieties, 30 students were selected, and sensory analysis was carried out by a panel. Table 4.9 shows a comparison of different cultivation method and lettuce varieties on lettuce taste. Minor differences were found in three cultivation methods, lettuce grown in the hydroponics wick system had the highest sensory evaluation, and While Red Rapid lettuce had the highest sensory evaluation in competition to other lettuce varieties.

Table 4.9 Mean taste evaluation of lettuce growing at different cultivation method and lettuce varieties

Lettuce variety	Vertical hydroponic system	Hydroponic wick system	Growing in soil
Red Rapid	3.3	3.5	3.3
Romaine	3.1	3.3	2.6
Grand Rapids Leaf	2.9	3.2	2.9

Means based on 5 point observational scale

4.2.6 Leaf color and chlorophyll content

Leaf color: The color readings (L*,a*, b*) of red rapid, romaine and grand rapids leaf lettuce cultivars were significantly affected by cultivate methods (Table 4.10).

L*: The results shown that L* values in leaf lettuce grown in the vertical hydroponics system were higher than in the hydroponics wick system and soil. Among lettuce varieties, Grand Rapids Leaf lettuce had higher L* values than others.

a*: Red rapid lettuce grown in the hydroponics wick system and in soil had higher a* values than other treatments.

b*: Romaine lettuce grown in the vertical hydroponics system had higher b* values than other treatments.

Table 4.10 Leaf color and chlorophyll content of lettuce growing at different cultivation method and lettuce varieties

Treatment	Leaf color			Chlorophyll
	L*	a*	b*	content(mg/100g)
Cultivate method				
Vertical hydroponic system	47.13[a]	-11.77[a]	27.67[a]	16.28[a]
Hydroponic wick system	42.47[b]	-12.43[b]	24.16[b]	15.34[b]
Growing in soil	42.41[b]	-12.32[ab]	24.04[b]	14.88[c]
F-test	**	**	**	**
CV%	15.23	10.45	18.43	8.45
Lettuce variety				
Red Rapid	34.89[c]	1.21[a]	8.78[c]	13.88[c]
Romaine	44.59[b]	- 19.62[c]	34.42[a]	16.86[a]
Grand Rapids Leaf	52.54[a]	-18.11[b]	32.67[b]	15.77[b]
F-test	**	**	**	**
CV%	19.34	79.43	24.34	12.54
Cultivate method x variety				
Vertical system x Red Rapid	39.56[e]	-1.63[b]	10.93[d]	14.70[e]
Vertical system x Romaine	46.80[c]	-17.76[d]	37.66[a]	17.60[a]
Vertical system x Grand Rapids	55.03[a]	-15.90[c]	34.40[b]	16.53[b]
Wick system x Red Rapid	32.06[f]	2.43[a]	7.70[e]	13.70[f]
Wick system x Romaine	43.56[d]	-20.36[fg]	33.13[bc]	16.67[b]
Wick system x Grand Rapids	51.76[b]	-19.36[ef]	31.63[c]	15.67[cd]
Growing in soil x Red Rapid	33.00[f]	2.83[a]	7.70[e]	13.23[f]
Growing in soil x Romaine	43.40[d]	-20.73[g]	32.46[c]	16.30[bc]
Growing in soil x Grand Rapids	50.83[b]	-19.06[e]	31.96[c]	15.10[de]
F-test	**	**	**	**
CV%	17.85	80.72	47.77	9.22

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

Chlorophyll content: There was a highly significant effect of cultivation method, lettuce varieties and the interaction between cultivation and lettuce varieties had a significant effect on chlorophyll content of lettuce. The recorded data in table 4.10 showed that lettuce grown in the vertical hydroponics system had the highest chlorophyll content. This is because lettuce grown in the vertical hydroponic system receives less light, which results in an increase of chlorophyll content to ensure the process of photosynthesis. Beneragama and Goto (2010) reported that chlorophyll content in leaves would be higher in low light conditions than in strong light conditions.

Concerning varieties in the experiment, Romaine lettuce had the highest chlorophyll content in competition to other varieties.

It can be concluded that different cultivation methods had significant effects on some parameters of lettuce growth, yield and quality. The data showed that, lettuce grown in hydroponics wick system had the highest lettuce growth and quality, but the vertical hydroponic system was the best method for growing lettuce with the yield purposes.

Different lettuce varieties had significant effects on some parameters of lettuce growth, yield and quality. The data revealed that Red Rapid lettuce had the highest lettuce growth, yield and quality.

4.3 Effect of growing media and period of irrigation on growth, quality and yields of Lettuce by vertical hydroponic system

4.3.1 Stem length

Lettuce height was measured every 5 days, which started from the 25th day after sowing. Results are shown in table 4.11. The recorded data in table 4.11 showed that both different growing media and period of irrigation had effect on stem length of lettuce through the period of plant growth.

Lettuce stem length increased with the increase of period of irrigation and was highest with 4 irrigation times/day and lettuce height reached 19.49 cm at harvest. The watering formulas 2 times and 3 times/day gave plant height of 18.11 cm and 18.66 cm, respectively. This suggests that the period of irrigation is one of the important factors affecting plant height of lettuce. Lettuce that is provided with more water is much more

Table 4.11 Stem length of lettuce after planting at different growing media and period of irrigation

Factor	Stem length (cm) after planting (days)				
	25	30	35	40	45
Period of irrigation					
2 time	5.73^{c}	8.16^{b}	12.83^{c}	15.66^{c}	18.11^{c}
3 time	6.21^{b}	8.33^{b}	13.66^{b}	16.06^{b}	18.66^{b}
4 time	6.75^{a}	8.70^{a}	14.38^{a}	16.57^{a}	19.49^{a}
F-test	**	**	**	**	**
CV%	10.45	8.46	13.59	9.49	10.41
Growing media					
Coconut coir	6.72^{a}	8.97^{b}	14.60^{ab}	17.18^{ab}	19.73^{ab}
Carbonized rice husk	6.41^{a}	8.89^{b}	14.14^{b}	16.78^{b}	19.14^{b}
Coconut and carbonized rice husk	6.73^{a}	9.32^{a}	14.88^{a}	17.38^{a}	19.97^{a}
Rock wool	5.07^{b}	6.41^{c}	10.83^{c}	13.04^{c}	16.17^{c}
F-test	**	**	**	**	**
CV%	11.32	15.93	14.33	15.43	15.42
Irrigation x Growing media					
2 time x coconut coir	6.13^{de}	8.83^{bc}	13.67^{cd}	16.70^{b}	19.00^{cd}
2 time x carbonized rice husk	5.97^{ef}	8.70^{c}	13.50^{d}	16.70^{b}	18.60^{d}
2 time x coconut and CRH	6.27^{cde}	9.07^{abc}	14.13^{bcd}	17.00^{b}	19.20^{cd}
2 time x rock wool	4.57^{h}	6.03^{e}	10.03^{f}	12.23^{d}	15.63^{f}
3 time x coconut coir	6.70^{bcd}	8.87^{bc}	14.67^{abcd}	17.03^{b}	19.63^{bcd}
3 time x carbonized rice husk	6.23^{de}	8.87^{bc}	13.97^{bcd}	16.77^{b}	19.00^{cd}
3 time x coconut and CRH	6.83^{abc}	9.37^{ab}	14.87^{abc}	17.33^{b}	19.87^{abc}
3 time x rock wool	5.10^{gh}	6.23^{e}	11.00^{ef}	13.10^{c}	16.13^{ef}
4 time x coconut coir	7.33^{a}	9.20^{abc}	15.47^{a}	17.80^{a}	20.57^{ab}
4 time x carbonized rice husk	7.03^{ab}	9.10^{abc}	14.97^{ab}	16.87^{b}	19.83^{abc}
4 time x coconut and CRH	7.10^{ab}	9.53^{a}	15.63^{a}	17.80^{a}	20.83^{a}
4 time x rock wool	5.53^{fg}	6.97^{d}	11.47^{e}	13.80^{c}	16.73^{e}

Table 4.11 continued

Factor	Stem length (cm) after planting (days)				
	25	30	35	40	45
F-test	**	**	**	**	**
CV%	13.87	14.73	13.82	11.68	9.27

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = P ≤ 0.01, * = P ≤ 0.05, ns = non significant, CRH: carbonized rice husk

likely to develop better in terms of plant height and the number of irrigation 4 times/day does not exceed the amount of water that lettuce needs. The results of this study are not similar to the study of Bozkurt and Mansurolu (2011). According to their studies, they suggest that the increased volume of water used for lettuce may increase a number of indicators of growth and yield of lettuce, but do not affect the height of lettuce. However, study results of Bozkurt and Mansurolu (2009) show some similarities with this study. They studied irrigation levels for lettuce and reported that, when the volume of water used for lettuce increased, the lettuce height would increase proportionally.

For Growing media used, the recorded data in table 4.11 showed that lettuce grown in Coconut mix carbonized rice husk had the highest stem length with a height of 19.97 cm during the harvesting period. Coconut and Carbonized rice husk are also two of the best growing media which can be used to grow lettuce in vertical hydroponic system with lettuce height of 19.14 cm and 19.73cm in harvesting stage. Rock wool is not suitable for the development of lettuce stems length grown in vertical hydroponics system, lettuce height on harvest stage reaches only 16.17 cm.

The results from table 4.11 also revealed that interaction between growing media and period of irrigation had highly significant effect on lettuce stem length. Among them, lettuce grown in Coconut, carbonized rice husk and Coconut mix carbonized rice husk with 4 irrigation times/day had the highest stem length.

4.3.2 Number of leaves, plant diameter, leaf area and leaf area index

Different growing media, period of irrigation and interaction between growing media and period of irrigation had significant effect on the number of leaves, plant diameter, leaf area and leaf area index of lettuce (Table 4.12).

4.3.2.1 Period of irrigation: The data in table 4.12 shows that when watering times/day increase, number of leaves, plant diameter, leaf area and leaf area index of lettuce tend to increase correlatively and reached the highest results with 4 watering times/day In particular, the achieved results in the harvest period are 18.15 leaves/plant, 15.45 cm of plant diameter, 0.078 m^2 of leaf area and 12.53 m^2 leaf/m^2 land of leaf area index. This is due to the increased times of watering, which not only increases the amount of water but also increases nutrient supply for lettuce, this will lead to better performance

Table 4.12 Number of leaves, plant diameter, leaf area and leaf area index of lettuce growing at different growing media and period of irrigation

Factor	Number of leaves (leaves)	Plant diameter (cm)	Leaf area (m^2)	Leaf area index (m^2 leaf/m^2 land)
Period of irrigation				
2 time	17.29^{b}	15.02^{b}	0.069^{b}	11.07^{b}
3 time	17.67^{b}	15.11^{ab}	0.072^{b}	11.48^{b}
4 time	18.15^{a}	15.45^{a}	0.078^{a}	12.53^{a}
F-test	**	**	**	**
CV%	8.45	5.35	12.43	8.75
Growing media				
Coconut coir	18.02^{b}	15.30^{b}	0.076^{b}	12.12^{b}
Carbonized rice husk	17.70^{b}	15.12^{b}	0.074^{b}	11.75^{b}
Coconut and carbonized rice husk	18.84^{a}	15.91^{a}	0.084^{a}	13.49^{a}
Rock wool	16.24^{c}	14.43^{c}	0.059^{c}	9.40^{c}
F-test	**	**	**	**
CV%	12.54	8.45	15.42	13.67

Table 4.12 continued

Factor	Number of leaves (leaves)	Plant diameter (cm)	Leaf area (m^2)	Leaf area index (m^2 leaf/m^2 land)
Irrigation x Growing media				
2 time x coconut coir	17.70^{cd}	15.23^{bcd}	0.072^{d}	11.52^{d}
2 time x carbonized rice husk	17.57^{de}	15.03^{bcd}	0.068^{de}	10.88^{de}
2 time x coconut and CRH	18.23^{bcd}	15.57^{b}	0.080^{bc}	12.85^{bc}
2 time x rock wool	15.67^{g}	14.60^{de}	0.056^{f}	9.013^{f}
3 time x coconut coir	17.83^{cd}	15.23^{bcd}	0.074^{cd}	11.78^{cd}
3 time x carbonized rice husk	17.63^{d}	15.10^{bcd}	0.072^{d}	11.46^{d}
3 time x coconut and CRH	18.87^{ab}	15.73^{ab}	0.084^{ab}	13.44^{ab}
3 time x rock wool	16.33^{fg}	14.00^{e}	0.058^{f}	9.226^{f}
4 time x coconut coir	18.53^{bc}	15.43^{bc}	0.082^{ab}	13.06^{ab}
4 time x carbonized rice husk	17.90^{cd}	15.23^{bcd}	0.081^{bc}	12.90^{bc}
4 time x coconut and CRH	19.43^{a}	16.43^{a}	0.089^{a}	14.18^{a}
4 time x rock wool	16.73^{ef}	14.70^{cde}	0.062^{ef}	9.97^{ef}
F-test	**	**	**	**
CV%	6.34	4.63	14.81	14.81

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant, CRH: carbonized rice husk

of lettuce leaf development. The results of this study are similar to results of Bozkurt and Mansurolu (2009), who reported that the increased volume of water used for lettuce grown on drip irrigation system will also increase the nutrient content for plants, which will increase the indicators number of leaves, plant diameter, leaf area and leaf area index of lettuce. This is also confirmed by Karam*et al*. (2002), who did experiments with drip irrigation watering for lettuce and found that indicators of lettuce leaf increased corresponding to the increase in the quantity of irrigation.

With regard to growing media factor, lettuce grown in coconut mix carbonized rice husk had the highest number of leaves, plant diameter, leaf area and leaf area index. The interaction data between growing media and period of irrigation showed that lettuce with 4 irrigation times/day had the highest number of leaves, plant diameter and leaf area when they grew in coconut mix carbonized rice husk.

4.3.3 Total fresh weight, total dry weight, and yield

The data in table 4.13 shows that, there was high significant effect of period of irrigation on total fresh weight and total yield of lettuce, but not significant effect on total dry weight. The data also shows an increase in total fresh weight and total yield of lettuce when watering times increased from 2 to 4 times/day. During the harvest period, lettuce had the highest total fresh weight and total yield in with 4 watering times/day (total fresh weight reached 15.56 g/plant, total yield reached 2.5 kg/m^2). This result is similar to findings of Karam*et al.* (2002), who argued that the increased quantity of irrigation led to an increase in the total fresh weight and total yield of lettuce due to the increase in volume of water and nutrients for lettuce. Bozkurt and Mansurolu (2009) also confirmed that the increase in watering quantity in the drip irrigation system for lettuce also made the total fresh weight and total yield of lettuce increase proportionally. In his experiments, he also showed that irrigation quantity does not affect the total dry weight of lettuce. Similarly, Gallordo *et al*. (1996) reported that the decrease in water applied from field capacity (FC) to 87% of FC generally did not affect the final dry matter but slightly decrease the fresh weight. They also declared that the mean dry matter production and plant fresh weight for the 45% of FC treatment for the three cultivars in relation to the FC treatment were 72 and 58%, respectively, indicating that the decreased water supply had a greater effect on the fresh weight than on the dry matter. Additionally, Soundy *et al*. (2005) reported that the root dry weights were unaffected by moisture deficit, however shoot dry weight and leaf N content increased with increasing moisture deficit in the growing media and period of irrigation on lettuce total fresh weight. Lettuce grown in coconut, carbonized rice husk, and coconut mix carbonize rice husk with 4 times of irrigation/day had the highest total fresh weight. In relation to total dry weight, the period had no significant effect, but the growing media had a significant effect on lettuce grown in coconut mix carbonized rice husk, which help plants have the highest total fresh weight.

Total yield: The data show that lettuce grown in coconut mix carbonized rice husk with 4 irrigation times/day had the highest total yield.

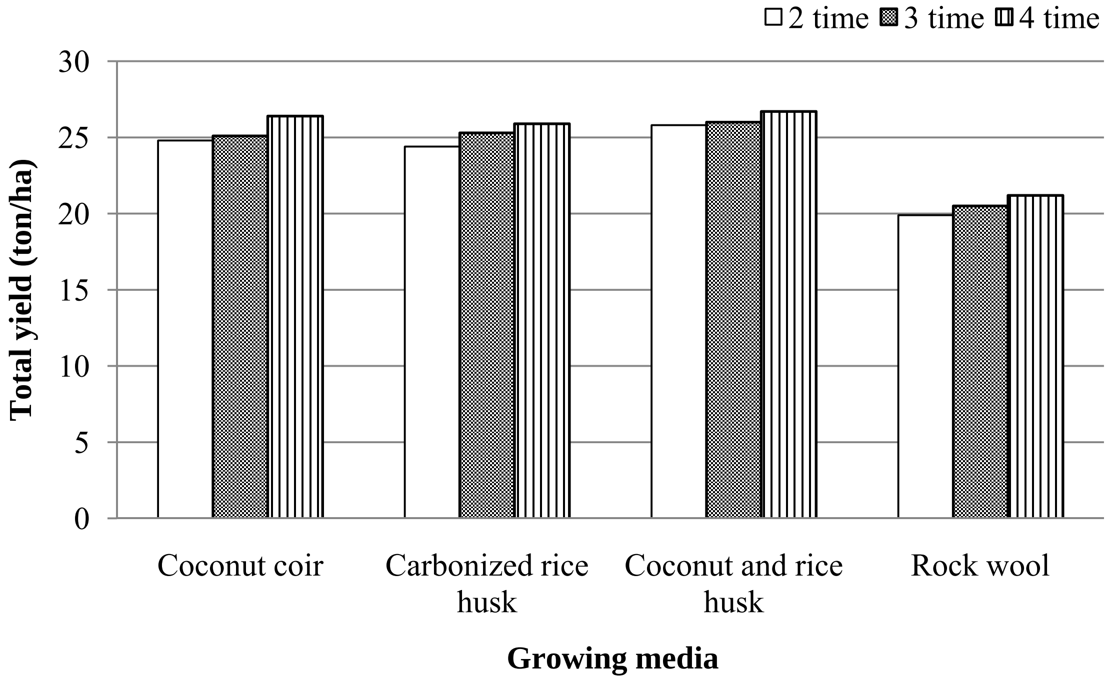

Figure 4.3 Effect of growing media and period of irrigation on lettuce total yield

Table 4.13 Total fresh weight, total dry weight and total yield of lettuce growing at different growing media and period of irrigation

Treatment	Total fresh weight (g/plant)	Total dry weight (g/plant)	Total yield (kg)/m^2	Total yield (ton)/ha
Period of irrigation				
2 time	14.84^{b}	0.85	2.37^{b}	23.7^{b}
3 time	15.15^{b}	0.87	2.42^{ab}	24.2^{ab}
4 time	15.65^{a}	0.88	2.50^{a}	25.0^{a}
F-test	**	ns	**	**
CV%	9.45	6.54	7.62	7.62
Growing media				
Coconut coir	15.90^{ab}	0.92^{b}	2.54^{a}	25.4^{a}
Carbonized rice husk	15.76^{b}	0.91^{b}	2.52^{a}	25.2^{a}
Coconut and carbonized rice husk	16.37^{a}	0.97^{a}	2.62^{a}	26.2^{a}
Rock wool	12.83^{c}	0.67^{c}	2.05^{b}	20.5^{b}
F-test	**	**	**	**
CV%	14.32	15.43	12.47	12.47
Irrigation x Growing media				
2 time x coconut coir	15.53^{cd}	0.91^{c}	2.48^{cd}	24.8^{cd}
2 time x carbonized rice husk	15.27^{d}	0.90^{c}	2.44^{cd}	24.4^{cd}
2 time x coconut and CRH	16.13^{abcd}	0.94^{abc}	2.58^{abc}	25.8^{abc}
2 time x rock wool	12.43^{e}	0.65^{d}	1.99^{ef}	19.9^{ef}
3 time x coconut coir	15.70^{bcd}	0.91^{bc}	2.51^{bcd}	25.1^{bcd}
3 time x carbonized rice husk	15.80^{bcd}	0.91^{bc}	2.53^{bc}	25.3^{bc}
3 time x coconut and CRH	16.27^{abc}	0.98^{ab}	2.60^{ab}	26.0^{ab}
3 time x rock wool	12.83^{e}	0.67^{d}	2.05^{def}	20.5^{def}
4 time x coconut coir	16.47^{ab}	0.94^{abc}	2.64^{ab}	26.4^{ab}
4 time x carbonized rice husk	16.20^{abc}	0.92^{abc}	2.59^{abc}	25.9^{abc}
4 time x coconut and CRH	16.70^{a}	0.99^{a}	2.67^{a}	26.7^{a}
4 time x rock wool	13.23^{e}	0.69^{d}	2.12^{de}	21.2^{de}
F-test	**	**	**	**
CV%	10.11	14.21	13.24	13.24

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant, CRH: carbonized rice husk

4.3.4 Ascorbic acid (vitamin C), Vitamin A, nitrate determination and shelf life

Vitamin C and vitamin A: Results showed that increasing the period of irrigation from 2 times – 4 times/day significantly ($P \leq 0.05$) increased the vitamin C and A content. However, this increase only stops at watering 3 times/day. When the irrigation increase to 4 times/day, the increasing the concentration of vitamin C and vitamin A has no meaning. The results are consistent with studies by Evers (1994) and Sorensen *et al.* (1994), they suggest that the increased quantity of irrigation will lead to the increase in nutrient supply, may have accounted for the response, as excess rates of nitrogen application have also been found to decrease ascorbic acid content in lettuce. The result also showed that there were not significant effect on vitamin C and A between lettuce grown in coconut, carbonized rice husk and coconut mix carbonized rice husk. But it had an effect in competition with lettuce grown in rock wool. Lettuce grown in rock wool had lower vitamin C and A than other growing media.

Nitrate accumulation: At both locations, the interactive effect of period of irrigation and growing media at harvest (6 weeks after transplanting) on the nitrate accumulation of lettuce heads was highly significant (Table 4.14). The highest nitrate accumulation in lettuce heads was found in lettuce grown in coconut and coconut mix carbonized rice husk with 4 times of irrigation/day. The result also showed that increasing the period of irrigation from 2 times – 4 times/day significantly ($P =< 0.01$) increased the nitrate accumulation. This is due to the increased quantity of irrigation, which will lead to increased nutrient supply for lettuce, accompanied by an increase in nitrate supply. The ability to absorb nitrate of plants is unlimited, so formula having many irrigation times will have higher nitrate accumulation than the those with less irrigation times. This was confirmed by Gento (1994), who reported that increasing the supply of nutrients to plants including nitrate will lead to higher nitrate accumulation in lettuce. When Karam*et al.* (2002) did experiments on providing nutrition for lettuce through drip irrigation systems, he reported that increased nutrient supply was a result of increased irrigation quantity, which led to increased levels of nitrate accumulation in lettuce. This result is similar to the study of Sanchez (2000).

Table 4.14 Ascorbic acid (vitamin C), vitamin A, nitrate determination and shelf life of lettuce growing at different growing media and period of irrigation

Treatment	Vitamin C (mg/100g)	Vitamin A (mg/100 g)	Nitrate accumulation (mg/kg)	Shelf life (day)
Period of irrigation				
2 time	16.13^{b}	2.68^{b}	348.7^{c}	4.67^{ab}
3 time	16.71^{a}	2.71^{ab}	431.4^{b}	4.97^{a}
4 time	17.17^{a}	2.73^{a}	520.6^{a}	4.52^{b}
F-test	*	*	**	*
CV%	10.43	7.58	17.45	8.56
Growing media				
Coconut coir	17.19^{a}	2.79^{a}	490.0^{a}	4.48^{b}
Carbonized rice husk	17.08^{a}	2.78^{a}	431.1^{b}	4.62^{b}
Coconut and carbonized rice husk	17.21^{a}	2.83^{a}	479.4^{a}	4.54^{b}
Rock wool	15.19^{b}	2.42^{b}	333.7^{c}	5.24^{a}
F-test	**	**	**	**
CV%	14.37	8.56	20.43	9.53
Irrigation x Growing media				
2 time x coconut coir	16.70^{bcd}	2.77^{b}	387.0^{ef}	4.40^{c}
2 time x carbonized rice husk	16.56^{cde}	2.77^{b}	349.6^{fg}	4.66^{bc}
2 time x coconut and CRH	16.43^{de}	2.79^{ab}	371.0^{ef}	4.53^{bc}
2 time x rock wool	14.80^{f}	2.38^{c}	287.0^{g}	5.10^{ab}
3 time x coconut coir	17.20^{abcd}	2.79^{ab}	483.0^{cd}	4.70^{bc}
3 time x carbonized rice husk	17.13^{abcd}	2.79^{ab}	420.3^{de}	4.90^{abc}
3 time x coconut and CRH	17.40^{abcd}	2.82^{ab}	483.6^{cd}	4.76^{bc}
3 time x rock wool	15.10^{f}	2.43^{c}	338.6^{fg}	5.53^{a}
4 time x coconut coir	17.66^{ab}	2.81^{ab}	600.0^{a}	4.33^{c}
4 time x carbonized rice husk	17.53^{abc}	2.79^{ab}	523.3^{bc}	4.30^{c}
4 time x coconut and CRH	17.80^{a}	2.86^{a}	583.6^{ab}	4.33^{c}
4 time x rock wool	15.66^{ef}	2.45^{c}	375.3^{ef}	5.10^{ab}
F-test	**	**	**	*
CV%	6.75	6.46	23.70	10.31

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant, CRH: carbonized rice husk

Shelf life: Lettuce grown with 4 times of irrigation had the time of 10% fresh weight loss lower than 2 times and 3 times irrigation. In regard to growing media, the data show that there were not any differences in the time of 10% fresh weight loss between lettuce grown in coconut, carbonized rice husk and coconut mix carbonized rice husk. But they had lower time of 10% fresh weight loss than lettuce grown in rock wool. Shelf life of lettuce is an indicator depending on the water content in plants and leaf area. Lettuce having high leaf area, more water content will have less time of 10% fresh weight loss. This has been confirmed by Sanguandeekul (1999). Ryall and Lipton (1979) also said that the time of 10% fresh weight loss depend leaf dry matter percentage.

4.3.5 Sensory evaluation

To determine whether there were any significant taste of lettuce growing at different growing media and period of irrigation, 30 students were selected, and sensory analysis was carried out by a panel. Table 4.15 shows a comparison of different growing media and period of irrigation on lettuce taste. Minor differences were found in table 4.15, lettuce grown in Coconut mix carbonized rice husk had the highest Sensory evaluation. While increasing the period of irrigation from 2 times – 4 times/day increased the lettuce taste.

Table 4.15 Mean taste evaluation of lettuce grown at different growing media and period of irrigation

Growing media	2 time	3 time	4 time
Coconut coir	3.1	3.4	3.5
Carbonized rice husk	3.0	3.4	3.4
Coconut and carbonized rice husk	3.2	3.5	3.6
Rock wool	2.6	2.8	2.8

Means based on 5 point observational scale

4.3.6 Leaf color and chlorophyll content

Leaf color: There was a significant effect of growing media on a* values, but it did not affect L* and b* values. Among growing media, the data shown that, there was an effect on L* and a* values, but not significant effect on b* values.

Table 4.16 Leaf color and chlorophyll content of lettuce grown at different growing media and period of irrigation

Treatment	Leaf color			Chlorophyll content
	L*	a*	b*	(mg/100g)
Period of irrigation				
2 time	36.44	-1.42[a]	12.21	14.45[b]
3 time	36.93	-1.58[ab]	13.00	15.10[a]
4 time	37.72	-1.75[b]	13.23	15.38[a]
F-test	ns	**	ns	**
CV%	5.46	9.56	9.43	7.65
Growing media				
Coconut coir	37.50[a]	-1.66[b]	13.67	15.20[a]
Carbonized rice husk	36.71[ab]	-1.65[b]	12.94	15.26[a]
Coconut and carbonized rice husk	37.92[a]	-1.72[b]	11.53	15.56[a]
Rock wool	35.98[b]	-1.29[a]	13.18	13.90[b]
F-test	*	**	ns	**
CV%	8.56	12.47	10.45	9.45
Irrigation x Growing media				
2 time x coconut coir	36.96	-1.46[abc]	13.76	14.66[cde]
2 time x carbonized rice husk	36.70	-1.50[a-d]	13.23	14.66[cde]
2 time x coconut and CRH	37.06	-1.50[a-d]	9.00	14.83[cd]
2 time x rock wool	35.03	-1.20[a]	12.83	13.63[f]
3 time x coconut coir	37.73	-1.66[b-e]	13.30	15.23[bc]
3 time x carbonized rice husk	36.16	-1.63[b-e]	12.96	15.26[bc]
3 time x coconut and CRH	37.56	-1.76[cde]	12.60	15.70[ab]
3 time x rock wool	36.23	-1.26[a]	13.13	14.20[def]
4 time x coconut coir	37.80	-1.86[e]	13.93	15.70[ab]
4 time x carbonized rice husk	37.26	-1.83[de]	12.63	15.83[ab]

Table 4.16 continued

Treatment	Leaf color			Chlorophyll content
	L*	a*	b*	(mg/100g)
4 time x coconut and CRH	39.13	-1.90[e]	13.00	16.13[a]
4 time x rock wool	36.66	-1.40[ab]	13.56	13.86[ef]
F-test	ns	**	ns	**
CV%	4.69	18.52	20.26	5.93

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = P ≤ 0.01, * = P ≤ 0.05, ns = non significant, CRH: carbonized rice husk

Chlorophyll content: There was a highly significant effect on growing media and period of irrigation and interaction between growing media and period of irrigation on chlorophyll content of lettuce. The recorded data in table 4.16 show that lettuce grown in coconut, carbonized rice husk and coconut mix carbonized rice husk with 4 times of irrigation had the highest chlorophyll content. The increased chlorophyll content in lettuce tends to increase with the increase in the number of watering times per day. The cause of this is due to the increased amount of nutrients in the process of increasing the amount of irrigation water. These results are consistent with the findings of Fallovo *et al*. (2009). Chiloane (2012) also reported that the increased nutrient content made the chlorophyll content of lettuce increase as well Fallovo *et al*. (2009) also confirmed this in his experiments.

All above data indicated that, different growing media had a significant effect on some parameters of lettuce growth, yield and quality. The data show that red lettuce grown in coconut mix carbonized rice husk had the highest lettuce growth, yield and quality

Different period of irrigation had a significant effect on some parameters of lettuce growth, yield and quality. The data revealed that increasing the period of irrigation from 2 times – 4 times/day increased the lettuce growth, yield and quality, but this increase was not significant. Therefore the growers can choose the number of period of irrigationis2times/day to reduce costs.

4.4 The effect of Electrical Conductivity (EC) of the Nutrient Solution on the growth, quality and yields of Lettuce by vertical hydroponic system

4.4.1 Stem length

Plant height is an indicator showing growth ability of lettuce. This indicator depends on lettuce varieties and cultivation techniques, in which the EC of the nutrient solution is an important indicator affecting this indicator. Research results of lettuce height at five EC levels of the nutrient solution are shown in table 4.17.

Table 4.17 Stem length of lettuce at different Electrical Conductivity

Factor	Stem length (cm) after planting (days)				
	25	30	35	40	45
EC= 0.5	6.77	7.76^{b}	11.36^{c}	14.20^{c}	15.80^{c}
EC= 1	6.80	7.77^{b}	12.23^{c}	14.60^{bc}	16.63^{c}
EC= 1.5	7.00	8.17^{b}	13.63^{b}	15.60^{b}	18.60^{b}
EC= 2	7.10	9.26^{a}	15.03^{a}	17.23^{a}	20.43^{a}
EC= 2.5	7.30	9.63^{a}	15.76^{a}	17.70^{a}	21.63^{a}
F-test	ns	*	**	**	**
CV%	5.19	10.59	13.08	9.90	12.77

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

The data recorded in table 4.17 showed that different EC levels of nutrient solution did not affect lettuce height in the period of 25 days after planting, but have an impact on lettuce height in the period of 30 - 45 days after planting. This suggests that, when lettuce are still young, the needs for nutrients is not really significant, so low level of EC is still capable of providing nutrition for lettuce. However, when lettuce grows older, low EC levels are not able to provide nutrition for lettuce to develop in relation to height due to higher nutrient demand.

The data in table 4.17 also shows that, when the EC of the nutrient solution increased from 0.5 - 2.5, the height of lettuce tended to increase. But this increase stopped at EC = 2.0, and the lettuce height did not increase significantly when the EC continued to increase up to 2.5. This suggests that the EC = 2 is the level that provides enough nutrition for lettuce to grow in terms of height. The results are consistent with the research of U.C. Samarakoon (2006), who did experiments on growing lettuce at the EC level of 1.4, 2.0 and 3.0 and reported that lettuce height increased as the EC increased from 1.4 to 2.0. But when the EC continued to increase up to 3.0, the lettuce height did not increase further. TS Chiloane (2012) also said that lettuce height seemed to increase when the EC of the nutrient solution increased from 1 to 4, but this increase stopped at EC = 3.

4.4.2 Number of leaves, plant diameter, leaf area and leaf area index

Leaves are usable parts of lettuce, so the development of the leaf will decide lettuce yield. Besides, the leaves are the photosynthetic organelles of the plants, which decide the development of lettuce. Results of collecting data on indicators of lettuce leaf at different EC levels are shown in table 4.18.

The data in table 4.18 show that EC levels of different the nutrient solutions significantly affect the indicators: number of leaves, plant diameter, leaf area, and leaf area index of lettuce grown in the vertical hydroponic system. This suggests that the EC of the nutrient solution is an important factor in determining the development of these indicators.

4.4.2.1 Number of leaves/plant: The data indicate that increasing the EC of the nutrient solution from 0.5 to 2.5 causes the number of leaves of lettuce to increase proportionally and they achieve the highest quantity at the EC of 2.0-2.5. Total number of leaves during the harvest period at these two EC levels was 18.93 and 19.46 leaves/plant. This result is opposite to findings of U.C. Samarakoon (2006), who reported that the increasing EC level of nutrient solution from 0.5 to 1.0 and 2.0 caused the number of lettuce leaves to decrease. TS Chiloane (2012) also said that there are no significant differences in lettuce leaves when they were grown at EC level of 1, 2, 3 and 4. However, the result is similar to study of Sunlarp Sanguandeekul (1999). He grew lettuce at the EC level of the nutrient solution 0.5, 1.5, 2.5 and 3.5 and he believed increasing EC level would increase the number lettuce leaves.

4.4.2.2 Plant diameter: There is a significant difference in diameter of lettuce at different EC levels of nutrient solution. The data indicate that plant diameter of lettuce tended to increase when EC increased from 0.5 - 2.5. But this increase stopped at EC = 2.0. This suggests that the EC = 2.0 is appropriate for the diameter development of lettuce. At harvest period, plant diameter of lettuce grown at EC = 2.0 reached 14.26 cm, which was 3.86 cm higher than those grown at EC = 0.5.

4.4.2.3 Leaf area and Leaf area index: there was significant difference in leaf area between different treatments. There was a tendency of increasing leaf area with increasing nutrient solution concentration (Table 4.18). The highest leaf area was obtained from plants grown at EC levels (nutrient concentrations) of 2 and 2.5 mS/cm. This result is consistent with the research of Chiloane (2012), who reported that leaf area and leaf area index of lettuce peaked at EC level from 2 to 3 mS/cm. This is also consistent with a test conducted by Fallovo *et al*. (2009) who found that fresh yield, leaf area and leaf area index of lettuce significantly reduced at extremely low or high EC level.

Table 4.18 Number of leaves, plant diameter, leaf area and leaf area index of lettuce growing at different Electrical Conductivity

Factor	Number of leaves (leaves)	Plant diameter (cm)	Leaf area (m^2)	Leaf area index (m^2 leaf/m^2 land)
EC = 0.5	11.70^{d}	10.40^{c}	0.052^{c}	8.32
EC = 1.0	14.23^{c}	12.40^{b}	0.067^{b}	10.72
EC = 1.5	17.06^{b}	12.80^{b}	0.076^{ab}	12.16
EC = 2.0	18.93^{a}	14.26^{a}	0.083^{a}	13.28
EC = 2.5	19.46^{a}	14.60^{a}	0.085^{a}	13.6
F-test	**	**	**	--
CV%	19.31	12.88	18.09	--

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = P ≤ 0.01, * = P ≤ 0.05, ns = non significant

4.4.3 Total fresh weight, total dry weight, and yield

Productivity is the end result that the lettuce growers desire to achieve. In addition to depending on lettuce varieties, the yield of lettuce also depends on cultivation method and the ability to provide nutrition. Study results of productivity of lettuce grown in the different EC levels of nutrient solution are shown in table 4.19.

The recorded data in table 4.19 show that, there was a highly significant effect of EC level of nutrient solution on lettuce yield characters. The data in table 4.19 also show that increasing the level of EC led to a corresponding increase in total fresh weight, dry weight and total yield of lettuce and they peaked at EC = 2 and 2.5. The end result indicates that lettuce yield reached 27.5 tons/ha at EC = 2.5, which was 10.9 tons higher than that at EC = 0.5.

This result is consistent with studies of Sanguandeekul (1999), who reported that increasing EC made the fresh weight of lettuce increase, but this increase leveled off at EC = 1.5. If the EC level continues to increase, the fresh weight of lettuce stops increasing but even shows a decrease trend. Morgan *et al.* (1980 b) also reported that lettuce can be grown at the EC level up to 5 mS/cm, but the most optimal level is 2 mS/cm. Economakis (1990) proposed that lettuce could be grown at EC from 1.5 - 5.5 mS/cm, but plants would achieve the highest yield at EC of 2-3 mS/cm. Chiloane (2012) also reported that lettuce yield peaked when they were grown at EC of 2 to 3 mS/cm, and lettuce yield tended to decrease at lower or higher EC level.

Many studies have also shown that lettuce grown at high EC levels can reduce the development ability and yield of lettuce (Terry *et al.*, 1983; Longnecker, 1994, AI-Harbi, 1994). The reason is that high levels of EC will reduce the permeability of the cell, which would reduce the ability of plants to absorb water. This is also consistent with a test conducted by Fallovo *et al.* (2009) who found that fresh and dry yield of lettuce significantly reduced at extremely low (0.5 mS/cm) or high EC level (> 4 mS/cm).

Table 4.19 Total fresh weight, total dry weight and total yield of lettuce growing at different Electrical Conductivity

Treatment	Total fresh weight (g/plant)	Total dry weight (g/plant)	Total yield /m^2 (kg)	Total yield /ha (ton)
EC=0.5	10.40^{c}	0.57^{d}	1.66	16.6
EC=1	13.56^{b}	0.69^{c}	2.17	21.7
EC=1.5	14.86^{b}	0.80^{b}	2.38	23.8
EC=2	16.66^{a}	0.89^{ab}	2.67	26.7
EC=2.5	17.20^{a}	0.91^{a}	2.75	27.5
F-test	**	**	--	--
CV%	17.88	17.97	--	--

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD) at P** = 0.01, P* = 0.05, ns = non significant

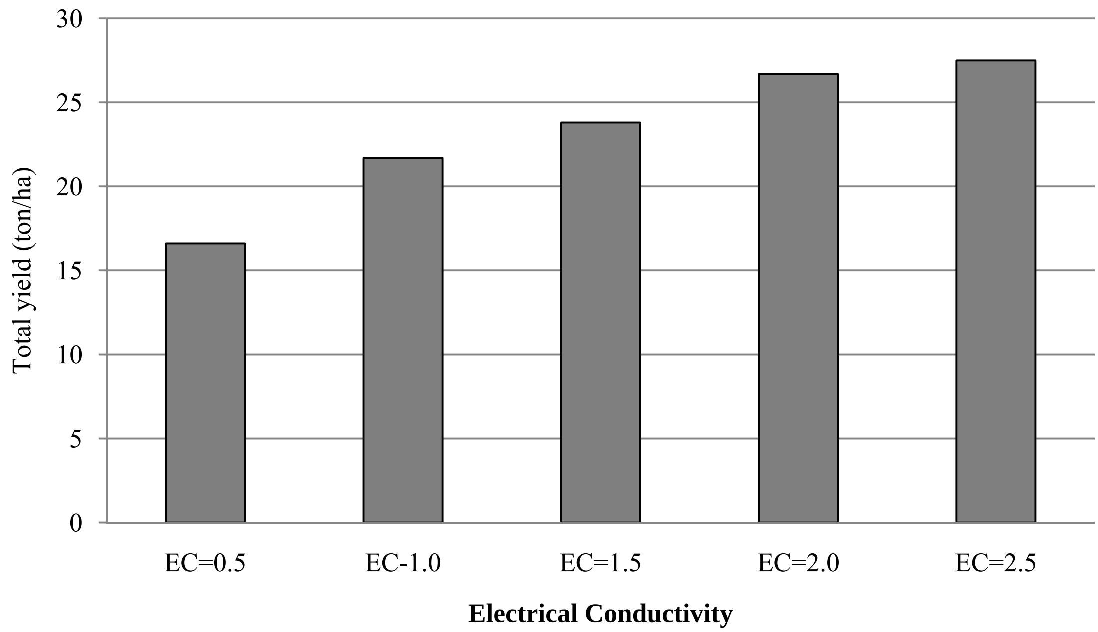

Figure 4.4 Effect of electrical conductivity on lettuce total yield

4.4.4 Ascorbic acid (vitamin C), Vitamin A, nitrate determination and shelf life

4.4.4.1 Vitamin C: Vitamin C content (Ascorbic acid) in lettuce leaves tends to be highest at EC levels 1 and 1.5 mS/cm. At lower (0.5) or higher (2.0 and 2.5 mS/cm) EC level, vitamin C content in lettuce leaves tends to fall. In his experiment, Sunlarp Sanguandeekul (1999) also reported that vitamin C content of lettuce hit the highest level when they were grown at the EC level of the nutrient solution 1.5. At EC higher or lower level, the vitamin C content of lettuce had a decrease trend.

4.4.4.2 Sensory evaluation: Consumers tend to prefer the lettuce grown at EC 1.5 and 2 mS/cm. The reason is that lettuce grown at these EC levels has beautiful color, large stem size. For lettuce grown at EC of 2.5, they have quite bitter taste, so some consumers seem not to prefer this kind of lettuce.

4.4.4.3 Nitrate accumulation: Nitrate accumulation in vegetable crops is of concern because of the potential conversion to nitrite after uptake which can cause methemoglobinemia in infants and because it is a precursor of nitrosamines, which are carcinogenic (Addiscott *et al*., 1991). The European standards for nitrate concentration under Belgian and Dutch climatologically conditions (from 1/1/98) is 3,500 ppm NO_3 per kg, fresh head lettuce weight from 1/1 1 to 30/4 and 2,500 from 11/5 to 31/10 (Benoit and Ceustennans, 1995).

The research results of nitrate accumulation in lettuce leaves grown at different EC levels of nutrient solution are shown in table 4.20. Results in table 4.20 shows that different EC levels of nutrient solution influence significantly nitrate accumulation of lettuce. The law of impact is that increasing the EC will cause nitrate accumulation in lettuce leaves to increase and reach the highest level at EC 2.5 mS/cm (644.6 mg/kg). This result is consistent with the results of the study performed by Sanguandeekul (1999), who argued that the increased EC levels of hydroponic nutrient solution led to a corresponding increase in the nitrate accumulation in lettuce leaves.

Table 4.20 Ascorbic acid (vitamin C), Sensory evaluation, nitrate determination and shelf life of lettuce growing at different Electrical Conductivity

Treatment	Vitamin C (mg/100g)	Sensory evaluation	Nitrate accumulation (mg/kg)	shelf life (day)
EC= 0.5	15.33[c]	2.5	241.3[d]	3.20[b]
EC= 1	17.30[ab]	3.1	306.3[cd]	3.30[b]
EC= 1.5	17.76[a]	3.4	358.6[c]	3.76[ab]
EC= 2	16.76[b]	3.6	489.0[b]	4.00[a]
EC= 2.5	15.70[c]	3.2	644.6[a]	4.16[a]
F-test	**	--	**	*
CV%	6.42	--	37.09	12.84

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

4.4.4.4 Shelf life: the time of 10% fresh weight loss increased with increasing nutrient solution concentration (table 4). However, this increase was not significant between the EC 0.5 and 1 mS/cm, EC 1.5 - 2 and 2.5 mS/cm. The reason leading to the time of 10% fresh weight loss increased with increasing nutrient solution concentration is because lettuce grown at high EC has high leaf dry matter percentage. This has been confirmed by Sunlarp Sanguandeekul, 1999. Ryall and Lipton (1979) also said that the time of 10% fresh weight loss depended on leaf dry matter percentage.

4.4.5 Leaf color and chlorophyll content

4.4.5.1 Leaf color: No significant differences were found in terms of lettuce color. The color of the lettuce samples was described as ranging from normal lettuce color, pale green to dark green. The color differences are related to higher chlorophyll content due to increased nutrient solution concentration treatments. Chiloane (2012) also reported that leaf color lettuce became more dark green when EC levels of nutrient solution increased. This is due to the increase of the concentration of chlorophyll content. Fallovo *et al.*(2009) also reported that the a* value (greenness) of lettuce tended to increase with the increase of the EC of the nutrient solution.

4.4.5.2 Chlorophyll content: There was a significant increase of the chlorophyll content with increasing EC levels of the nutrient solution concentrations, with the highest chlorophyll concentration observed at EC 1.5, 2 and 2.5 mS/cm. These results are consistent with the findings of Fallovo *et al.* (2009). Chiloane (2012) also reported that the increased level of nutrient solution EC, the chlorophyll content of lettuce tend to increase and reached the highest level of EC from 2 to 3 mS/cm. Fallovo *et al.* (2009) also said that the chlorophyll content in lettuce leaves tended to increase when EC level of nutrient solution increased.

Table 4.21 Leaf color and chlorophyll content of lettuce grown at different Electrical Conductivity

Treatment	Leaf color			Chlorophyll content
	L*	a*	b*	(mg/100g)
EC= 0.5	35.83	-1.34[a]	12.90	13.40[b]
EC= 1	36.73	-1.35[a]	11.66	14.20[b]
EC= 1.5	36.66	-1.39[ab]	13.10	15.90[a]
EC= 2	37.26	-1.43[b]	12.96	16.16[a]
EC= 2.5	37.70	-1.46[b]	13.30	16.36[a]
F-test	ns	*	ns	**
CV%	3.62	4.36	8.33	8.75

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant

It can be concluded that the ability to grow, yield and quality of lettuce grown in vertical hydroponic systems were significantly affected by nutrient solution concentrations (EC). The results also indicated that increasing the fertilizer concentration increased plant growth parameters, yield and quality of lettuce. The use of nutrient solution concentrations of 2 mS/cm to grow lettuce in vertical hydroponic systems is considered to bring the best productivity, quality and efficiency.

4.5 The effect of the ratio of compost extract in chemical solution nutrient on growth, quality and yields of Lettuce by vertical hydroponic system

4.5.1 Stem length

Plant height is an indicator showing growth ability of lettuce. This indicator depends on lettuce varieties and cultivation techniques, in which the nutrient solution supplied for plants is an important factor affecting this indicator. Research results of lettuce height from 6 experimental formulas are shown in table 4.22.

The recorded data in table 4.22 show that different combinations of compost extract and chemical nutrient in hydroponic nutrient solution have significant influence on lettuce height in all growth stages. The rule of this effect is that the height of lettuce tends to increase with formula having a low proportion of compost extract and peak at the formula having the rate of 1/5 compost extract + 4/5 chemical nutrient solution (plant height reached 20.60 cm during the harvest stage). The formula using 100% compost extract produces the lowest plant height in all stages of growth, in which plant height only reaches 16.43 cm at harvest stage. The reason for this is that despite the high content of enzyme, vitamin and growth stimulants, the concentration of mineral nutrients in the compost extract is relatively low and unbalanced. Therefore, the formula using 100% compost extract or high rate of compost extract will not supply enough nutrients for lettuce to grow in terms of height. These study results are consistent with the findings of Hosseny and Ahmed (2009). They concluded that using only organic fertilizers would not be sufficient for plants to develop their height. Plant height would grow faster when the nutrients were supplied through a mixture of organic manure and chemical fertilizers. They also pointed out that the plant height largely depended on the protein content in chemical fertilizers. This is also confirmed by Shafshak and Abo-Sedera (1990).

The results in table 4.22 also show that, lettuce height with formula using 100% chemical nutrient solution is relatively high, but still less than that using the mixture of 1/5 compost extract + 4/5 chemical nutrient solution. This suggests that the presence of compost extract had an impact on the development of lettuce height. The improvement resulting from using bio-fertilization with lettuce plant, leading to increase in plant growth was presented by many workers such as, Brown (1974), Carletti *et al*.

(1996) and Lazarovits and Nowak (1997). Also, the improving in plant growth associated with a decrease in N level. The decrease of N application with used organic or bio-fertilizer was reported in many investigations such as Agwah and Shahaby (1993) and El-Gamal (1996).

Table 4.22 Effect of the ratio of compost extract in chemical solution nutrient on lettuce stem length

Treatment	Stem length (cm) after planting (days)				
	25	30	35	40	45
1/2 CX + 1/2 CNS	6.63[b]	8.54[c]	11.23[c]	14.12[c]	17.21[cd]
1/3 CX + 2/3 CNS	6.77[b]	8.76[bc]	11.36[bc]	14.20[c]	17.80[bc]
1/4 CX + 3/4 CNS	6.54[b]	8.77[bc]	12.23[abc]	15.60[bc]	18.63[b]
1/5 CX + 4/5 CNS	7.14[ab]	9.17[ab]	13.63[a]	17.60[a]	20.60[a]
100% CX	5.10[c]	7.26[d]	11.03[c]	14.23[c]	16.43[d]
100% CNS (control)	7.56[a]	9.63[a]	12.76[ab]	16.70[ab]	18.83[b]
F-test	**	**	**	**	**
CV%	12.44	9.35	9.60	9.94	8.14

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant, CX: compost extract, CNS: chemical nutrient solution

4.5.2 Number of leaves, plant diameter, leaf area and leaf area index

Leaves are usable parts of lettuce, so the development of the leaves will determine the productivity of lettuce. Besides, they are also the photosynthesis organ of the plant, and is the part determining the development of lettuce. Collected results of some indicators of lettuce leaves at different mixes of organic and chemical fertilizers are shown in table 4.23.

The data in table 4.23 show that different levels of mixing organic and chemical fertilizers significantly affect the number of leaves, Plant diameter, Leaf area, and Leaf area index of lettuce grown with vertical hydroponic method.

4.5.2.1 Number of leaves/plant: The data show that when the rate of compost extract in hydroponic nutrient solution is reduced, the number of leaves/plant of lettuce tends to increase and reach the highest level at the mixing level of 1/5 compost extract + 4/5 chemical nutrient solution. Like plant height, lettuce needs much nutrient for leaf development, so lettuce has lower number of leaves with formulas using 100% compost extract or high proportion of compost extract than those using formulas with high portion of chemical nutrient solution. The results are consistent with that of Gardener and Pew (1974) who presented that leaf formation depended on N supply. Ahmed *et al*. (2000) found that lettuce plant treated with nitrobien as a bio-fertilizer showed significant increases in shoot height, number of leaves and fresh weight, while there are significant decreases for lettuce treated with microbien.

4.5.2.2 Plant diameter: There is a significant difference in the diameter of lettuce for different experimental formulas. The comparison between the levels of mixing organic manure and chemical fertilizers showed that the diameter of lettuce increased with the formula having high levels of chemical fertilizers. The final results represented that the diameter of lettuce reached the highest level with the formula using a mix of 1/5 compost extract + 4/5 chemical nutrient solution and formula using 100% chemical nutrient solution. The formulated using 100% compost extract is still the one resulting in lowest plant diameter. This again confirms that chemical nutrient solution is the determining factor in the development and indicators of lettuce leaves. This result is consistent with the findings of Hosseny and Ahmed (2009). They said that when mixing compost and chemical fertilizer to fertilize the plants, plant diameter of lettuce increased a little, but not significantly, the diameter of lettuce almost exclusively depended on the concentration of chemical fertilizers supplied for lettuce. This is also confirmed in the study by Pew *et al*. (1984), Abdel-Razik and Barakat (1990), Walworth *et al*. (1992) and Moussa *et al*. (1993).

4.5.2.3 Leaf area and Leaf area index: There was significant difference in leaf area and leaf area index among the different ratios of compost extract in chemical solution nutrient. Leaf area and leaf area index of lettuce was found to be highest in the formula using 1/5 compost extract + 4/5 chemical nutrient solution, followed by the formula using 100% chemical nutrient solution. The formulas using high concentrations of organic fertilizer resulted in a relatively low leaf area and leaf area index. This result suggests that mixing compost extract and chemical fertilizer with a low rate of compost will promote the growth of leaf area and leaf area index of lettuce. Seçkin Kaya *et al*. (2008), also reported that the exclusive use of organic fertilizers will not supply enough nutrients for plants to develop in terms of leaves. Plants grown with the formulas using organic manures have poorer indicators of leaves than formulas using chemical fertilizers. This comment was also checked and confirmed by Dias *et al*. (2009) and Ahmed *et al*. (2000).

Table 4.23 Effect of the ratio of compost extract in chemical solution nutrient on number of leaves, plant diameter, leaf area and leaf area index of lettuce

Factor	Number of leaves (leaves)	Plant diameter (cm)	Leaf area (m^2)	Leaf area index (m^2 leaf/m^2 land)
1/2 CX + 1/2 CNS	17.24[c]	12.11[c]	0.060[e]	8.40
1/3 CX + 2/3 CNS	17.70[bc]	12.43[c]	0.062[d]	8.68
1/4 CX + 3/4 CNS	18.23[ab]	13.48[b]	0.071[c]	9.94
1/5 CX + 4/5 CNS	19.06[a]	14.21[a]	0.079[a]	11.06
100% CX	15.93[d]	12.14[c]	0.058[f]	8.12
100% CNS (control)	18.46[ab]	14.16[a]	0.074[b]	10.36
F-test	**	**	**	--
CV%	6.29	7.41	12.45	--

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant, CX: compost extract, CNS: chemical nutrient solution

4.5.3 Total fresh weight, total dry weight, and yield

Productivity is the end result that the lettuce growers desire to achieve. In addition to depending on lettuce varieties, the yield of lettuce also depends on cultivation method and the ability to provide nutrition. Study results of productivity of lettuce grown in different levels of mixing organic and chemical fertilizers are shown in table 4.24.

The data in table 4.24 show that different levels of mixing organic and chemical fertilizers have significant impact on indicators related to the productivity of lettuce. The rule of this impact is that the productivity indicators of lettuce (total fresh weight, total dry weight, and yield) have a tendency to increase with the formula using low concentrations of organic fertilizers. The results also show that lettuce treated with 100% chemical nutrient solution have relatively high productivity indicators (rank No. 2 among the experimental formulas involved), but still lower than the formula using the ratio of 1/5 compost extract + 4/5 chemical nutrient solution. This suggests that mixing a small amount of organic fertilizers with chemical fertilizers will promote the development of productivity indicators of lettuce. Dias *et al*. (2009) studied the effect of mixing ratio between organic manure and mineral fertilizers. Results showed that, due to high nutrient content, lettuce grown with the formula using only mineral fertilizer or high rate of mineral fertilizers had better indicators related to productivity. This is also confirmed by Paudel *et al*. (2004) when they performed experiments of fertilizing chickens and duck poop for lettuce plants. They reported that lettuce produced higher productivity when chicken and duck poop were mixed with chemical fertilizers in comparison with the case of chicken and duck manure alone. Similar results were also reported by many investigators with respect to the reduction of N fertilization through the use of bio-fertilizer inoculation such as Kumaraswamy and Madalaggeri (1990) and El-Gamal (1996). There were many investigations presenting the increases in lettuce yield due to N application (Richared*et al*. 1985; Sanchez *et al*., 1989a; Custic *et al*. 1994). Pandy and Kumar (1989) reported that the increases in yield in lettuce plants related to bio-fertilizer not only due to the beneficial effects of the bacterial and their N fixation capacity, but also because of their ability to produce antibacterial and antifungal compounds, growth hormones and siderophores. Also, there were many workers presenting the increases in yield obtained as a results of different biofertilizers inoculation such as Azcon *et al*. (1996) on lettuce, El-Gamal (1996) on potatoes and Wange (1996) on carrot.

Table 4.24 Effect of the ratio of compost extract in chemical solution nutrient on total fresh weight, total dry weight and total yield of lettuce

Treatment	Total fresh weight (g/plant)	Total dry weight (g/plant)	Total yield /m^2 (kg)	Total yield /ha (ton)
1/2 CX + 1/2 CNS	15.12^{c}	0.73^{de}	2.11	21.1
1/3 CX + 2/3 CNS	15.34^{c}	0.79^{cd}	2.14	21.4
1/4 CX + 3/4 CNS	16.43^{b}	0.85^{bc}	2.30	23.0
1/5 CX + 4/5 CNS	17.32^{a}	0.93^{a}	2.42	24.2
100% CX	12.43^{d}	0.67^{e}	1.74	17.4
100% CNS (control)	16.84^{ab}	0.91^{ab}	2.35	23.5
F-test	**	**	--	--
CV%	10.83	12.39	--	--

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = P ≤ 0.01, * = P ≤ 0.05, ns = non significant, CX: compost extract, CNS: chemical nutrient solution

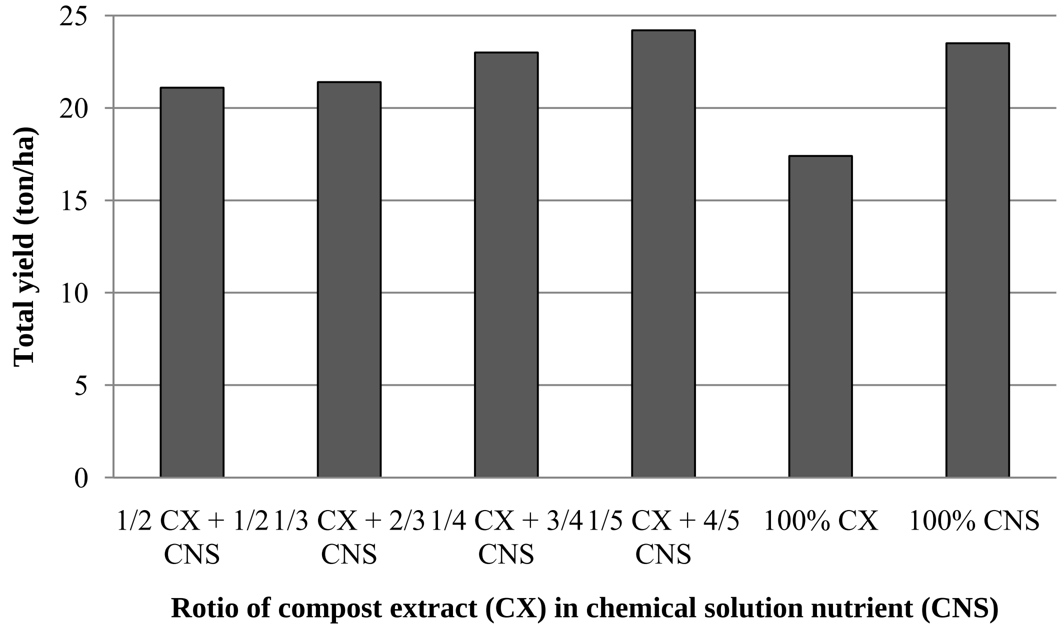

Figure 4.5 Effect of the ratio of compost extract in chemical solution nutrient on lettuce total yield

4.5.4 Ascorbic acid (vitamin C), nitrate determination and shelf life.

4.5.4.1 Vitamin C: Vitamin C content (ascorbic acid) in lettuce leaves tend to slightly increase in accordance with the concentrations of mineral fertilizers in hydroponic nutrient solution. However, this difference was not significant statistically. This suggests that the rate of mixing organic manure with mineral fertilizers in hydroponic nutrient solution does not affect significantly the vitamin C content in lettuce leaves. Vitamin C in lettuce leaves can be created even with low nutrient levels (EC = 1 - 1.5 mS/cm). This is the cause of no significant difference in vitamin C in lettuce leaves in the experimental formulas. This is also consistent with the findings of Sanguandeekul (1999).

4.5.4.2 Sensory evaluate: Consumers tend to prefer lettuce grown with the formula using the ratio of 1/5 compost extract + 4/5 chemical nutrient solutions. The reason is that lettuce grown with this recipe has beautiful color, large plant size. Lettuce grown with 100% chemical nutrient solution receives relatively low appreciation from consumers because of light-colored leaves, although the plant size is large.

4.5.4.3 Nitrate accumulation: Nitrate accumulation in vegetable crops is of concern because of the potential conversion to nitrite after uptake which can cause methemoglobinaemia in infants and because it is a precursor of nitrosamines, which are carcinogenic (Addiscott *et al*., 1991). Research results on Nitrate accumulation in lettuce grown with the experimental formulas are shown in table 4.25. The results depict that different rates of mixing organic manure and mineral fertilizers in hydroponic nutrient solution have significant impact on nitrate accumulation. The rule of the impact is that nitrate accumulation in lettuce leaves increase with the increase of the concentration of mineral nutrients in hydroponic nutrient solution. This is because the formula using 100% chemical nutrient solution or high proportion of chemical nutrient solution wills provide much higher nitrate for lettuce than the formulas using high level of compost extract.

Table 4.25 Effect of the ratio of compost extract in chemical solution nutrient on ascorbic acid (vitamin C), sensory evaluate, nitrate determination and shelf life of lettuce

Treatment	Vitamin C (mg/100g)	Sensory evaluate	Nitrate accumulation (mg/kg)
1/2 CX + 1/2 CNS	16.2	2.3	302.60 [e]
1/3 CX + 2/3 CNS	16.4	2.7	342.70 [d]
1/4 CX + 3/4 CNS	17.2	2.5	378.30 [c]
1/5 CX + 4/5 CNS	17.8	3.4	425.30[b]
100% CX	16.7	2.1	206.40 [f]
100% CNS (control)	17.5	2.8	586.40[a]
F-test	ns	--	**
CV%	5.74	--	37.09

Letters within columns, means followed by a different letter are significant different by Least Significant Difference test (LSD), ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = non significant, CX: compost extract, CNS: chemical nutrient solution

The experimental results indicated that, addition of compost extract into the hydroponic nutrient solution had significant effects on growth, yield and quality of lettuce grown in vertical hydroponic systems. The data also shows that, lettuce plant had the highest yield and quality at addition doses of 1/5 compost extract + 4/5 chemical nutrient solution. The increasing of compost extracts concentrations or 100% compost extract used in hydroponic nutrient solution will tend to decrease the lettuce yield and quality. In the case ofusing100% chemical nutrient solution, the yield and quality of lettuce also relatively high.

CHAPTER 5

GENERAL CONCLUSION

Five experiments were carried out to finding the basic and simple technique to build a vertical hydroponic system, which can develop the cultivation and maintenances techniques of lettuce (*Lactuca sativa* L.)

The first experimental results indicated that different materials of the vertical hydroponics system had no significant effect on some parameters of lettuce growth and yield. However in comparison to weight of system, cost of system, evaporate of water /m2, and usefulness after one season of system revealed that Mat was the best material to use for the vertical hydroponics system due to its light weight, low cost, low surface evaporation, and especially durability. In other aspects, plant density was a crucial factor affecting the growth and yield of lettuce cultivars when they were grown on the vertical hydroponics system. Lettuce with plant densities of 14 x 16 cm and 16 x 16 cm gave the highest parameters of lettuce growth, while lettuce with plant densities at 10 x 12 cm and 12 x 14 cm brought the highest yield because of large number of plants/m2. From the above results, the plant densities of 10 x 12 cm or 12 x 14 cm was the most suitable for growing lettuce on the vertical hydroponics system to achieve high yield.

The second experiment results indicated that, different cultivation methods and lettuce varieties had significant effects on some parameters of lettuce growth, yield and quality. Lettuce grown in the hydroponics wick system had the highest lettuce growth and quality, but the vertical hydroponic system was the best method for growing lettuce for yield purposes. For lettuce varieties, the data revealed that red rapid lettuce had the highest lettuce growth, yield and quality.

The third experiment results indicated that different growing media and the period of irrigation had a significant effect on some parameters of lettuce growth, yield and quality. Lettuce grown in coconut mix carbonized rice husk had the highest lettuce growth, yield and quality. And the period of irrigation of 2 times/day was the best suited for growing lettuce in vertical hydroponics system.

The fourth experiment results concluded that, the ability to grow, yield and quality of lettuce grown in vertical hydroponic systems were significantly affected by nutrient solution concentrations (EC). The results also indicated that increasing the fertilizer concentration increased plant growth parameters, yield and quality of lettuce. The use of nutrient solution concentrations of 2 mS/cm to grow lettuce in vertical hydroponic systems is considered to bring the best productivity, quality and efficiency.

The fifth experiment results indicated that the addition of compost extract into the hydroponic nutrient solution had significant effects on growth, yield and quality of lettuce grown in vertical hydroponic systems. The data also shows that lettuce plant had the highest yield and quality at addition doses of 1/5 compost extract + 4/5 chemical nutrient solution. The increasing of compost extracts concentrations or 100% compost extract used in hydroponic nutrient solution will tend to decrease the lettuce yield and quality.

From this study it is clear that the vertical hydroponics system was the best method for growing lettuce for yield purposes. The study results also indicated that lettuce grown in the vertical hydroponics system had the lower on development indicators, total fresh weight and total dry weight, the high total yield due to its large number of plants per unit area. Thus the vertical system can be used to grow crops having small size such as lettuce, strawberries with the aim of improving productivity per unit area. Many previous studies have shown that plants grown on vertical hydroponics system reduced development indicators and plant weight due to low light provided for plants. Therefore for the future work, it is important to study the solutions to increase the light absorption for plants. The promising solutions can be study on suitable distance between vertical hydroponics systems and system installation towards the orientation sun to plants get the most light.

The use of compost extract as a hydroponic nutrient solution, or additional part of compost extract in hydroponic nutrient solution is a promising direction. This aims at providing more adequate nutrients and growth stimulants for plants, which will make hydroponic crops produce not only high yield but also better color and taste. However the results of experiment 5 indicated that, the increasing of compost extracts concentrations or 100% compost extract used in hydroponic nutrient solution will tend to decrease the lettuce yield and quality. This is due to the low of mineral nutrients concentration in the compost extract, which made from earthworm compost. Therefore for the future work, it is important to study effect of another compost extract kind such as compost extract made from head fish or animal excrement to development yield and quality of lettuce grown on vertical hydroponic system.

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Appendices

Appendix A

Earthworm’s compost extract

Table A.1 Main chemical characters of earthworm’s compost extract

Properties	**Content**	**Test method**
pH (1:10)	7.42 – 7.55	
EC (1:10) dS/cm	1.01 – 1.11	
Total nitrogen %	3.8 – 4.2	10 TCN 304 – 2002
Total phosphorus %	3.8 – 4.2	10 TCN 306 – 2002
Total potassium %	2.85 – 3.15	10 TCN 308 – 2002
Ca	3.5 – 3.9	10 TCN 362 – 1999
Mg	>= 0.05	10 TCN 362 – 1999
Cu	>= 0.07	10 TCN 362 – 1999
Zn	>= 0.05	10 TCN 362 – 1999
Mn	>= 0.02	10 TCN 362 – 1999
B	>= 0.05	10 TCN 362 – 1999
Mo	>= 0.0015	10 TCN 362 – 1999
Organic matter %	30 - 34	10 TCN 366 – 2002

Appendix B

Sensory evaluation questionnaire

Table B.1 Sensory evaluation questionnaire for Appearance of lettuce

Sample	1. Dislike very much	2. Dislike	3. Neither like or Dislike	4. Like	Like very much	Comments

Source: FAO, 2000

Table B.2 Sensory evaluation questionnaire for texture of lettuce

Sample	1. Dislike very much	2. Dislike	3. Neither like of Dislike	4. Like	Like very much	Comments

Source: FAO, 2000

Table B.3 Sensory evaluation questionnaire for color of lettuce

Sample	1. Dislike very much	2. Dislike	3. Neither like of Dislike	4. Like	Like very much	Comments

Source: FAO, 2000

Table B.4 Sensory evaluation questionnaire for taste of lettuce

Sample	1. Dislike very much	2. Dislike	3. Neither like of Dislike	4. Like	Like very much	Comments

Source: FAO, 2000

Appendix C

Dissertation Figure

Figure C.1 Lettuce grown on vertical hydroponics system

Figure C.2 Lettuce grown on vertical hydroponics system

Figure C.3 Lettuce grown on vertical hydroponics system

Figure C.4 Lettuce grown on hydroponics wick system

Biography

Biography

Name	Mr. Nguyen Van Quy
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Research grants & awards

Prizewinner in E-idea competition, British royal council funding. 2011

Prizewinner in inventor competition, ministry of science of Vietnam funding. 2012

Prizewinner in creativity science product competition, ministry of science of Vietnam funding. 2013

Research output

National patent of vertical hydroponics system kit, Patented by patent office of Vietnam. 2013