THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Doctor of Philosophy (Tropical Agriculture)

DEGREE

Tropical Agriculture	Agriculture
FIELD	**FACULTY**

TITLE: Development of Soilless Culture for Crop Production in Thailand

NAME: Mr. Ekasit Wattanapreechanon

THIS THESIS HAS BEEN ACCEPTED BY

-- **THESIS ADVISOR**

(Associate Professor Patana Sukprasert, Ph.D.)

-- **GRADUATE COMMITTEE CHAIRMAN**

(Assistant Professor Sudsaisin Kaewrueng, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON --

-- **DEAN**

(Associate Professor Gunjana Theeragool, D.Agr.)

THESIS

DEVELOPMENT OF SOILLESS CULTURE FOR CROP PRODUCTION IN THAILAND

EKASIT WATTANAPREECHANON

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Doctor of Philosophy (Tropical Agriculture)
Graduate School, Kasetsart University
2014

Ekasit Wattanapreechanon 2014: Development of Soilless Culture for Crop Production in Thailand. Doctor of Philosophy (Tropical Agriculture), Major Field: Tropical Agriculture, Faculty of Agriculture. Thesis Advisor: Associate Professor Patana Sukprasert, Ph.D. 214 pages.

Thailand has a high demand for safe vegetable especially to serve local consumption for over 22 million a year of tourists. Growing number of tourists and health conscious Thai people are the important market for hydroponic vegetable production. The objective of this research was to identify appropriate soilless culture systems for cash crops, like temperate lettuce and herbs that are normally imported, and for some other popular local crops.

The study comprised of 2 phases : the first phase : studied and identified hydroponic systems in Thailand and other countries, the collected data and information will be analyzed and synthesized to identify the advantages, disadvantages problems and solutions suitable for crops and efficiency. Then trials will be conducted to develop the system that are appropriate to local conditions and resources and revised the data by focus group technique. The second phase: interviews of 58 farmers to collect information and follow up on soilless culture technology transfer.

The result from the first phase indicated that 1) soilless culture systems for crop production used in Thailand were: dynamic root floating techniques (DRFT), nutrient film techniques (NFT), substrate culture, deep flow techniques (DFT), and aeroponics; and 2) DRFT, NFT and DFT were appropriate for vegetable production, but substrate culture was suitable for fruit vegetables. In the second phase, it was shown that 1) Farmers were in favor of the hydroponic techniques in the following order: the Nutrient Film Techniques (NFT), Dynamic Root Floating Techniques (DRFT) and Deep Flow Techniques (DFT) for their soilless growing of leafy vegetable while the Substrate Culture Technique is more suitable for fruit vegetables. 2) Most farmers learnt and adopted the soilless culture technology, but they modified the equipments using local material to cut the cost. 3) Most farmers in this group were well-educated, adopted the appropriate soilless culture technologies and grew temperate leafy vegetable by using NFT. 4) Those farmers were interested in improving the growing techniques to meet the standard for each individual vegetable variety as well as trying to reduce the cost and adapting the equipment by using local materials.

In order to undertake the hydroponic production, growers need to 1) to obtain better understanding of the technology, having good management and good varieties, having the suitable production sites and contract market. 2) Most production should not limit only temperate lettuce and herbs but also some popular local crops sold at a reasonable prices. 3) The commercial hydroponic production to be successful, there are need to develop many necessary hydroponic equipments using local material for establishing the hydroponic farm. 4) There are the need to increase education and training at all level.

____________________ ____________________________ ____ / ___ / ____

Student's signature Thesis Advisor's signature

ACKNOWLEDGEMENTS

This research was financially supported by Kasetsart University. I would like to thank the Bureau of the Royal Household, The Royal Project Foundation, the Phra Dabos Foundation and the Sai Jai Thai Foundation for providing information, facilities, and areas to carry out experiments.

I would like to express my gratitude and appreciation for the kind considerationand advice tomy thesis adviser, Associate Professor Dr.Patana Sukprasert as chairman, for his kind actives which was extremely helpful throughout all phases of the development of my thesis, and would also like to thank Professor Dr.Sorasith Vacharotayan, Professor Dr. Tusanee Autanan,Associate Professor Dr. Jariya Chanpaisaeng and Associate Professor Dr. Ittisoontorn Nantakit as consultants, for their valuable advice, warm encouragement and for taking care of my thesis.

This thesis would never have been accomplished if it was not for the assistance provided by ML. Uemsuk Kitiyakornand Ms.Chayanut Intudommoreover, this thesis would never been successful if never not for the support and encouragement from my colleagues, Mr. Samanmitr Patana, Ms. Darika Musikul, Ms.La-ong Worawong and Mr.Amorn Tongtub. I would like to say many thanks to them for all support.

Special thanks are also extended to the Thai Soilless Culture Forum Committee ,experts from Kasetsart University, and soilless culture farmers who join the brainstorming session and all interviewees with data which my research need.

Finally, I would like to dedicate the success of this research to my family.

Ekasit Wattanapreechanon
August, 2014

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF TABLES (CONTINUED)

Table **Page**

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

Appendix Table **Page**

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

CHAPTER I

INTRODUCTION

Increasing food production for the world population is one of the challenging subjects. The population growth rate increases, but at the same time the developing countries of the Third World cannot provide food production in a limited area. Climate change has also constrained the agricultural development. Therefore, it needs efficient technique that can provide food in regions with vast areas of non-arable land, such as deserts and oceanic regions.

The fact that there are 22 million tourists come to Thailand in 2012, and the growing number of the Thai people with health consciousness makes Thailand the important market for hygienic vegetable production. Soilless culture or hydroponic farming can be done all year round and all over Thailand because the environment, especially temperature, can be controlled in crop production. With the development of Thai tourism, economy, and the people's living quality, there is a tendency showing that more consumers intend to seek and purchase healthy, safe, and high quality vegetables.

Thai population increased to 63.38 million in 2008 (Wikipedia, 2009) but only 41% of total land area was cultivated. There has been a steady decrease in the size of farm holdings with a corresponding increase in the number of farms and total rural population. According to the FAO report, the world population has doubled every 40 years, but food production increases at the lower rate than a population growth rate. Daily intake of vegetables is essential for healthy life as a result of the increase of safe vegetable production. Today, people are consuming more fresh vegetables than before and encouraging the growing of vegetables.

Hydroponic technology could increase food production and income, improve product quality and increase the diversity of food to achieve national food security. It is a high technology and can be capital intensive. But it can be modified to use in

Thailand for cash crops all year round. Soilless plant production in greenhouse is the most environment-friendly growing technique because it can decrease the use of chemical pesticides and realize the efficient use of natural resources. It is also a low load cultural system to the soil.

Thailand is located in the tropical zone and can earn a great deal from tourism industry. While the arable land is decreasing everyday and replaced by buildings and industries, hydroponic technology is the answer to this problem for vegetables and fruit production, especially to serve the need of the health conscious groups and tourists alike. Moreover, with good marketing strategies hydroponic farming can generate satisfactory income. It is advisable that other countries with the similar problem, like those in the oceanic and Africa, should study from Thailand.

Statement of Problem

Soil is the most available natural growing medium, and plant normally grows in it. It provides anchorage, nutrients, air, water, optimum temperature, buffer stage, etc., for successful plant growth. However, growing plant for a long period of time, many problems could happen, for instance, the depreciation of soil fertility, problem of insects, pests and diseases, unsuitable soil reaction, unfavorable soil compaction, and poor drainage. The continuous cultivation of crops could result in poor soil fertility, which in turn reduces the opportunities for natural soil fertility built up by microbes. This situation thus leads to poor yield and quality.

Furthermore, conventional crop growing in soil is becoming more difficult as it involves large space, spends a lot of labor and a large amount of water supply. In some places like metropolitan area, soil is not available for crop growing. Since nineteenth century, scientists have developed new technology to grow plant without soil called soilless culture or hydroponics. Under controlled conditions, most crops can grow with better quality and higher yields using minimal labor. In the temperate zone, farmers can grow vegetable in glass houses and supply fresh vegetables for people during winter at higher price.

The number of soilless culture growers has increased every year. In 2010,there were 188 growers compared to 250 registered hydroponics growers in 2014 for commercial vegetable production in Thailand (Department of Agriculture (DOA), 2014). In addition, several small hydroponic units were used in vegetables production for home consumption. Those commercial hydroponic vegetable farms are located in Bangkok and its surrounding areas as well as in tourist attraction provinces such as Phuket, Chiang Mai, PrachuapKhiri Khan and SuratThani. All equipment is locally manufactured, reducing the initial investment and capital cost required by the growers.

Objectives

1. To identify and develop the hydroponic systems suitable for growing cash crops like temperate lettuce and herbs normally imported from other countries.

2. To select the hydroponic systems suitable for producing some popular local crops with food safety techniques at a reasonable price.

3. To develop hydroponic equipment using local materials for commercial hydroponic farms e.g. substrates, water improvement techniques, cooling systems, automatic controlled water sprayer, and nutrient solution controller.

Benefits of the Study

1. The hydroponic systems will enable farmer to cultivate certain temperate crops to substitutes the import.

2. The recommended hydroponic systems will enable farmers to grow popular local crops with food safety at a reasonable price.

3. Developed the hydroponic equipment by using local materials will substitute the import and reduce the production cost for farmers.

Scope of Study

This research covers the literature review on related research. Data is collected from research reference, resulting from trial works, the collection of primary and secondary data, selection, and evaluation of the best systems that can be extended to farmers so that they would be able to produce crops to substitute the import of temperate vegetables and herbs as well as popular local crops, with safety and at a reasonable price. The period of the study has been set for 2008-2014.

Conceptual Framework

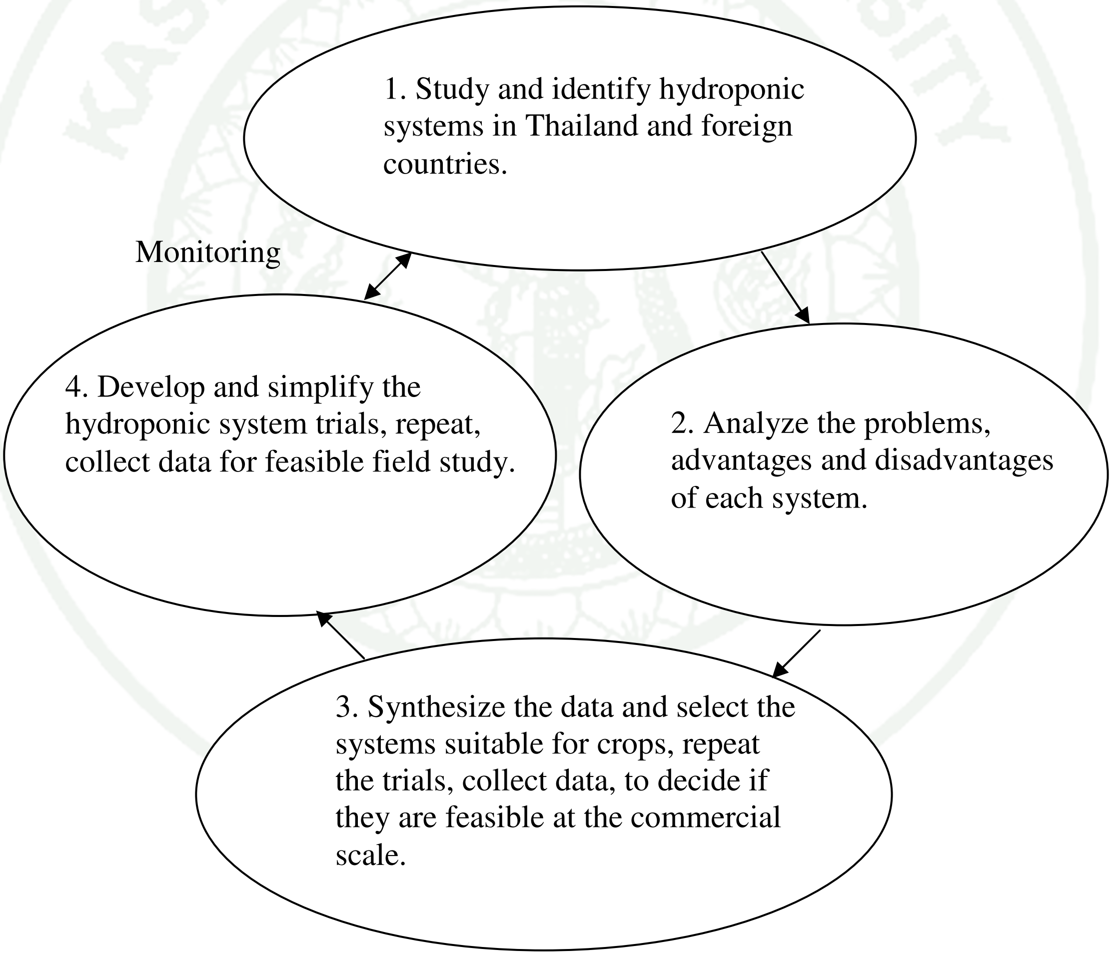

Figure 1 Conceptual Framework.

The Development of Hydroponic Systems for Thai Farmers

The conceptual framework of the research is to study the hydroponic systems in Thailand and other countries. The collected data and information will be analyzed and synthesized to identify the advantages, disadvantages, problems and solutions, suitable and efficiency. Then trials will be conducted to develop the systems that are appropriate to local conditions and resources.

Research Methodology

The research methodology to be used conducted in 4 steps.

1. Primary and secondary data will be collected both from literature reviews and field works.

2. All data and information will be analyzed to identify the advantages, and disadvantages, of each system. Then synthesized the best system suitable for Thailand conditions, will be selected, followed by interviewees and focus groups consists of

   2.1 farmers conducting hydroponic systems.

   2.2 specialists in hydroponic systems.

   2.3 consumers

3. Potential crops will be identified for equipment.

4. Develop the best system using locally produced equipment and carry out the crop productiontrials using soilless culture at Chitralada Palace, Bangkok, H.M.'s Private Development Sapansung, Bangkok, Sai Jai Thai Garden (Vocational Training Centre for the Handicaps) Bangkok and Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan.

Definitions

Soilless culture. Soilless culture is a technique to grow plants without soil. In this growing method, crops are grown in a nutrient solution or on a proper solid medium organic or inorganic substrates where crops are planted and nutrient solution is supplied with optimum oxygen, temperature and pH.

Hydroponics. Hydroponics is a technique for growing plants without solid media or with inert media. This technique involves nutrient solution, oxygen, temperature and pH at appropriate condition. Nowadays, however, soilless culture and hydroponics are often used interchangeably.

NFT (Nutrient Film Technique) NFT is a water-based system in which nutrient solution flows down channels or gullies and is circulated. The basic principle of the technique is that the nutrient solution should be maintained as a thin film to provide adequate oxygen for the solution.

DFT (Deep Flow Technique, Deep Floating Technique) The principle of DFT is the simple one of recirculating a deep nutrient solution. Plants are grown on urethane foam that put on the holes of polystyrene board. The roots of crops are continuously or intermittently immersed in nutrient solution. The catchments tank of DFT is much bigger than the NFT system but is safer in case of possible electricity shock.

DRFT (Dynamic Root Floating Technique) The DRFT is the growing system, which is modified from the DFT system by putting the air inducer to suck clean fresh air to mix with nutrient to maintain a good supply of oxygen before releasing to plants. The system is also equipped with a nutrient adjuster to control the nutrient solution levels as required by each age of crops.

Aeroponics It is one of the modified forms of hydroponic culture. It is a method of growing plants where the roots of the plants are suspended in the air within an enclosed chamber to which nutrient is fed in the form of a mist. The access nutrient solution drops down and isrecirculated by pump.

Substrate culture It is a growing system, which crops are planted in solid medium instead of soil. Nutrient solution is supplied to the medium by dripping, spraying, and flood fertigation systems. Natural or artificial media, organic or inorganic media are used as growing substrates. It looks like growing in soil but free from soil-borne diseases and pests.

EC (Electric Conductivity) It is an indicator of the strength of a nutrient solution, as measured by an electric conductivity meter. This is the preferred term used worldwide. Its most common unit is milliSiemen per centimeter (mS/cm). Another unit is microSiemens per centimeter (uS/cm). A limitation of EC is that it indicates only the total concentration of a solution and not the individual nutrient component.

pH A scientific and practical measure of acidity, as measured by a pH meter or pH test kit. It has no unit. A pH of 7.0 is neutral. Figures higher than 7.0 are alkaline and lower than 7.0 are acidic. Adding acid to a solution will lower the pH. Adding alkaline will raise the pH.

Hydroponic Nutrient Solution. It is composed of clean water, dissolved air and a dozen or so chemical elements in their correct proportion, including acidity.

GAP (Good Agricultural Practice) GAP is Agricultural production with safety, good hygiene with standard of growing technique.

Photosynthesis The process by which chloroplasts in the presence of light split water (H_2O) combines with carbon dioxide (CO_2) to form simple carbohydrate and release oxygen (O_2).

$$6CO_2+6H_2O \xrightarrow{\text{chloroplasts in light}} C_6H_{12}O_6+6O_2$$

CHAPTER II

LITERATURE REVIEW

Related Concepts, Theories and Research Results

The research deals with the development of soilless culture for crop production in Thailand. Research has reviewed on literature on related research reference, result from trial works, the collected from primary and secondary data, selected and evaluated of the best systems that can be extended to farmers so that they would be able to produce crops to substitute the import of temperate vegetables and herbs as well as popular local crops with safety and at a reasonable price.

The conceptual framework of the research was to study the hydroponic systems in Thailand and other countries. The collected data and information will be analyzed and synthesized to identify the advantages, disadvantages, problems and solutions, suitable and efficiency. Then trials will be conducted to develop the systems that are appropriate to local conditions and resources.

Research results and synthesized the conceptual framework for this research comprises of the following :

1. Understanding Plant

   1.1 How plant grow
   1.2 Factor effecting plant growing in soil and hydroponic

2. History of Soilless culture / hydroponic

   2.1 Soil culture VS Soilless culture
   2.2 Why Soilless culture / hydroponics can work for us

2.3 Present situation of Soilless culture in developed countries
2.4 History of Soilless culture in Thailand
2.5 Soilless culture / hydroponics development in Thailand
2.6 Hydroponics in the near future

3. Hydroponic and its effects

3.1 Hydroponics and environment
3.2 Hydroponics and agricultural development

4. Adoption of technology

5. SWOT analysis and its application

1. Understanding Plants

1.1 How plants grow

Soil naturally maintains the temperature and aeration needed for root growth. Plants absorb nutrients released from soil through osmosis pressure. Water is absorbed into the roots due to the loss of water from the plants by the process called transpiration, which takes place mainly on leaves' surface. Water entering through the roots is pulled up mainly through the xylem, and evaporates from the exposed leaves' surface. In order for water to enter the roots, the roots must be fully functional. Temperature, ion content of the water, aeration, pH, etc. are factors that can affect water absorption of the roots. As water is pulled into the plant roots, those substances dissolved in the water will also be brought into the plants although there is a highly selective system that regulates which ions are carried in and which ions are kept out. Therefore, as the amount of water absorbed through plant roots increases, the amount of ions will also increase, even though a regulation system exists.

Plants hold a unique position because they are the only living organism that can produce their own food by converting carbon dioxide and water into sugars using light energy. This process is called photosynthesis and is currently man's only basic source of food, either directly or indirectly (Romer, 1997).

Plants need oxygen for their respiration. The soil condition suitable for plant growth should be comprised of 5% organic matter, 25% air space, 25% water space, and 45% mineral matter. (Resh, 1993: 34)

Other raw materials required by plants are: water, carbon dioxide, sunlight (energy), and mineral elements. The limiting factor in all of these basic requirements is the availability of mineral elements of the right type and in the right quantity (Sundstrom, 1985: 2)

Plant growth requires different composition of nutrients depending on species, and period of growth such as seedling, vegetative or reproductive stage. Some crops are more sensitive to particular elements than others. Plants grow well in suitable nutrient requirements but poorly if less or much more than they need. Different series soil profile, plants are growing differently. The most important problem of soil is the lack of trace elements. Although scientists can analyze the soil properties to determine how to add some trace elements, plants sometimes do not grow well due to improper pH of soil or unsuitable required elements. Natural soil does not only keep the suitable pH for plant roots, but also the optimum temperature for soil microorganism.

1.2 Factors effecting plant growing in soil and hydroponics

1.2.1 Water (H_2O)

Water for the provision of hydrogen and for the translocation of the plant nutrition

Water is the raw material, from which the plant extracts hydrogen for food production and uses for transpiration purposes. It is also the vehicle by which we actually apply our mineral nutrition to plant roots. Normally, we can use rain water as well as water from other sources like the river, lake, irrigation system, spring or well. However, it is necessary to deliver a sample to be analyzed by a reputable laboratory. If there should be any problems, special treatments such as resin deionization and reverse osmosis systems, are needed.

a. Water Quality

In many parts of the world, water quality can be a major problem for hydroponic/soilless culture use due to contamination by various inorganic and organic substances. Even water supplies suitable for domestic and/or agricultural use must be considered suspect by the hydroponic/soilless grower. Therefore, a complete analysis of the water to be used for any type of hydroponic/soilless culture system is essential. Natural water supplies can contain sizable concentrations of some of the essential elements required by plants.

Most of hydroponic grower use tap water for nutrient solution, while the remaining depend on irrigated, river, rain water, etc. Mean electric conductivity and acidity values are 0.02-0.7 mS/cm and pH 6.9-7.3 respectively.

b. Raw Water

It is important to know what this water contains. In addition, the actual mineral content in the water can swing dramatically over the period of the year. No matter, where it are obtained, it needs a professional analysis from the laboratory.

Water samples should be submitted to a testing laboratory for a complete analysis before use, and the analysis should be repeated whenever a change in the water source is made. It is also advisable to have the initial nutrient solution assayed to be sure that its composition is as expected before its use. Instrumental devices and analysis kits can be used when monitoring water and nutrient solutions. For example, pH and conductivity meters are handy for self-monitoring of the nutrient solution.

Every water supply should have a complete analysis done a minimum of 4 times per year. In between times, the water should be tested for pH and conductivity every time you prepare to mix a nutrient solution. The things that show up on analysis which cause the problems the most are the trace elements. It helps a lot if the report tells the actual concentration of the elements found in the water and the state of the elements.

Table 1 Suitability of water for irrigating potted plants.

Water Classification	Electric Conductance (mMhos/cm)	Total Dissolved Solids (salts) (mg/L, ppm)	Sodium (% of total solids)	Boron (mg/L, ppm)
Excellent	<0.25	<175	<20	<0.33
Good	0.25-0.75	175-525	20-40	0.33-0.67
Permissible	0.75-2.0	525-1400	40-60	0.67-1.00
Doubtful	2.0-3.0	1400-2100	60-80	1.00-1.25
Unsuitable	>3.0	>2100	>80	

Source: Waters *et al.* (1972)

In most cases, some form of water treatment will be necessary to make and maintain useful solutions. Depending on what the analysis of the water supply indicates, surplus salt may be removed by mean of ion exchange or reverse osmosis as well as filtering using sand beds or fine-pore-type filters may be required.

In hard-water areas, there may be sufficient calcium and magnesium in the water to provide a portion or all of the plant requirement, or the micronutrient element concentration could be sufficient to preclude the need to add this group of elements to the nutrient solution. These determinations can and should be made only on the basis of an element analysis of the water.

Extracting some minerals from river, dams, well water or bores is not easy, however we can simply treat these water to overcome some particular problems, for example, we could treat calcium carbonate with nitric acid and get calcium nitrate which is easy to dissolve in water and useful for plant. In this case, phosphoric acid was not recommended because it released phosphate which was difficult to dissolve in water and would leave residue effect on plant roots and substrates (Chiumchaisri, 1973: 45).

Water should be chemically clean and free from pathogens (disease causing organisms). Water used in hydroponics could come from a variety of sources. Probably, the best was scheme water. Water intended for human consumption was generally fairly clean and usually suitable for hydroponics. Other water sources such as dams, bores and water collections from building each presented their own problems. For a commercial hydroponic enterprise, the water should be tested by professional laboratories to determine their chemical composition and pathogen load before too much money has been spent. The best response to salt in the water supply was to remove it by reverse osmosis (R.O.). The cleaner the water the growers could start with less headache and pain (Barry, 1996: 19-21).

Water was the raw material, from which the plant extracted “hydrogen” for food production and which was also used for transpiration purposes. The quality of water especially water drawn from underground, out of well or pond should be treated before use. Nitric and phosphoric acid were recommended in controlling pH of the nutrient solution because they would give nitrate and phosphate needed by plants. Nitric acid was not only cheaper than phosphoric but also was the source for calcium nitrate, which was useful to plants, and carbonic acid, which would release carbondioxide and water. Nitric was stronger than phosphoric. It could be used in less amount and should be recommended for growers to use in water improvement (Pumhirun, 2004: 41-42).

Reverse osmosis for water treatment system can yield some very clean water. There are some serious drawbacks to its use. It is expensive to install, operate, and maintain. It yields relatively little clean water, generally about

25% of the input water. The most serious concern is the fact that a water conditioner is required to exchange the calcium for sodium before the water reaches the treatment unit. This results in the introduction of sodium into the waste water and this is being recognized as a serious problem.

Ozone Treatment is the least expensive and most effective treatment available today. Ozone generators are inexpensive to buy and operate. Ozone is 6,000 times more effective than chlorine and last only a matter of seconds in the water before breaking down into oxygen. It has the additional benefit of precipitating excess iron from raw water making nutrient formulation easier.

c. Solution pH

The pH scale indicates how acidic or alkaline, water or other liquid is. The scale ranges from 0 through to 14. Pure water is neutral. It is not acidic or alkaline. On the pH scale, pure water is rates as 7. The pH of water is critical to plant mineral uptake and this pH is, in most hydroponic systems, an indicator of the dissociated oxygen which may be available to the plant roots as a result of water uptake. Water is also an important source of oxygen and hydrogen for a wide variety of processes in the plant metabolism (Muckle,1993:39).

The ability of the solution to provide nutrition to the plants depends on four factors :

1) the amounts of the various essential elements present in the nutrient,

2) their forms of combination,

3) the processes by which these elements become available to plants,

4) the soil solution and its pH.

The effect of pH on availability of essential element e.g. iron, manganese, and zinc becomes less available as the pH is raised from 6.5 to 7.5 or 8.0. Molybdenum and phosphorus availability, on the other hand, are affected in the opposite way, being greater at the higher pH levels. At very high pH values the bicarbonate ion (HCO_3-) may be present in sufficient quantities to interfere with the normal uptake of other ions and thus is detrimental to optimum growth (Resh, 1993: 36).

d. Electronic pH Testers

There are many options available and it is important to know the accuracy and range of the meter you are considering. For most growing applications, the meter needs only be accurate to .2 of a pH point. For horticultural purposes, a range of pH measurement from 2-12 is more than adequate.

Normally, the solution pH change during cultivation, when plants absorb more cations, the pH will become down, and when plants absorb more anions, the pH will go up. It is necessary to control the solution pH because pH strongly affects mineral absorption and the growth of plants. However, in the soilless cultivation, effects of solution pH on plants growth are rather mild. Addition of acid or alkali solution to control the suitable of pH solution is practiced in soilless culture. Practically, pH is measured by the pH meter or pH drop test kit. However, a pH sensor should be checked and adjusted by the standard solution every week and pH sensor has not so long life. It availability may be only/less than one year.

e. Adjustment of nutrient solutions by use of electrical conductivity

Total dissolved solutes instruments which determine the dissolved solids in water are basically water conductivity measuring instruments call electrical conductivity meter. The quantity of dissolved solids in parts per million (ppm) or mg/l by weight is directly proportional to conductively in millimhos (mmho) per cm. However, the electrical conductivity (EC) varies not only to the concentration of salts present, but also to the kinds of chemical and composition of the nutrient solution. Electrical conductivity measures total solutes. It does not differentiate among the various elements.

f. Conductivity Meters

These meters are available with readouts in micromos, millimos or parts per million. Each of them can be converted back and forth easily. By the way, none of these meters identify the actual individual mineral content of the solution. Again, there are essentials to the proper care and maintenance of a conductivity meter. A good general meter should be accurate to 2% of full scale with a repeatability of within 1% for readings.

As water is pulled into the plant roots, those substances dissolved in the water will also be brought into the plant, although there is a highly selective system that regulates which ions are carried in or kept out. Therefore, as the amount of water absorbed through plant roots increases, the amount of ions will also increase, even though a regulation system exists. This partially explains why the elemental content of the plant can vary depending on the rate of water uptake. Therefore, atmospheric demand can affect the elemental content of the plant, which can be either beneficial or detrimental (jones,1997:13-14).

g. Water Uptake

Water is literally sucked into the roots due to the loss of water from the plant by a process called transpiration, which takes place mainly from leaf surfaces. To understand this process, we can visualize continuous columns of water from the root surface up to all the atmospherically exposed plant (leaf) surfaces: water entering through the roots, is pulled up through the plant (mainly in the xylem), and is evaporated from the exposed leaf surfaces. When water content declines, wilting occurs and the plant begins to lose its shape and droops. There may be conditions where water uptake and movement within the plant are insufficient to keep the plant fully turgid, particularly when the atmospheric demand is high. In order for water to enter the roots, the roots must be fully functional. Temperature, ion content of the water, aeration, pH, etc. are factors that can affect water absorption by roots. The flow of water within the plant itself is fairly complex (Jone,1997:13-14).

1.2.2 Oxygen (O_2)

Oxygen is a major component of plants. It is taken in through the stomata on the leaves and the roots as a component of the water and the oxygen absorbed by the root during the process of respiration. Oxygen is a vital ingredient of the metabolism of plant both for respiration and a component of virtually all plant compounds. Plant respiration process needs oxygen and carbohydrate as elements for the growth process while releasing carbon dioxide, water and energy.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy.}$$

Plant respiration occurs all the time. If oxygen has been withheld from the root cells, the plant will be under stress and begin to wilt and die finally.

a. Aeration

Aeration is another important factor that influences root and plant growth. Oxygen (O_2) is essential for cell growth and activity. If not available in the rooting medium, severe plant injury or death will occur. The energy required for root growth and ion absorption is derived from the process called respiration, which requires O_2. Without adequate O_2 to support respiration, water and ion absorption ceases and roots die.

b. Respiration

Respiration is a process which involves the conversion of stored energy into available energy to carry out many functions performed within the plant, including growth. Technically, it is the burning up of organic molecules, especially sugar, with the controlled release of energy. Simply stated, sugars react with oxygen to give carbon dioxide, water and energy. Respiration of the plant is important for two reasons: firstly, all functions within the plant require energy and secondly, growth and food storage require that the products of photosynthesis must exceed the plant's requirement for respiration. The important factor oxygen is required for respiration. Hence, if there is a shortage of oxygen in the root zone, they will not be able to perform their functions effectively. A major advantage of hydroponics over soil is that the roots of the plants do not have to compete with soil microorganism for the available oxygen. Temperature has a marker effect on the rate of respiration of the plant and increases at the rate of two to four times for every 10 °C rise in temperature in the range 0°C to 30°C. At higher temperature respiration decreases as the cells and enzymes break down, and growth is retarded. Low light intensity also reduces the rate of respiration, partly through the lower amounts of photosynthetic products but also because of the lower plant temperatures caused by the lower heat absorption by the leaves of the plants.

If air exchange between the medium and surrounding atmosphere is impaired by overwatering or the pore space is reduced by compaction, O_2 supply is limited and root growth and function will be adversely affected.

In hydroponic system, the grower is faced with a problem in periods of high temperature. The solubility of O_2 in water is quite low (at 75°F, about 0.004%) and decreases significantly with increasing temperature. However, since plant respires therefore, O_2 demand increases rapidly with increasing temperature and considerable attention to O_2 supply is required. Therefore, the nutrient solution must be kept well aerated by either bubbling air into the solution or by exposing as much of the surface of the solution as possible to air by agitation. One of the significant advantages of the aeroponic system is that plant roots are essentially growing in air and, therefore, are adequately supplied with O_2. Root death, a common problem in most nutrient film technique systems and possibly other growing systems as well, is due in part to lack of adequate aeration within the root mass in the rooting channel (Jones, 1997:18-19).

Essential elements in the root zone are oxygen, water and a particular concentration of macro and micro elements ionized in the water. The medium can remain completely inert. All these requirements can be provided by a hydroponic system (Pual, 2001: 42).

c. The role of oxygen in plant metabolism

Oxygen appears to be of importance in every metabolic process in the plant. It is a key factor in fueling the transport system of the plant. Oxygen is the internal fuel which provides the energy which drives such essential functions as the hydrostatic pressure which moves fluids in the plant. In addition, you find oxygen as a component of virtually every molecular structure in the plant including all proteins and enzymes. Like animals, plants are oxygen reduction machines. The reduction in the availability of oxygen has very detrimental effects on the growth potential of the plant.

Low internal oxygen levels can cause mature cells to go dormant as available oxygen is used to bring young cells to maturity. If oxygen levels are low in root cells the uptake of minerals is severely inhibited and nutrient deficiency symptoms may manifest which have nothing to do with the nutrient solution. It is also necessary to note that 90% + of plant matter is made up of water. Water could not be without oxygen and through the use of ozone technology can be manipulated to provide previously unavailable oxygen.

Dissolved Oxygen levels can be increased in several ways: The use of aeration systems in solution reservoirs: injection of atmospheric oxygen into the irrigation lines, and injection of oxygen rich air obtained through the use of oxygen concentrations, the use of magnetic field generation of low level ozonation in the irrigation water.

The greatest problem facing the water culture system has been root dieback caused by sudden inadequacy of oxygen in the nutrient solution around the roots. This root dieback results in water stress within the plants which causes wilting and blossom- end rot on fruit in crops such as tomatoes. The problem is associated with large root mats developing in the bottom of the gully which impedes the flow of water, especially at the interface between the gully and plant roots. This stagnation of water allows plant roots to use up all the available oxygen in that area and with slow exchange of water, a shortage of oxygen develops.

1.2.3 Carbon dioxide (CO_2)

Plants need carbon dioxide for their photosynthesis. Chlorophyll in chloroplasts when absorbing light can perform a wonderful process called photosynthesis. The plant takes oxygen and hydrogen from water molecule and combines carbon atom from carbon dioxide to produce hydrocarbons and ultimately carbohydrates. These are mainly in the form of sugar which is transformed into various compounds, including starches, for carrying out particular tasks within the plant growth system.

$$6\,CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light energy}} \underset{\text{Carbohydrate}}{C_6H_{12}O_6} + 6H_2O$$

Naturally, there are carbon dioxide about .03% (300 ppm.) but plant needs air movement to provide a good supply of carbon dioxide to increase growth rate. Carbon dioxide is absorbed through stomata and mixed with water to create carbonic acid or carbonate which will be absorbed through plant cells and chloroplasts. Plant can convert sugar to another compounds such as carbohydrate, fat and protein.

a. Air movement (wind)

One basic requirements of the plant is good ventilation within growing structure. Air movement controls the temperature humidity and optimum transpiration. Without adequate air flow (ventilation) throughout the crop, insufficient supplies of CO_2 would not be available for production of food supply.

b. Air movement (to provide a good supply of carbon dioxide)

Carbon dioxide enrichment may be expected to increase fertilizer and water requirement, because plants will be growing more vigorously. Two experiments were carried out to investigate the effects of CO_2 concentration in the air and light intensity on the utilization of NO_3 and NH_4 by vegetable crops (lettuce, tomato, kidney bean, spinach). The growth of each crop was enhanced by CO_2 enrichment (360-1800 ppm.) and lower growth was obtained under the shaded condition. The growth of each crop was markedly increase by CO_2 enrichment under unshed higher light intensity (Ikeda and Osawa, 1988).

Carbon dioxide enrichment and supplementary artificial lighting may be economic in greenhouses used to produce vegetable seedlings and bedding plants. These practices produce sturdier plants in much less time than conventional systems. For maximum profits there is an optimum CO_2 concentration inside the greenhouse that depends upon the stage of growth and species of crop, as well as the location, timing of year, and type of greenhouse. Generally levels at 2 to 5 times the normal atmospheric levels (1000 to 1500 ppm CO_2) may be taken as the optimum levels. Carbon dioxide enrichment may be expected to increase fertilizer and water requirement, since plants will be growing more vigorously. Young tomato plants are especially responsive to CO_2 enrichment.

In northern regions, carbon dioxide enrichment in commercial greenhouse operators claims a 20 to 30 percent increase in tomato yields, better fruit set in early clusters, and larger fruits. In Ohio, cucumber yields have increased as much as 40 percent. Lettuce yields have increased 20 to 30 percent per crop, and faster growth rates have allowed production of an extra crop each year (Rest, 1993: 351).

1.2.4 Transpiration

Transpiration is related to water transport up a plant depends on two factors: continued evaporation from the leaves into a vapour pressure deficit greater than that within the leaves; and on physiological pumping by the roots. If transpiration is shut down by very low air vapour pressure deficits (high humidities - the air can take no more water), root pressure will continue to push water through the plant.

The most abundant compound in the living plant is water with approximately 80-90% of plant weight. It acts as a raw material in photosynthesis, as a solvent for vital chemical and physiological processes, as a carrier for the products of photosynthesis, chemical salts and growth-promotion materials and as a source of turgor in plant cells. The loss of water in vapour form from a living plant is called transpiration. Most of this water is lost through the stomata in the leaves of the plant. The rate of transpiration is affected by the relative humidity of the air surrounding the plant, the amount of air movement, the temperature of the air, light intensity, and the concentration of the nutrients in the nutrient solution. The root systems of plant are extremely efficient at extracting water from the soil while other structures within the plant can efficiently transport it against the force of gravity, up to 100 meters high in some kind of trees (Dalton and Smith, 2003: 16) .

a. Air movement (to allow for optimum transpiration and good supply of oxygen).

Transpiration is important for the removal of oxygen through the leaves and the entry of air containing carbon dioxide. The rate of transpiration is effected by the relative humidity of the air surrounding the plant, the amount of air movement, etc. Air movement is a good supply of oxygen.

b. Humidity

Humidity is related to air movement, while not having as great an effect on the plant as temperature or radiation, humidity within the growing environment is still important. Variation in relative humidity in the greenhouse can influence fruits' sizes. Research has shown that high humidity levels (95%) resulted in the development of large fruits which contained significantly more seeds than fruits on plants grown at lower humidities. However, high humidity levels are conducive to the development of a number of diseases and physiological disorders and should be avoided, particularly in winter when diseases can rapidly infect the crops (Morgan and Lennard, 2000: 54).

1.2.5 Light

Light is related to air movement because light is the main source of energy for plants, so optimum light conditions will play an important part in achieving optimum growth. Light influences other processes that take place in the plant such as flowering, seed germination, pigment production, stomatal opening, translocation substances including food to the stem tips during the day and to the root tips at night, and growth movements. Normally, plants need 8-16 hours length of day for their photosynthesis with the suitable light intensity approximately 2,000-5,000 fc (foot-candles) on their leaves. The plant converts light energy into stored energy in the form of sugars. The rate of photosynthesis is proportional to the intensity of the light only at low to moderate light intensities. The concentration of carbon dioxide in the air surrounding the leaves markedly affects photosynthesis. Normally the atmosphere around us contains about 0.03 per cent of carbon dioxide.

a. Light (energy for photosynthesis – the manufacturer of the plant food)

The light intensity affects plant growth in many ways, in particular it influence the rate of photosynthesis activity. Large amounts of water and minerals were absorbed by plant under high light intensity compared with middle or low light intensity. Effects of light quality on the absorption of water and minerals were generally clear under high light intensity. The amount of absorbed water was larger under white and blue light and decreased in the following order green, red, yellow color (Fukuda, Ikeda and Nara, 1993).

Under low light conditions, most crops become more susceptible to diseases. Examples range from African violet and geranium to grey mould, cucumber to gummy stem blight, and tomato to bacterial canker, Did melba stem canker, and *verticillium* and *fusarium* wilts (Jarvis, 2001). It could be cause of bolting in lettuce. Low light also means the plant cannot maintain the supply of photosynthesis (carbohydrates) to developing flowers and fruit. Heavy fruit loads will also do that. Those depleted tissues in both foliage and roots become susceptible to diseases.

1.2.6 Heating or Cooling

Temperature is a major controller of the rate of plant growth. Generally, as temperature increases, chemical processes proceed at faster rate. Most chemical process in plants are regulated by enzymes, which perform at their best within narrow temperature ranges. Good growth of hydroponic is a low air temperature with warmed solution. A rise in solution temperature above 35^0c or fall below 15^0c is not desirable for many species. In warm climates, hydroponic permits an economical cooling of plant roots avoiding the more expensive cooling of the entire greenhouse. Solution cooling is particularly effective for reducing crop temperature at stress and is used in many tropical climates. Controlling solution temperature at approximately 25^0c, which 8 ppm of oxygen will dissolve, is suitable for many crops (Shinohara, 1999).

a. Temperature

The temperature of the nutrient solution should be less than the ambient air temperature, particularly in systems where plant roots are exposed to intermittent surges of a large volume of nutrient solution below. On warm days, when the atmospheric demand on plant is high, roots contact with nutrient solution below the ambient temperature results in plant wilting – an undesirable stress on plants. However, plant roots sitting in warm nutrient solution cannot absorb sufficient water and elements to meet the demand imposed by warm air and bright sunshine. Repeated exposure to cool nutrient solution results in better plant growth and performance. In such circumstances, it may be necessary to cool the nutrient solution to avoid this stress.

Top growth of lettuce plants cultured in a plastic greenhouse in winter generally increased with rising solution temperature. At the end of treatment, top growth at 24 °C was best and better yield was detected in 12/0 and 6/6 by 24% and 47% respectively (ratio of NH4 to NO3 in the solution) (Ikeda and Osawa, 1984).

In warm climates, NFT permit an economical cooling of plant roots, avoiding the more expensive cooling of the entire greenhouse. Problems could occur in hydroponics if the temperature of the nutrient solution exceed 20 °C. For example, it could cause 'bolting" in lettuce crops. Channel surfaces in NFT systems might be colored white to maintain lower nutrient temperatures. Cooling the liquid for lettuce production not only reduce bolting but also lessen the incidence of the damping off fungus *Pytium,* which cause plant damage and death, particularly of small seedling.

Air temperature is a major controller of the plant growth rate. Generally, as temperatures increase, chemical processes proceed at faster rates. Most chemical processing in plants are regulated by enzymes, which perform at their best within narrow temperature ranges. Solution cooling is particularly effective in reducing crop temperature stress in lettuce and are used in many tropical climates. Shading of the crop with covers is also effective at reducing air temperatures up to 5-8 degrees under summer conditions. There is a range of material available for use as thermal screens for both greenhouses and cloche system (Morgan, 1999: 70-71).

Temperature solution for many species is 25 °C but an acceptable optimum range is 20-30 °C. A rise in solution temperature above 35 °C or a fall below 15 °C is not desirable for many species. Good growth of NFT lettuce is a low air temperature with warmed solution obtained by commercial growers. One problem in using the circulating liquid to carry heat to the crop is the loss of heat as the liquid flows down the length of a gully. Higher nutrient temperatures up to 28 °C have been found to give greater growth and increase absorption of water and nutrient (Cooper, 1982: 13).

Cooling the solution temperature may be beneficial for plant growth and yields in warm climate environment. It is sometimes difficult to grow some crops in summer because the decrease of the dissolved oxygen may reduce the respiration of the roots. Root hairs in the moist-air may often play a useful role by direct absorption of oxygen from the air (Ito, 1994).

1.2.7 Plant nutrients

Plants require soluble mineral elements for growth, whether they be supplied by those elements from the soil or as dissolved salts in a hydroponic solution. Nine of the 16 essential elements are classified as major elements, they are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur. The other microelements are chlorine, boron, iron, manganese, zinc, copper and molybdenum. The principle of hydroponics is to supply the plant with an aerated nutrient solution. The nutrient solution provides all the essential nutrient elements required for complete growth, including root development, leaf and foliage development, flowering and fruiting. The other important feature of a hydroponic nutrient is that all the elements required for plant growth must be in the correct proportions. Carefully manipulating the nutrient solution, pH level, temperature and electrical conductivity and replacing the solution whenever necessary, will lead to a successful hydroponic garden. The optimum pH range for hydroponic nutrient solution is between 5.5 - 6.5.

Table 2 Volume of plant nutrients needed for growth.

Element	Symbol	Available Form	Atomic Weight	Concentration in Dry Tissue		Relative No. of Atoms Compared to Molybdenum
				ppm	%	
Hydrogen	H	H_2O	1.01	60,000	6	60,000,000
Carbon	C	CO_2	12.01	450,000	45	35,000,000
Oxygen	O	O_2, H_2O	16.00	450,000	45	30,000,000
			Macronutrients			
Nitrogen	N	NO^-_3, NH_4^+	14.01	15,000	1.5	1,000,000
Potassium	K	K+	39.10	10,000	1.0	250,000
Calcium	Ca	Ca^{++}	40.08	5,000	0.5	125,000
Magnesium	Mg	Mg^{++}	24.32	2,000	0.2	80,000
Phosphorus	P	$H_2PO^-_4, HPO_4=$	30.98	2,000	0.2	60,000
Sulfur	S	$SO_4=$	32.07	1,000	0.1	30,000
			Micronutrients			
Chlorine	Cl	Cl^-	35.46	100	0.01	3,000
Boron	B	$BO_3=, B_4O_7=$	10.82	20	0.002	2,000
Iron	Fe	Fe^{+++}, Fe^{++}	55.85	100	0.01	2,000
Manganese	Mn	Mn^{++}	54.94	50	0.005	1,000
Zinc	Zn	Zn^{++}	65.38	20	0.002	300
Copper	Cu	Cu^{++},Cu+	63.54	6	0.0006	100
Molybdenum	Mo	$MoO_4=$	95.95	0.1	0.00001	1

Source: Salisbury and Ross (1969)

a. Electrical Conductivity

Most nutrient solution formulas have a fairly low electrical conductivity (EC) when initially made. An EC measurement of the nutrient solution can also be used to determine the nutrient element replenishment level required to reconstitute the solution before reuse. From previous determinations, the amount of replenishment solution required to be added to the nutrient solution would be based on that EC measurement. Although this system of nutrient solution management has worked reasonably well, it does not take into account individual losses of elements from the nutrient solution by root absorption or retained in rooting media. Therefore, replenishment based on an EC measurement may not fully reconstitute the nutrient solution in terms of its elemental composition.

b. pH

The pH of water is critical to plant mineral uptake. In most hydroponic systems, an indicator of the dissociated oxygen may be available to the plant roots as a result of water uptake. Water is also an important source of oxygen and hydrogen for a wide variety of processes in the plant metabolism.

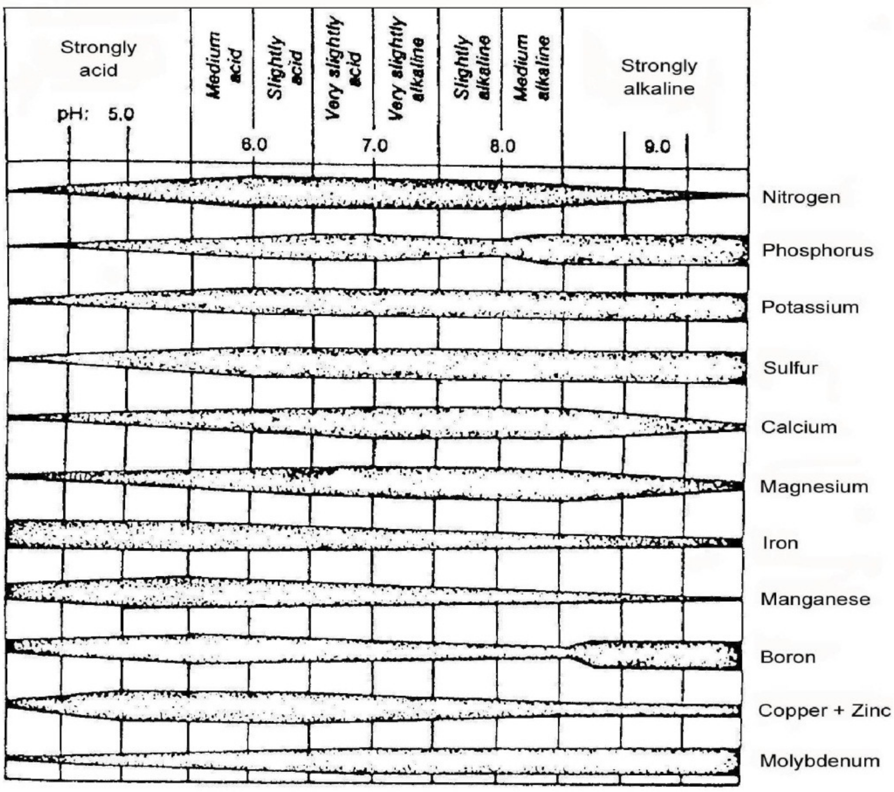

Figure 2 The effect of soil pH on the availability of plant nutrients.
Source: Resh (1993: 35)

The above figure indicates the nutrient elements availability at different pH levels of the solution. Nutrient deficiencies will become apparent or toxicity systems will develop if the pH is higher or lower than the recommended range for individual crops. The chart shows a pH range of 4.0 to 10.0. The width of the coloured section for each nutrient represents the availability of that nutrient. The widest place denotes the maximum availability. The narrowest place denotes the least availability.

c. Balanced mineral nutrition (Hydroponic nutrients)

There are many kinds of mixed fertilizers provided for use in hydroponics in this country. Each hydroponic system has its own mineral nutrient components recommended for the growers. Nutrient solutions are used for many horticultural plants. Hydroponic farmers uses mixed fertilizers provided by manufacturers. Some growers mix their fertilizers under the guidance of researchers or by themselves. Monitoring EC and pH with the aidof EC-meters and pH-meters is generally carried out manually or automatically. Chemical analysis of solution is very rared. Solution temperature are controlled in summer, a few farmer do cooling nutrient solution with chillers.

d. Automation of Growing Systems

One of the most interesting advantages of hydroponics is labor saving by adopting highly mechanized methods. Adjustment of nutrient solution is generally carried out automatically by means of electric conductivity meters measuring total salt concentration and connected to the stock solution and water supply. Ion sensors have been developed recently in order to control each ion separately. Plant density in hydroponics can be easily controlled without any injury to the roots. Spacing panels may be beneficially used for this purpose. Many kinds of easy growing systems have been developed recently.

Hydroponics gave gardener a control over the feeding of plants which was not available in any other type of garden. In this case, hydroponics was defined as any system of growing in which the plant was fed, not soil or some other substrate. In other words, the nutrients were dissolved in water and as such were immediately available to the plant. To accomplish this, it was necessary to use nutrients which were in fact complete nutrients, not soil supplement fertilizers. There was no soil supplement fertilizer which was in fact a complete nutritional package for a plant. In addition, soil supplement fertilizers were generally made from a lower grade of ingredients than hydroponic nutrients. This meant an unwanted level of contamination in soil fertilizer (Muckle, 1993: 5).

A major difference between soil and hydroponics was that soil had an inbuilt buffer which stored up the nutrients. This buffer was the decayed organic material. In hydroponics, the buffer action was not needed because it would be difficult to control the nutrient supply to the plants and to remove any excess salt build-ups that could occur. With the presence of this organic matter the nutrient salts may be selectively absorbed and may or may not be released on demand by the plants (Romer, 1997: 12).

Proper instruction in the design and operation procedure of the hydroponic/soilless culture system was absolutely essential. Those who were not familiar with the potential hazards associated with these systems or failed to understand the chemistry of the nutrient solution required for their proper management and plant nutrition would normally fail to achieve commercial success with most hydroponic/soilless culture system (Jone, 1997: 4).

Using the Quantitative Nutrient Management (QNM) at low concentration condition, this solution was sustained at low concentration level. However, the initial plant growth decreased slightly with the QNM, there was no significant difference in marketable weight at the final harvest between these two methods. The QNM reduced nitrate content and increased ascorbic acid content in edible parts of spinach. The QNM had the great benefit to maintain the nutrient solution at low concentration and to reduce the emission without any disadvantages for plant growth and yield of this crop (Maruo, 1999).

Immediate change of the nutrient solution concentration before harvest might improve the quality of leaf vegetable. Hydroponic culture of leaf vegetables in Japan involves the use of DFT or NFT with style-form panels floating on the solution and it was comparatively easy to change the concentration of the nutrient solution by moving the panels. It was suggested that the transfer of the lettuce plant into a very diluted solution immediately before harvest may result in a high content of sugar and ascorbic acid and a low nitrate content (Shinohara and Suzuki, 1988).

Growing tomatoes, lettuces and cucumbers in 3,000 ppm of salt solution, yield of tomatoes, lettuces decreases 10-15 % and cucumber 20-25 % respectively comparing with normal water. The salt stress forces plant can not intake water as usual. It impacts the growth rate and decreases yield. However, the sugar content in tomatoes and cucumbers is much higher than usual (Schwaz, 1968).

e. Factors effecting plant growing in hydroponic.

The important basics of growing plants could be summary under the following headings (Dalton and Smith, 1999: 35).

1) Light (energy for photosynthesis – the manufacturer of the plant food).

2) Air movement (to provide a good supply of carbon dioxide).

3) Water (for the provision of hydrogen and for the translocation of the plant nutrition).

4) Balanced mineral nutrition (Hydroponic nutrients).

5) Air movement (to allow for optimum transpiration).

2. History of Soilless culture / hydroponic

2.1 Soil culture VS Soilless culture

There is no physiological difference between plants grown hydroponically and those grown in soil. In soil, both the organic and inorganic components must be decomposed into inorganic elements, such as calcium, magnesium, nitrogen, potassium, phosphorus, iron and so on, before they are available to the plants. Theseelements adhere to the soil particles and are exchanged into the soil solution where they are absorbed by the plants. For hydroponics, the plant roots are moistened with a nutrient solution containing the elements. The subsequent process of mineral uptake by the plants is the same (Resh, 1993: 37).

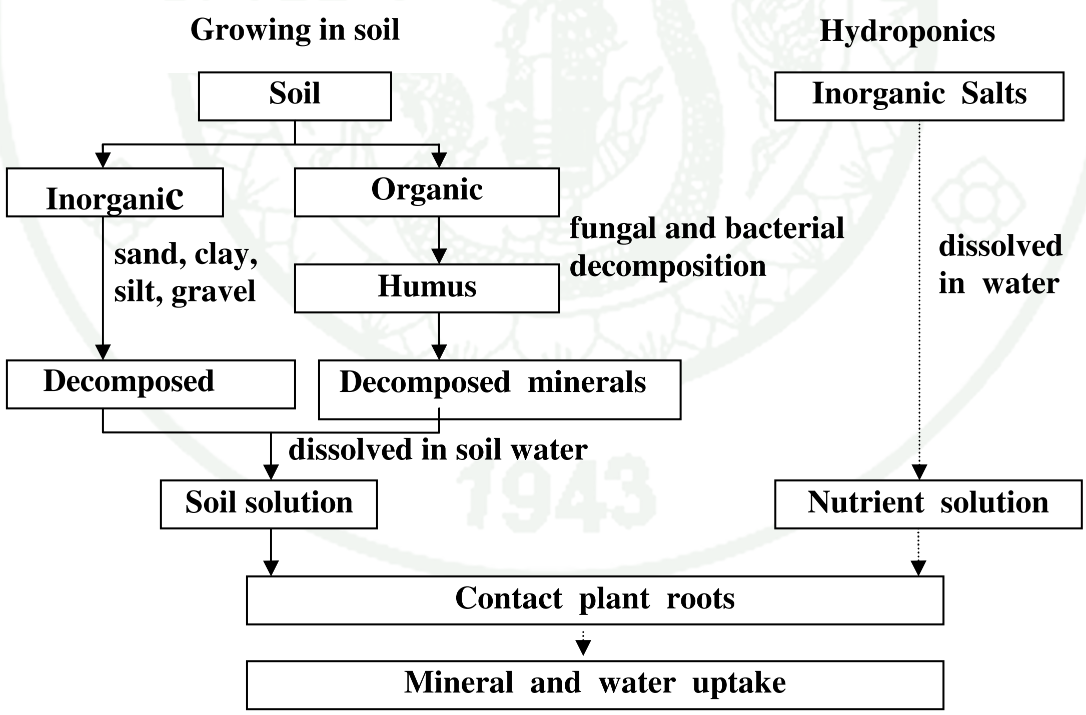

Figure 3 Origin of essential elements in soil and hydroponics.

Source: Resh (1993: 38)

Similar to soil culture, in hydroponics or soilless culture, substrates such as gravel, sand, sawdust, perlite, peat, pumice or vermiculite must provide oxygen, water, nutrients and support for plant roots, but it is not necessary to add organic matter. The nutrient solution will provide water, nutrients and some oxygen with the suitable pH and temperature that satisfy plants' need. A major difference between soil and hydroponics is that soil has an inbuilt buffer which stores up the nutrient. This buffer is the decayed organic material. In hydroponics there is no need for buffer action because it will be difficult to control the nutrient supply to the plants or to remove any possible excess salt build-ups. By this method, plants can give higher yield with better quality. Moreover, hydroponics enables us to formulate nutrient solutions right to the need of plants, and to avoid too many elements from organic matter (Chiumchaisri, 2007).

Photosynthesis is a process to produce food for plants. The green areas of plants contain the material called chlorophyll, and it is the pigment which give the leaves and other parts of the plants their green appearance. Sunlight provides energy, and without light plants can not produce their own food. The chlorophyll which absorb light is able to perform a wonderful process called photosynthesis. Plants convert light energy into stored energy in the form of sugars. This is not a simple one-stage process but a series of complicated reactions which can be roughly split into two separate components. One stage takes in the light and is a photochemical reaction. The other stage is called the dark reaction because it takes place in both the light and in the dark and is an enzyme reaction. Hence plants should have a resting period or a period of darkness for the final conversion of carbon dioxide and water into sugars with the release of oxygen (Romer, 1997: 14).

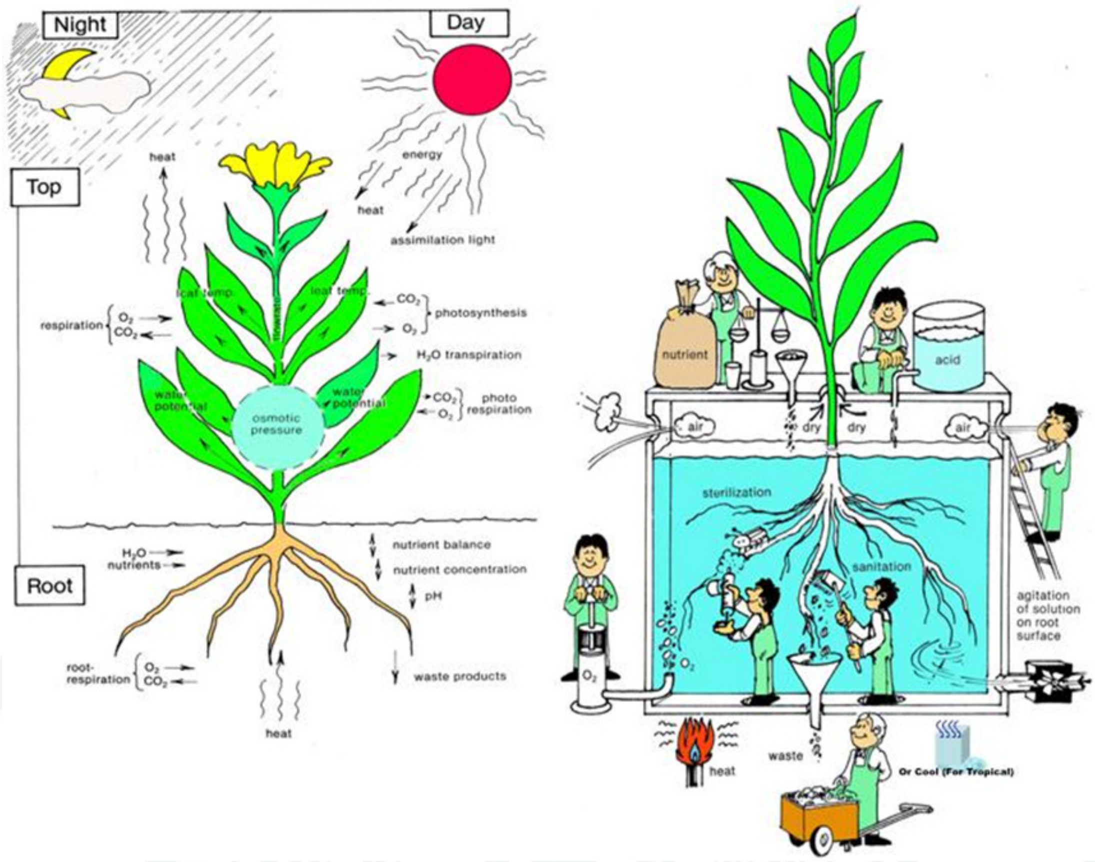

Figure 4 Plant model and the principles of hydroponic.
Source: Ikeda (2007b: 66)

2.2 Why soilless culture/hydroponics can work for us

Normally, standard method of growing plants all over the world is in soil. However, there are many problems in soil cultivation such as soil-born diseases due to continuous cropping, residue effects from pesticide, highly mechanized and overuse of fertilizer regardless of environmental limitations. Daily intake of vegetables is essential for a healthy life. However, there are many places in the world where plants can not be grown, e.g. deserts, coral islands, areas contaminates with heavy metals and unfertile soil. Furthermore, according to the Food and Agriculture Organization report, world population has doubled every 40 years (Taporn, 1999), but food production increases at the lower rate than population growth rate.

Soilless culture or hydroponics is a technique that can solve such problems described above. Soilless culture does not involve works using such tools as spades, hoes, and tractors. There are many characteristics which are different from soil cultivation. Traditional works as intertillage and weeding are eliminated and almost all management works, including fertilizing and watering are automated. There is no problem caused by continuous cropping in this growing system. We can control both aerial and root environments of plant to get better plant growth, extending the growing season and finally increasing crop yields and income. In combination with a greenhouse, soilless culture or hydroponics is becoming increasingly popular in the world. It is a high technology and can be capital intensive but can be modified to grow in the tropics for cash crops all year round. Soilless culture is highly productive, gives stable yield, using minimal water, fertilizer, and land, as well as environmental friendly. Soilless culture is possibly the most intensive method of crop production in today's agricultural industry. The technology for this growing system of food production has advanced a great deal in the last 60 years. This growing technique is used not only in a commercial greenhouse but also in a home garden. Until now, many soilless systems have been developed both for commercial and home uses. By this system, we can grow vegetables, ornamental plants, fruit crops, herbs, medicinal plants, etc., very easily.

It can be said that soilless plant production in a greenhouse is the most environment-friendly growing technique because it can decrease the use of chemical pesticides, and realize the efficient use of natural resources and is a low load cultural system to the soil. In addition, a little amount but frequent fertigation is the most advanced cultural technique, because it can reduce labor for management, improve the productivity, and realize the stable production (Ikeda, 2007a: 55).

Along with technological advance, some disadvantages also seem to appear, for example, the initial construction cost per area is great but we can modify to suit the local condition.

The trained personnel are required to supervise the growing operation, as knowledge of how plants grow and the principles of nutrition are important. The problems of soil-borne diseases and nematodes could spread quickly to all beds on the same nutrient tank of the closed system. The reaction of the plant to good or poor nutrition is very fast, the growers must observe their plants every day. In addition, soilless culture or hydroponics system needs steady supply of electricity for many equipment and good quality water.

What is soilless culture/hydroponics

The term hydroponics was coined in the U.S.A. in the early 1930's to describe the growing of plants with their roots suspended in water containing mineral nutrients. Derived from the Greek words for water_hydro and to work_ponos hydroponics literally means "working with water". The definition has gradually become broaden to describe all forms of gardening without soil (Dalton and Smith, 2003:8). During the second World War, the United States Army established large hydroponic gardens on several islands in the Western Pacific to supply fresh vegetables to troops operating in that area (Eastwood, 1947). In 1946, the United States forces in Japan began this culture system at Chofu near Tokyo and at Ohtsu near Kyoto to obtain clean vegetables for fresh salad. The acreage was 20 ha of open-field and 2 ha of greenhouse at Chofu and 10 ha of open field at Ohtsu. The adopted growing system was graveled culture for growing cucumber, green onion, salad and tomato (Ikeda, 2007b: 68).

During 1940-48, J. Sholto Douglas developed soilless culture system using sand and gravel as substrate to grow cereal crops and vegetable call "The Bengal system" at Darjeeling district in India (Douglas, 1975). Since 1950, hydroponics has been developed to the commercial level and extended throughout the world, for instance Italy, Spain, France, Germany, Sweden, Russia, Israel etc.

In 1960, The Horticultural Research Station of the Ministry of Agriculture and Forestry in Japan developed the first commercial gravel culture as an original system in Japan. This system gradually spread across the country for tomato, cucumber and sweet pepper production. In the second half of 1960, a variety of Deep Flow Techniques plants made of plastic panels were manufactured and sold by some companies mainly for fruit and leafy vegetables. These plants were grown by farmers with the help of the government funds for agriculture modernization and other financial support programs. Hydroponic greenhouses increased markedly to 282 ha in 1970 (Ikeda, 2007b: 68).

Since 1970, Dr. Allen Cooper has developed the Nutrient Film Technique (NFT) system for growing plants in a shallow layer of nutrient solution. Originally, the plants had been grown with their roots in nutrient solution circulating between two layers of polythene sheet. A Nutrient Film Working Party was set up at the Glasshouse Crops Research Institute to conduct the research work on the techniques that have been extended all over the world.

In 1970, along with improved nutritional formulations that made the hydroponic growing of a wide range of plants commercially viable, the automatic control systems have become available as well as digital testing equipment which has opened up the field of hydroponics to home gardeners (Dalton and Smith, 2003: 8).

The commercial hydroponic growing system has become cheaper with the use of plastic as hydroponic material and equipment, resulting in larger member of commercial hydroponic growers all over the world : America, Europe, Australia, Africa and Asia. Since 1990, hydroponic systems have developed and used in commercial farms all over the world (Tongaram, 2003). The contributing factors are:

1. Research and development of new substrates.

2. Research and development of new systems and new equipments.

3. Research and development of automatic controller, the use of plastics in electric pumps, gullies, equipments etc.

4. The use of high accuracy and efficiency of computer controller.

Hydroponics expanded since 1946 when the United States Force began soilless culture in Japan for 32 ha. In 1996, hydroponic greenhouses increased markedly to 12,000 ha all over the world, and up to 25,000 ha in 2000, with the increasing rate of 3,000-4,000 ha per year. In 2000, the Netherlands occupied the largest area of hydroponic greenhouses at 6,000 ha, followed by Spain, Japan, Israel, France, Belgium, Korea, and China respectively (Ikeda, 2005).

In Asia, commercial hydroponic farms increased markedly each year: Japan, the People' s Republic of China, Korea, Taiwan, Hong Kong, Malaysia, Vietnam, and Thailand. For the People's republic of China alone, soilless culture increased from 0.1 ha in 1985 to 83 ha in 1996, and expanded to 1,250 ha in 2005. The eco-organic soilless technique was up to 60% (Jiang, 2006).

In Korea, soilless culture increased from 23 ha in 1993 to 847 ha in 2004, 37 times increase within 11 years (Jeong, 2006).

Soilless Culture Area in the World (2000)

Netherlands	6,000	ha
Spain (South East Spain)	4,000	ha
Japan	1,056	ha
Israel	1,000	ha
France	1,000	ha
Belgium	1,000	ha
Korea	648	ha
China	500	ha

Ikeda (2005) However, soilless culture area in Japan increased to 1,700 ha. in 2007 (Ikeda, 2011b).

2.3 Present situation of soilless culture in developed countries

Soilless culture is a technique to grow plant without soil, and hydroponics originally meant nutrient solution culture with no supporting medium. However, plant growing in solid media for anchorage using nutrient solution is also included in hydroponics. Current hydroponic systems of cultivation can be classified according to the techniques employed. Hydroponic technique refers to the method of applying nutrient solution to the plant roots.

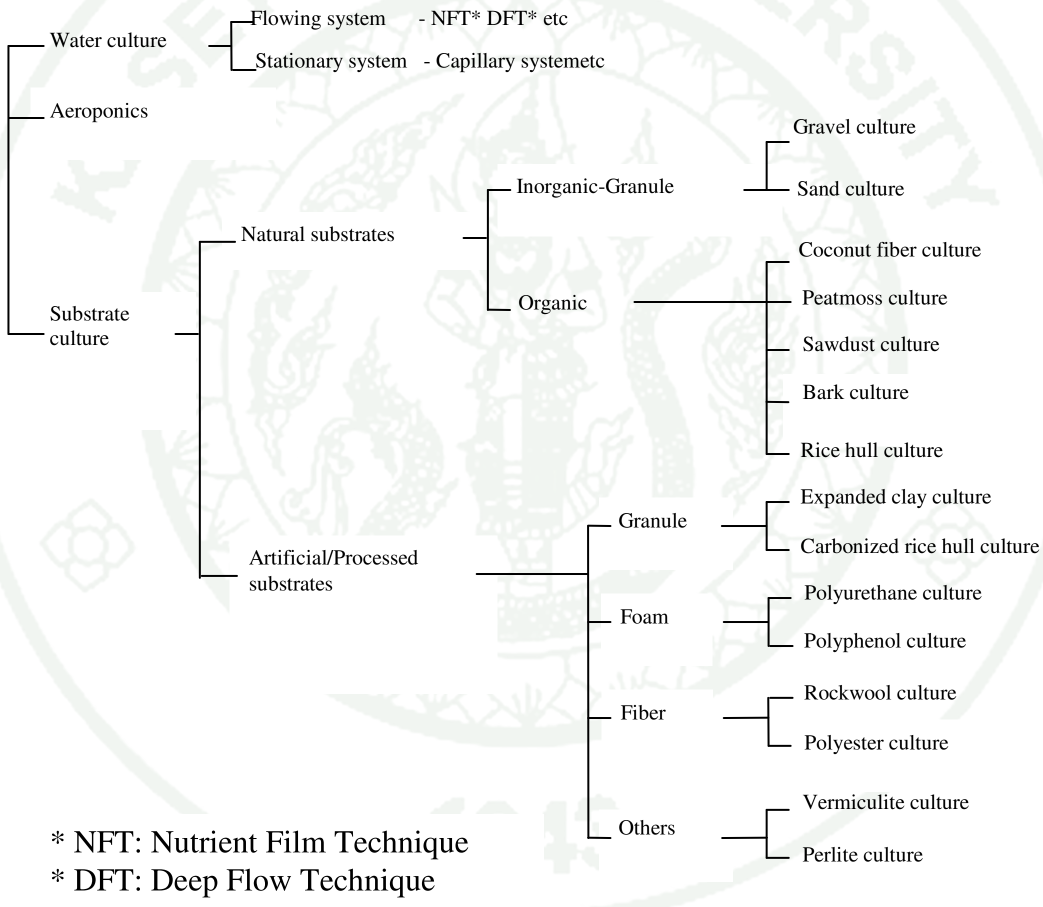

Figure 5 Soilless Systems.
Source: Ikeda (2007b: 69)

2.3.1 Soilless Culture / Hydroponics in Japan

Since 1945 many hydroponic methods have been developed. Hydroponics in Japan were introduced in the form of "Hydroponic farms", in which gravel culture was used for all year round production of fresh vegetable. These were supplied to the U.S. Army of East Asia in 1946. Fundamental and practical studies on mineral nutrition of hydroponics were carried out intensively in many agricultural and horticultural experimental stations after its introduction. In 1960, the first commercial gravel culture was established in this country, followed by 240 facilities in the following five years. Rapid extension of gravel culture, however, has resulted in several difficulties; shortage of gravel, occurrence of soil-borne diseases and sterilization of growing media. Many kinds of Deep Flow Techniques made of plastic panels were developed by companies mainly for fruit and leaf vegetables. Hydroponic greenhouses increased markedly from 31 hectares (ha) to 282 ha. in the 1970s. Nutrient Film Technique and rockwool culture were introduced into this country in the 1980s, and were accepted as feasible growing systems with the great advantages of lower cost and labor saving. Hydroponic greenhouses, thus, increased again in the vegetable and cut flower industries (Ito, 1994).

Soilless culture in Japan is classified into deep flow technique, nutrient film technique, rockwool culture, gravel culture and sand culture. Hydroponic system is installed in plastic greenhouses and the remaining in glasshouses. Three quarters of a hydroponic greenhouse are provided with a heating system for winter cropping. This suggests that more intensive farming is being carried out in hydroponics than the normal protected cultivation practiced in this country. The average acreage of the hydroponic farm is 1,334 m^2 for 2-3 persons of family labor. Since the farm labor population has decreased rapidly, hydroponic growing which has been recognized to be clean farming has a great advantage when employing part-time workers. It has been commonly accepted that plant growth in hydroponic growing is generally faster than that in the conventional soil culture. Efficiency of the use of hydroponic greenhouses, therefore, is 6.0 times a year for lettuce, 5.6 times for mitsuba, 4.8 times for Welsh onion, and 1.7 times for both tomato and cucumber, showing increases in successive cropping by 15-20%.

Main growing systems

1. Deep Flow Technique

The growing systems of DFT structures are composed of light weight polystyrene boards. Each system is characterized by a circulation method of nutrient solution and a device for oxygen enrichment. Since DFT has abundant water volume around the root zone, root temperature is almost independent of the greenhouse temperature. Main crops grow in DFT are mitsubas, Welsh onions and lettuces.

2. Nutrient Film Technique

NFT has been popularized with the high bench system for the growers so as not to bend their backs to manage the lower height plants, such as strawberries and leaf vegetables. Winter crops are economically grown with heated nutrient solution in a reservoir. Summer crops, on the other hand, have an unfavorable high root temperature, prompt and precise supplements should be required in this system.

3. Rockwool Culture

The nationwide spread of rockwool culture originally started with tomatoes, with the beneficial effects of high sugar content of fruits by controlling the water content in the medium. Success in the case of tomatoes brought wide adoption for other crops such as cherry-type tomatoes and melons. Another advantage of rockwool culture is that it is suitable and has easy measures to avoid contamination by soil-borne diseases. Roses, cucumbers and tomatoes are good examples cultivated in this medium.

4. Gravel Culture

Gravels used for the growing medium originate from two sources, one is porous volcanic gravel and the other is of non-volcanic mountain origin. The former is now considered a good material for growing tomatoes to maintain root moisture at a favorable level to produce high quality fruits. Sterilization or renewal of this medium faces the present difficulty of environmental pollution and labor.

5. Sand Culture

Coarse and fine mixed-sands, mainly used for lettuce production, have good physical and biological properties as natural growing media. Since the growing techniques are quite similar to those of conventional soil-culture, few difficult problems arise in this growing system, except for sterilization or renewal of the medium.

In recent years, horticultural plant production in Japan changed from a classical production-oriented market to a customer-oriented market. It is no longer the grower who decides about the amount and quality of the products. One of the results is a change from large amounts of a single quality and bulk products to a very segmented presentation of products with different qualities and with added values. In this situation, it is important for the grower how the consumers look at the sustainability of cultivation methods. Many consumers are paying their attention to the environment-friendly growing methods.

New model technology of vegetable cultivation in Japan to solve the problem of arable land and planting material are quite limited, and sometimes having an insufficient sun light can be troublesome. These factors have resulted in low quality produce. So Japan had invented a new technology called "Plant Factory" that will fix all these troubles, as an answer for the current situation. The use of Light Emitting Diodes (LED) is better than fluorescence in term of higher efficiency, cost saving with longer life time, and releasing little amount of heat while being in uses. Plant Factory with LED gives light for photosynthesis 16 hours per day and induces with higher CO_2, it gives yields better and spends shorter time when compared to normal cultivation. (Pomrit, 2013: 182-185).

Ikeda (2013) stated that plant factory is a new innovation of soilless culture which suitable for a small area for those who live in the city with various production systems. More environmental factors can be controlled for the most effective way in Plant Factory. Plant Factory in the greenhouse can control environment suitable for plant growth. Growers should understand what is the plant needs to grow and manage under suitable condition for high density production such as light from LED, CO_2, nutrient solution, temperature, humidity etc. Growers can produce high quality and yields all year round. In Japan, crops grown in Plant Factory are herbs, lettuces, tomatoes and vegetable seedling. Sensors with computer programmer are used to control what the plant needs. With vertical farming, Plant Factory is the intelligent plant growing system in the advanced greenhouse and/or in the artificial environment. It can realize:

Highly efficient plant growing,
Stable and scheduled crop production,
Clean and valuable crop production,
Horizontal or vertical farming.

Jarujareet and Oshita (2013) stated that the new technology, micro and nano - bubbles (MNB_s) for horticulture and agriculture will help with plant germination, plant growth, better root development, reduction of micro-organism and maintain the quality of the products especially for cut and ready to eat salad. This is one of many well done researches from Agri-foods for Health + Wealth 2013.

A Japanese scientist is the pioneer in this research and can develop micro and nano-bubbles quite stably. In hydroponic systems, MNB_s can increase oxygen dissolve of the nutrient solution, then it gives better a lettuce root system, good nutrient absorption, high yields and rapid harvest (Jarujareet and Oshita,2013 :183-185).

2.3.2 Recent hydroponic in Australia and New Zealand.

Hydroponic growers can meet the stringent catering specifications set by the Sydney Organizing Committee for the Olympic Games (SOCOG). The main hydroponic crops in demand for Olympic supplies are tomatoes, lettuce, cucumbers, capsicums, eggplants and strawberries. But hydroponic flower grower will be big winners too (Wilson, 2000: 19).

Wattanapreechanon (2012) Stated that in Sydney, some farms grow vegetables employing with hydroponic systems all year round. Health conscious customers accepted on safety, good hygienic with standard of growing technique. Especially, growers earn more money with high price in winter. Accent Hydroponics Company sells all equipments and fertilizers not only in Australia but also exports world wide. The same as farmers in New Zealand, they concentrate on bio-control to prevent pests (Wattanapreechanon, 2012: 171-173).

Hydroponic Lettuce has been produced in New Zealand for many years, but has increased dramatically in popularity during the early 1990's. There still is an increasing number of outdoors lettuce units being installed, which a number of large established greenhouse growers also exist. Many outdoor growers install a simple farm of cloche over the individual lettuce tables for crop production. Some growers have automatic pH and conductivity controllers on their systems, while most smaller producers rely on manual control. Other crops that grow in soilless culture are watercress, tomatoes, egg plants, capsicums, roses, anthurium, etc (Wattanapreechanon, 2011: 134-140).

2.3.3 Soilless culture in Israel

Israel intends to provide intensive food production in a limited area. Its restraints are sources of fresh water and nutrients. Therefore, it has potential application in providing food in regions having vast areas of nonarable land, such as deserts.

Noomnu said that soilless vegetable cultivation in a greenhouse is another modern technology that Israelis are using to overcome water, temperature, humidity and pest problems. Soilless culture in an evaporative cooling house with controlled sunlight, temperature, humidity, nutrient solution concentration by a computer controller, automatic water sprayer, net screen room before entering to control insects and insects strictly taps are very effective in growing vegetables in the desert area at Arava region, Israel. By using NFT for leafy vegetables and coconut coir for substrates culture in planting fruit vegetable, e.g. sweet peppers, they can produce many economic off-season crops for their own consumption and exports (Noomnu, 2013: 139-142).

2.4 History of Soilless Culture in Thailand

It was in 1957 that soilless culture was started at The Botany Department, Kasetsart University, for academic study and researches (Satiensawas, 2003). During her visit to Israel in 1977 and to Japan in 1983, H.R.H. Princess Maha Chakri Sirindhorn observed the agricultural development including the hydroponic system at the commercial scale. She came up with the idea that the soilless culture techniques could possibly be useful for future agricultural development in Thailand. On the celebration of the King's 60^{th} Birthday Anniversary in 1987, the Food and Agriculture Organization granted financial support for research and development of soilless culture for crop production in Thailand to be conducted by the Faculty of Agriculture, Kasetsart University in collaboration with the Royal Development Projects, Bureau of the Royal Household. The purpose of this project was to do the research on the use of soilless substrates for crop production in Thailand. The project concentrated on alternative means of crop production for small farmers in the areas of problem soils (e.g. sandy, saline or acid-sulfate soils) which covered about 30% of arable land. The target of the project was to develop methods of crop production using locally available materials such as rice hulls and coconut coir as planting media. If successful, such technology could be useful for crop production by small farmers.

Another aspect of the project was the more complex and demanding techniques of hydroponics, i.e. crop production in nutrient solutions with or without an inert solid substrate, The project therefore included the construction of a small, automatically controlled hydroponic system. The experiments were conducted on various crops and growing techniques to best suit local requirements, climate and facilities. The developed simple procedures could quite easily be used by farmer. The project had set up 3 soilless culture trial centers, 2 at Kasetsart University, the Soil Science Department and the Botany Department, one at the Royal Development Project at Chitralada Palace.

2.4.1 The Royal Development Project at Chitralada Palace

The trials were on the soilless substrate from local materials and the forms of containers. Many local varieties of crops were used in the experiments such as vegetables like Chinese kale, pakchoi, coriander, green onion, cucumber and muskmelon; flowers and ornamentals plants like miniature roses, marigolds, petunias, cordylines and codiaeums. A complete system to control pH and conductivity from a United Kingdom supplier was installed at Chitralada to be used in maintaining nutrient levels for both Nutrient Film Techniques and Deep Flow Techniques. Some crops e.g. lettuce, Chinese celery, green onion, coriander, cucumber, muskmelon, tomatoes grew well with this hydroponic system (Wattanapreechanon, 1993)

2.4.2 Kasetsart University, Bangkhen Campus at the Soil Science Department

The study of soilless substrate with some crops e.g. Chinese kales, pakchoi, tomatoes etc. were conducted. At the Botany Department the experiments on nutrient formulation suitable for some crops e.g. chili, water convolvulus, yard long bean, and some ornamental plants like fern, were studied.

2.4.3 Kasetsart University, Kamphaengsaen Campus at the Soil Science Department

Experiments were done on the use of soilless substrates and containers with some crops e.g. Chinese cabbages, Chinese kales, cucumbers, muskmelons, chili and tomatoes.

The FAO funded project terminated in 1989, but the research team carried on with their works in collaboration with the Japan Society for the Promotion of Science (JSPS*)* through the National Research Council of Thailand for another 3 years, 1990 to 1992, under the project entitled "Comparative Studies on Conventional and Improved Techniques in Controlled Environment for Crop Production".

In 1997, under the technical cooperation program between the Royal Project Foundation and the Republic of China or Taiwan, a financial support was granted for research and development of the Dynamic Root Floating Hydroponic Techniques as a means to grow vegetables on the highland all year round (Kao, 1997). Since Thailand's economic crisis in 1997 followed by bird flu in 2002, soilless culture or hydroponic has expanded throughout the country as the private sectors had obtained the technology from the developed countries, and could produce up to 16 crops of leafy vegetables with consistently superior quality, high yield, and rapid growth all year round (Montri and Wattanapreechanon, 2006).

The research findings were published and released to public, including the Ministry of the Agriculture and Cooperatives, and attracted interests of many scientists concerned resulting in a lot more research works from the Botany Department of Chulalongkorn University, the Soil Science Department of King Mongkut Institute of Technology Ladkrabang, Maejo University, and the Royal Project Foundation (Wattanapreechanon, 2007).

The private sectors started the first farm in 1987 at Na Dee Ta farm, Samut Sakhon province. They grew the leafy vegetables e.g. Chinese kales, Chinese cabbages, and pakchois, using the aerated technique from Taiwan.

The soilless culture or hydroponics has expanded throughout the country since the private sector has obtained the technology from the developed countries. They also imported planting material and equipments e.g. new varieties of seeds, substrates, and plastic gullies.

In 1995, Mr. Apitep Tuntiseree, the Manager of the Accent Hydroponics (Thailand), Co., ltd., introduced the first Nutrient Film Technique similar to that of the Accent Hydroponics, Australia, at a lettuce farm in Bangkok, and since then it has been used in growing lettuce in Thailand.

In 1997, G.P. Technology started their hydroponic farm by growing lettuce and herbs using Nutrient Film Techniques. They also grew cucumbers and table tomatoes with the substrates culture in the evaporative cooling system house.

With the expansion of soilless culture in Thailand, the Thai Soilless Culture Forum was set up on 30 March 2004 to serve as the center for members to exchange knowledge and experience.

2.5 Soilless culture / Hydroponic Development in Thailand.

After HRH Princess MahaChakriSirindhorn graciously suggested that soilless culture techniques should be seriously studied and developed in Thailand. Many research works on soilless culture were carried on by many universities and research institutes. Various research report were presented to the public.

Muskmelon could be grown in some agricultural wastes that easily found in the country such as rice husk, coconut coir and chopped coconut husk as substrates for growing by means of soilless culture. When compared with sand culture at the Royal Development Project, Chitralada Palace in 1990, it was evident that all substrates in this experiment could be utilized as soilless substrates, and the mixture of rice husk, sand and coconut coir (1:1:1) was the best (Wattanapreechanon, Wattanapreechanon and Samart, 1991a).

Among the Japanese muskmelons grown in Nutrient Film Techniques (NFT) at the Royal Development Project, Chitralada Palace in 1990, the “Bonus” variety worked best in this system. The growth was excellent with the average fruit weight at 1.1-1.3 kg. and the sugar content at 11-17% Brix (Wattanapreechanon, Wattanapreechanon and Samart, 1991b).

Comparative studies were conducted on four varieties of Japanese muskmelons, namely, Shinju 100, Shinju 200, Earls Seinu Summer 2 and Earls Seinu Sumer 3 grown by the Nutrient Film Techniques (NFT) at the Royal Development Project, Chitalada Palace in 1991. It was found that all varieties could grow well with the fruit weights at 0.4-2.4 kg., and the highest sugar content at 16 Brix (Wattanapreechanon and Wattanapreechanon, 1991).

A feasibility of using some agricultural wastes as growing media for off-season tomatoes by soilless culture was studied during February to November 1991 at the Royal Development Project, Chitralada Palace. The medias used were sand, rice husk, coconut coir, rice ash, sawdust, bagasse and rice straw. It was found that the best growing medias were coconut coir (46.9 fruit and 715.2 gram/plant in variety Zombee) and those mixed medias with coconut coir such as sand + rice husk + coconut coir (1:1:1 by volume) mixture (30 fruit and 2,092.6 gram/plant in variety Sauce peto). The lowest yield (8.4 fruit and 127 gram/plant) was found in sawdust. For other media, mixture with rice husk or rice husk and sand gave better results (Wattanapreechanon and Wattanapreechanon, 1992).

Lettuce (*Lactuca sativa* Linn.) and Chinese celery (*Apiumgraveolens* Linn.) were alternatively grown for 3 crops, each in a recirculating hydroponic system at the Royal Development Project, Chitralada Palace, during June 1991 to May 1992. Fresh and dry weights, yield, cost and incomes were recorded. The results showed that it was feasible to grow them at the commercial scale. When the products were sent for analysis by the Department of Agriculture Laboratory, it was certified that, there was no residue of pesticide (Wattanapreechanon and Wattanapreechanon, 1993).

Bangchaud (2001) had study an analysis of financial return of 2 commercial hydroponic farms, Fresh HydrofarmCo.Ltd in which cultivating equipments were imported from abroad, and Meaklong Vegetable Co.Ltd in which equipments were modified and produced domestically. The results of financial analysis of the investment in hydroponics vegetable farm of 2 farms showed that both farms were financially feasible, the break even prices were 50.11 and 49.47 baht per kilogram while the break even yields were 25,725.60 and 65,097.00 kilograms per year, respectively.

Pimkote's studies (2003) on growth and nitrate accumulation in 'Cos' and 'Red oak' lettuces, grown in two concentrations of the Enshi solution (1.2 and 2.4 mS/cm) were compared during summer season of 2000 (March-April) and winter season of 2001 (November-December) in the open-air plastic greenhouse. The nitrate contents in the lettuces grown in both nutrient solution concentration were increased as the growing time increased and reached the highest values at week 5^{th} which exceeded the EU's regulation value for nitrate residue level of 3,000 mg/kg fw. Withdrawing the nutrient from the growing solution 4 days before harvesting was found to be the most effective method for reducing nitrate content to below the EU's regulation level for safe consumption in the 'Red oak' lettuce grown in 1.2 mS/cm nutrient solution without significant reduction in yield but not for 2.4 mS/cm.

Orchid, one of soilless cultures and is the most important flower export for Thai economy and Thailand was the biggest orchid producer in Asia. The popular varieties were *Dendrobium, Vanda, Cattleya, Paphiopedilum, Mokara* and local species. In 2004, the export value of orchid was over 2,000 million baht with 2,500 farmers and more than 300 export companies from approximately 3,165 ha of orchid plantation involved (Sangruksawong, 2004).

In Thailand, the automatic hydroponic control system already exists. The big problem is that Thai cultivators have to import the system from foreign countries, which is very expensive. There is also a problem with the after sale service. Therefore, the lower cost of automatic control system for hydroponic is a good alternative for Thai agriculture (Fuangpreechawai, 2005: 2).

There are numbers of commercial hydroponic vegetable planting systems in Thailand which required different capital investment to study the characteristics of hydroponic vegetable production systems by using DRFT method and PC method (PVC gullies). Jongjairuk (2005) found the result of the study showing the average product price of 42.99 baht and 40.00 baht per kg for both methods. The financial analysis of this hydroponic vegetable planting farms showed that both methods were financially feasible.

Luangna (2006) had studied growing lettuce in hydroponic system. The result showed that shading for lettuce growing in hydroponic system with 60% slan cover gave higher yield with very highly significant when compare with no shading. Shading of the crop can effectively to reduce air temperature under strong sunlight condition.

Reablerthirun (2007) recommended the checking of the germination test before using seeds in order to save labor, cost of seed and suitable time for transplanting in vegetable production. Plate method is an easy technique, using 100 seeds place on top of a damp tissue paper or cotton sheet in plastic box, cover them with plastic cover to keep humidity, and keep them in the 18-27 °C room (for temperate lettuce, it is recommended to keep it in 4-10 °C) for 2 days. Counting the seedling between 2-6 days, that is germination rate (Reablerthirun, 2007: 88).

The feasibility study to grow vegetable by using hydroponic system had set up in Sarapee district in Chiang Mai province which was 16 kilometers from the city. The farm areas of 3 rais used NFT system which was a popular system suitable for Thailand. From the result of the financial analysis, the total project investment life time was 10 years. This project used the operating cash flow to calculate the feasibility of investment which payback period was 2 years 11 months and 18 days. The project was feasible for the investment (Srinuanjan,2008).

Somchaiwong and Thampanya (2008) developed an automatic controller of some growing factors, the result of controlling the growing factors such as temperature and electrical conductivity of nutrient solution can decrease the burden of labor in growing hydroponic vegetable, and can increase O_2 dissolved in the solution.

Chamsawang (2008) and Chiemchaisri (2011) recommended that, adding spore suspension of *Trichodermaharzianum* (especially CH-Pin-1 of Kasetsart University) can prevent root rot caused by *Pythium* sp., stimulate growth and increase overall disease resistance of hydroponic vegetable. It also prevents the deposition of calcium phosphate in the growing gulley.

Spraying leaves with suspension of the *Trichoderma* that has been aerated for 12-24 hours with or without small amount of trace elements can improve growth and reduce leaf spots due to *Cercospora* sp., *Corynespora* sp. and *Alternari*a sp. to a large extent. Chamsawang (2113) stated that *Bacillus mycoides*, *Bacillus amyloliquefaciens*, *Bacillus cereus* can decrease root rot in summer or dry season. However *Trichoderma* and some *Bacillus* can not apply at the same time, because it antagonistic each other.

Biological pest control has become a popular alternative to the conventional or chemical counterparts. One of widely used biological pest control is a microbial insecticide *Bacillus thuringiensis* (B.t.). It is a bacterium naturally found in soil that can produce poisonous toxins to many types of insects. Numerous insecticides available on the market have the B.t. toxins as the active ingredients. B.t. is considered as an ideal agent for pest management because of its specificity to the pests and its minimal toxicity to both humans and other natural enemies of the target crop pests. There are various strains of B.t. and each strain has a high specificity to particular crop pests. In order to gain the effectiveness from B.t., target insect in the immature, feeding stage of development (larvae) need to ingest B.t. directly. It is ineffective against adult insects and is referred to as a stomach poison. B.t. crystals secreted from the bacteria dissolve in response to intestinal conditions of susceptible insect larvae. This paralyzes the cells in the gut, interferes with normal digestion and ultimately triggers the insect to stop feeding on host plants. B.t. spores can then invade other insect tissues and multiply in the insect blood stream until the insect dies. Death can occur within a few hours to a few weeks after B.t. application depending on insect species and the amount of B.t. ingested. From the studies in other animal species birds, guinea pigs, mice, rats and also in humans, B.t. has not shown acute toxicities. At present, Thai researchers can separate and reproduce local B.t. strains that are more suitable to agricultural environment in Thailand (Chanpaisaeng, 2011).

Reungrak *et al*. (2011) stated that coconut coir is low cost agricultural by product from coconut fiber industries. It is high potential to be used for substrate in tomatoes seedling to substitute high price of peat moss. Coir fiber has excellent structural properties, including high air filled porosity and water holding capacity. It is recommended to put coconut coir in 0.01% phosphoric acid for one month before using. Mixed substrate of coconut coir and ceolite (1:9 and 1:10) are recommended.

The summer season in Thailand is characterized by high temperatures above 40°C. This indicates that summer cropping is generally difficult to obtain satisfactory results without cooling instruments. Solar radiation is too strong, so it needs economically to create optimum temperature for plant growth by installing cooling units. Nantakit (2012) stated that temperate lettuce grows well at 10-25°C during winter in Thailand. However, in summer or rainy season with temperature increasing between 35-40°C, it is difficult to grow and yield decrease rapidly. Some farms can not harvest without some special equipment e.g. a nutrient solution chiller, water spray, shading etc. It needs to manage environmental suitable for lettuce production. So that we can grow temperate lettuce all year round with stable supply.

Planning and design for commercial NFT lettuce production are very important to growers. It should be synchronized the consistency between each stage of plant growth. Farm design should be easily for transplanting, harvesting, packaging and transportation to decrease cost of labor and times.

Yuktanun (2012) cited that, the decrease in nutrient solution temperature to lower than 30°C with the cheaper system is quite suitable for hydroponic growers. Mae BuaLuang hydroponic farm has invented an air cooler for nutrient solution which is cheaper when compare to a chiller with liquid gas compressor. An air cooler is modified from used car air supercharger to compress air passing through car cooling grill and fan with water springer to decrease air temperature and blow out pass through the tube to release cooling air into nutrient solution. It can decrease nutrient temperature to be approximately 27-29°C for the growing crop.

Chinese kale was grown in NFT system with 1.8 mS/cm and pH 6 for seedling, then changed to 3.5-4 mS/cm after 11 days, and applied *Trichoderma* (100 gm with 200 Liter) solution. Chinese kale needs strong sun light. After 25 days, high EC up to 3-3.5 mS/cm with pH 5.5 is given and some trace elements e.g. Fe, Nic spray, Ammonium molypdate and monopotassium phosphate added. After 33 days, EC should be decreased to 2.5-3 with pH 5.5. After 39 days, EC should be kept between 2.0-2.5 with pH 5.5. The harvest can be done at approximately 45 days. Growers can harvest the bigger stems and high quality kales to the high end market (Suboonsun, 2012: 205-208).

Senadee (2012a) stated that the owner of ACK hydro farm in NakhonRatchasima pointed out that his hydroponic farm was undertaken under Good Agriculture Practice with good management and yield all year round. He also had his own research and development on farm. His farm not only concentrated on vegetable production but also salad processing and new design of packing. Most of ACK vegetable products are grown in evaporative cooling houses with control temperature and humidity. He also paid attention to hygiene, safety and no residue effect on every stage of production for the health conscious groups. This farm can produce 80-100 tons of vegetable per month.

Hydroponic for the new generation : a university graduate, who has been in the loop of hydroponics since his student days had foreseen the future of hydroponic vegetables where the demands are growing higher and higher. He had rented an area of 3 rais or 0.48 hectare at Lard Krabang to produce more than 1 ton of vegetable a week and yield is only going higher. He can harvest approximately 24 crops per year with an automatic controller for nutrient solution. This farm can get a stable price and yield almost all year round (Senadee, 2012b: 151-156).

Greenhouse has become necessary to many growers due to climate change that causes a lower yield with lower quality effect. Greenhouse will be the answer to control limited factors such as pests, diseases, rain, temperature and sunlight. Just like what the Israelis say, "We are God in the greenhouse." Also on visiting greenhouse technology in Pakchong, NaknonRatchasima province, we can see how growers can produce good quality vegetable.

Greenhouse agriculture in tropical climate

Due to an unpredictable climate, the greenhouse technology has become necessary in vegetable production as well as other crops. For tropical climate, this technology needs to be developed by keeping humidity at 60-80 %. If humidity is more than 80%, it will be damaged by disease (Senadee *et al*., 2013: 148-153).

Advantage of greenhouse in plant production

1. The environment inside can be controlled. (temperature, humidity, rain)
2. It can protect insects and diseases.

3. It can save fertilizer use to 70% and also water.
4. It can predict the quality, yield for the high demand.
5. High efficiency of using land for plant production.
6. Environmental friendly.

Thailand started to grow cash crops like temperate lettuces because of the need to produce vegetable due to the growing number of tourists and health conscious. Thai consumers are the important market with the safety and environmental friendly crop production. The success of growing crops in greenhouse depends on knowledge, understanding and selecting the greenhouse type, fertigation, substrates suitable to vegetable, cultural practice, post harvesting and management of marketing due to the cost of investment in greenhouse which is quite high, approximately 800 – 3000 baht per square meter. If growers lack of knowledge and understanding in crops production, their business will be at risk. Most of crops grown in these greenhouse are leafy vegetable e.g. : temperate salad, spinach, leafy chrysanthemum, water cress, rocket, misuba, misunas; herbs e.g.: rose marry thyme, sage; fruit vegetable e.g. bell pepper, table tomatoes, egg plants, Japanese cucumbers, muskmelons, strawberry, grapes (Tongkate and Senadee, 2013: 85-108).

Consumption demand of popular local vegetable is in fact higher than exotic vegetable. Local vegetables e.g. Chinese kale, Chinese celery, Chinese cabbage etc. are routine food for Thai consumers and can successfully be grown by using hydroponic system at Siam Hydro Farm. Bigger market and safety, good hygienic with standard of growing technique can convince customers to buy hydroponic vegetable (Senadee, 2013: 177-180).

Higher temperature and humidity in Thailand can create troubles in growing plants without soil. Evaporative cooling house at Mae Bua Luang Hydroponic, growers can solve the problem by decreasing the temperature and controlling the humidity at suitable environment for plants to grow well. At the same time, it can reduce insects, diseases, pests, heavy rain and bring better quality and yield through out the year. The owner of the farm can pay turn over the cost of investment in 2 years (Senadee and Suboonsan, 2013: 143-146).

A new model of restaurant with hydroponic farm can increase value of vegetables. Small business gives income and happiness to the owners with less risk. It includes new service like vegetable basket with good decoration for birth day or new year gifts (Sirinupong, 2013: 119-121).

Some farmers can produce 24 crops of vegetable per year by harvesting vegetable twice per month, using the fallowing steps (Sirinupong, 2013: 128).

1. Seedling and transplanting to first nursery gulley for 2 weeks.

2. Transplant to second nursery gulley for 2 weeks.

3. Transplant to finishing gulley for 2 week and harvest. It is approximately 42 days early or late harvest depending on the seasons for example : growers can harvest early in winter and very late in summer.

Aquatic plant Centre, the big aquatic plant exporter has chosen NFT and DFT to produce more than 150 varieties of aquatic plant for export. Millions of*Anubias sp.* are grown in evaporation cooling house and export to Japan, USA, and E.U countries. One advantage of growing plants in evaporation cooling house for export is to decrease diseases and nematodes on plants (Sirinupong , 2013 :138-139)

2.5.1 Recent Soilless culture / Hydroponic farms in Thailand

There are various soilless culture systems in Thailand. Approximately, 97 % of the areas (3,150 ha) is substrate culture, especially for the production of orchids, fruits and vegetables followed by 3 % for water culture (70 ha), and <1% in aeroponic production (1 ha) of vegetables and aquatic plants. In hydroponic systems for vegetables, 40 % of the area (50 ha) is in substrate culture, 26% in the dynamic root float technique (DRFT), 20% using the nutrient film technique (NFT), 13% in deep flow technique (DFT) and 1% in aeroponic for vegetable production (Table 1). The five main growing systems in Thailand are listed below.

Table 3 Classification and estimated area of soilless culture growing in Thailand.

System	Crops	Area (ha)
NFT	Temperate lettuces	25
DRFT	Temperate lettuces, local vegetables (Chinese cabbage, Chinese celery, Chinese kale, water convolvulus etc.	32
DFT	Temperate lettuces, musk melon,	13
	aquatic plants.	3
Aeroponic	Temperate lettuces	1
Substrate	Sweet peppers, tomatoes	50
Coconut fiber and coir	Musk melon	
SubstrateCoconut husk	Orchids	3,100
	Total	**3,224**

Source: Montri and Wattanapreechanon (2006)

2.6 Hydroponic in the near future.

Hydroponic is a valuable means of growing fresh vegetables not only in countries having little arable land and in those which are very limited in area and have a large population. It could also be particularly useful in some smaller countries whose chief industry is tourism. In such countries, tourist facilities, such as hotels often take over most arable areas of the countries, forcing local agriculture out of existence. Hydroponics could be used on the remaining non-arable land to provide sufficient fresh vegetables for the indigenous population as well as the tourists. Typical examples of such regions are the West Indies and Hawaii, which have a large tourist industry and very little farm land for vegetable production (Resh, 1993: 25).

In the future, we will see more hydroponic food production in underdeveloped countries, where it presents significant potential for improving dietary standards. As hydroponically grown food is of consistently superior quality and high in nutrients, it has the capacity to reduce the effects of malnutrition and other diseases commonly associated with extreme poverty conditions (Paul, 2000: 29).

Jarujareet (2013) stated that creating a controlled environment by understanding plant physiology and plant's responses to environmental conditions such as light, temperature, humidity for plant to get better yield. Using Light Emitting Diodes (LED) for photosynthesis in plant factory will result in better growth and improved quality of products.

Vertical agriculture is small soilless culture with intelligent plant growing system in the artificial environment. It can result in highly efficient plant growing, stable crop production, clean and valuable crop production, and can be done horizontal or vertical farming. It is an alternative farming for crop production in the future which undertaken in Japan and some developed countries (Jarujarreet, 2013: 183-189).

Ikeda (2013) stated that plant growth is significantly higher in a greenhouse or in controlled environment than in an open field. Crop yield in soilless culture is much higher than in soil system. By creating a controlled environment, and by understanding plant physiology and plant's response to environmental conditions such as light, temperature, humidity, CO_2 concentration, air movement(wind), mineral, O_2 concentration and pH in rhizosphere, etc. With suitable factors, growth and quality of plants can be significantly improved.

However, understanding that plants growth as a result of photosynthesis, more yield of better quality products and additional economic advantages can be expected. Nowadays, plant can be grown even under unfertile soil and extreme conditions such as the polar areas.

Hydroponics was usually claimed to involve high initial capital cost and the complexity of the system operation. However, these problems could be reduced by using new simplified hydroponic methods and simple equipment. As in the case of Japan, farmers can simplify high technology by using local material and simple equipment to grow vegetable by themselves (Ratanakosol, 1997: 587).

Thailand, like other countries in the tropics, is influenced by the monsoon. During the rainy season (334 mm in September) in which various crops can be damaged, more or less, due to the heavy rainfall and severe plant disease attacks. Not only the chemicals used to control pests and diseases are very expensive, but also the requirements of high quality, less or free of pesticides residue in vegetables, both for the consumers in the country, and those for exports, these raise the awareness of clean environments, and alternative methods of growing plants have also been considered (Wattanapreechanon and Wattanapreechanon, 1997: 83).

The old style greenhouses in which growers are conscious of only the temperature has limitations on the plant growing. Stable, high productivity and quality crop production are required from the market. Lots of people are expecting the new industry different from old agriculture as a business. Science and technology for crop production are rapidly developing.

3. Hydroponic and its effects

Hydroponic technology give a great result in increase food production and income, improve product quality and increase the diversity of food to achieve food security. It is a high technology and can be modified to use for cash crops all year round. Soilless plant production in greenhouse is the most environment friendly growing technique because it can decrease the use of chemical pesticides and realize the efficient use of natural resources.

3.1 Hydroponic and environment.

The hydroponic system, which the surplus nutrient solution is recovered and recycled such as NFT, DFT, DRFT and aeroponic or closed system is a highly efficient system and may be the best system that should be recommended to growers because the cost of nutrient is low and it is environmental friendly (Tuncho, 2005).

From ecological point of view, the transition from the open system to the closed one should be requested as the common practice for hydroponic system in the near future (BÖhme, 1995).

Many researchers have been conducting experiments on the disinfection of the drain water and the nutrient management method for recycling solution (Benoit and Ceustermans, 1995).

Using agricultural waste and local resource to replace other imported substrates for growing plants is a good solution. Rice husk and rice husk charcoal are of ideal physical and chemical characteristics for soilless culture, and get good production output. These substrates can regenerated natural resources and not result in environmental problems. Therefore, much attention has been paid to these substrates recently, considerable researches in this regard were conducted. Agriculture waste such as rice husk and rice husk charcoal used for soilless substrates in replacing other substrate has received successful result and shown great economic potential as well as environment protection. Using local resources for soilless substrate can decrease cost. Two or three substrates are often mixed to improve physical and chemical properties. The advantages of this substrate include : good porosity., good drainage, good absorbability when reused, low volume weight easy to transport and slow degradation. Sand and coconut coir are always mixed with rice husk to improve the drainage.

Many different substrates have been tested for growing vegetable. Urethane foam cube or mixture of rice husk charcoal, sand and coconut coir (1:1:3 v/v) are good for seeding medium. The key factor is to transplant only healthy and vigorous seedlings. The transplant of weak or stunt seedling would not do well (Satiensawas, 1998.).

Coconut fiber imported from South-East Asian countries became popular for growing potted ornamental plants in Japan. It was a new substitute material which was environment friendly. Hydroponic growers were interested in the use of this growing media which was thought to be a promising environmentally friendly substrate for soilless culture. It had the potential as growing media in term of environmental friendliness (Shinohara *et al*., 1999).

Sand was generally best used in combination with other media for a higher water holding capacity and lighter nature. Sand should be purchased in a pre-washed state to eliminate any salt and silt which may contain fungi and weed seeds (Morgan and Lennard, 2000: 34).

Rockwool is making a major impact on horticulture around the world. It was first seriously considered as an inert substrate for glasshouse crops. The most important features of rockwool are those related to the way it responds to watering and feeding. It is totally inert chemically except for some minor effect on pH and it does not modify any nutrient solution which is applied to it (Smith, 1987: 3).

A new hydroponic system that did not require the use of electricity was developed. In this system, the irrigation of culture solution was achieved by gravity action and the supply of nutrients for crops by capillary action. High yield of tomatoes, sweet potatoes, melons and Chinese mustard using this system were obtained (Sakuma and Suzuki, 1997).

Strawberry growers worldwide fumigate the soil with methyl bromide before planting to control soil borne diseases, insect pests, and weeds. This fumigation is essential since it can result in high yield and high quality fruit. But growing strawberries hydroponically eliminates the need for methyl bromide on this crop (Stanley, 1998).

In examining the effect of hydroponic cultivation on selenium (Se) uptake and assimilation in garlic seedlings with potassium selenite for an additional week, when a sulfate-free nutrient was used for Se addition, the results demonstrate that hydroponic enrichment of Se in garlic seedling could be a practical means of producing organic Se compounds for nutritional supplements. Garlic enriched by selenium (Se) could be an excellent source of dietary Se for cancer chemoprevention.

The production of high Se garlic requires Se-fertilized soil, but such soil may pollute the environment (Tsuneyoshi *et al.*, 2006).

The 2011 floods in Thailand had big impact on lack of vegetable supply to the market not only in the central plain, but also in the eastern part of the country. To get advantage on these situation Ban NoenSumran society in Rayong province has set up hydroponic farms to grow crops for their own consumption and expanded to supply to local market with high income under the supported from Thai Women Empowerment Funds. Women, children and senior citizens could do the tasks without additional help. Home grown quality fruit and vegetable could be produced almost all year round. It could be an exciting family hobby and a means of earning some supplementary income. Each grower can get more than 10,000 baht/month. Most of farmers grow popular local crops with safety techniques at a reasonable price such as water convolvulus, Chinese kale, yard long bean, etc. with the harvest period between 20 – 45 days (Anonymous, 2013: 19).

Senadee and Kusakul (2013) stated that global warming has caused a major effect on farm cultivation. Open field cultivation is hard to control due to several factors such as rain, wind, sun, temperature and humidity. It become quite difficult for growers to control these factors and of course it may resulted in a low quality yield. And so greenhouse technology has become quite significant these days for the growers to be able to control and reduce the risk of natural disasters.

Evaporative cooling house, these type of greenhouse use pad and fan to control temperature and humidity. Water flow down pass through pad which make of paper fiber to evaporate, vapor at the same time can decrease temperature 4-6°C and make high humidity in the greenhouse.

Aquaponics: alternative of aquaculture with hydroponics.

Environmentally-friendly horticulture system should be promoted. Farming is not simply an economic activity, it is a way of life, both ethical and ecological. The concept of environmentally-friendly horticulture is a new concept, it comes back as a relatively recent response to the decline in the quality of the ecosystem and natural resource bases linked to conventional chemically-oriented one. To make horticulture more environmentally by changes in farming system and management, using sources of organic technology and materials, had to be reinforced, while ensuring alternative technologies to enhance resource-poor family farmers' real income, community food security and protecting the human health and environment (Kim, 2006).

In the search for intensive and efficient small to medium scale food production system aquaponics represents a clear option that must be considered within the menu of possibilities. The traditional concept of aquaponics is the combination of fish production in closed containers (aquaculture) plus hydroponic crop production using that same water (Radulovich, 2012).

3.2 Hydroponic and agricultural development.

According to Dr. Mosher, agricultural development is a combination of 6 different aspects (Leagans, 1971)

3.2.1 Arable land expansion, which refers to the condition utilized for agricultural production, employing additional labor and capital instruments,

3.2.2 Productivity improvement, which refers to higher yield per acre or per head of livestock,

3.2.3 Overall agricultural growth, which refers to the growth of agricultural production in contributing to national economy, no matter from agricultural land expansion or productivity,

3.2.4 Farmer's productivity improvement, which refers to the increase of farmers' income from agricultural production,

3.2.5 The rising income per employee in agricultural production, 3.2.6 The agricultural transformation, which refers to the situation when people in the agricultural sector leaves their land for other occupations.

The hydroponic agricultural production could effectively contribute to the five last categories above, but not the first as it does not require large land for cultivation.

In actual cultivation, soilless culture offers faster plant growth and higher yield to be compared with the conventional soil culture. At the same time, a more even supply of nutrient solution can be achieved to many plants and so more homogeneous crops can be obtained. In soilless culture, the quality of products is easily controlled and high quality products can be produced. It means that the grower can get more income in soilless culture than in conventional soil culture. (Figure 6)

Cultivation for stable plant production
We need the control of environment
Air and root zone temperature
Air humidity
CO_2 concentration in the air
Radiation (Light intensity/quality)
Wind
Nutrient solution ; pH, EC, composition and concentration of minerals,O_2 conc., flow rates

Figure 6 Stable crops production.
Source: Ikeda (2011a)

Furthermore, growers going to become rich people because of the stable production of crops and stable supply of quality product. Growers can earn high income with stable price which consumers are happy (Figure 7).

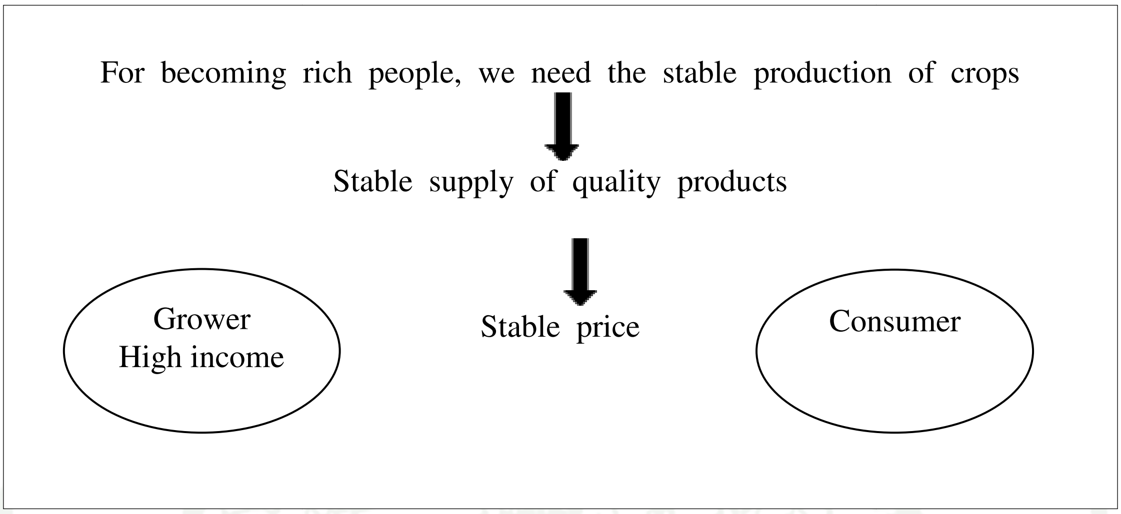

Figure 7 For becoming rich people.
Source: Ikeda (2011a)

To get stable production of crops, growers need to control changeable climate condition (Figure 8)

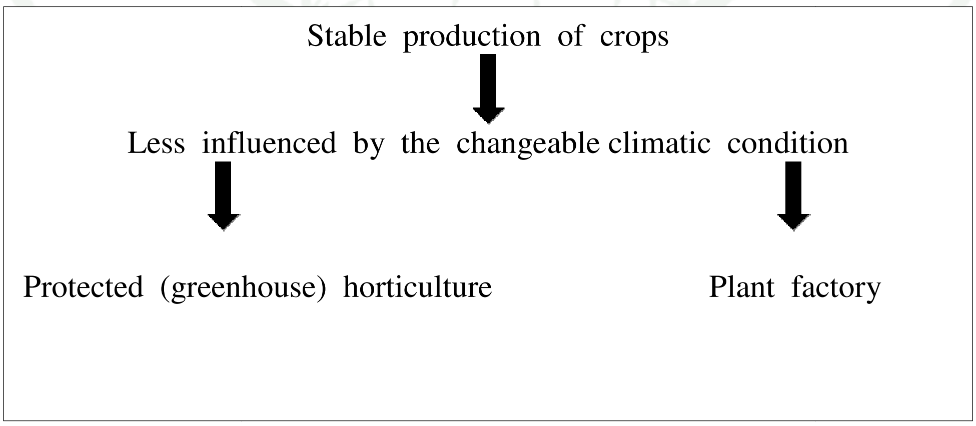

Figure 8 How to get stable production of crops.
Source: Ikeda (2011a)

In addition, the image of agriculture should be changed (Figure 9)

The image of agriculture should be changed

From	**To**
Dirty	Clean
Hard work	Light work
Bad working condition	Comfortable working condition
Low income	High income

Figure 9 Agriculture should be changed.
Source: Ikeda (2011b)

4. Adoption of technology.

Technology including idea, knowledge, method, practice or technique was one of the means to achieve the improvement of productivity and income. It would be accepted as valuable under the following conditions (Sukprasert, 2008: 244).

1. It was practicable as supported by evidence of scientific proof and credibility.

2. It was flexible or can be applied or modified for further development.

3. It could lead to multiplied effects, with various target groups continuing to transfer the technology to others (Figure 10).

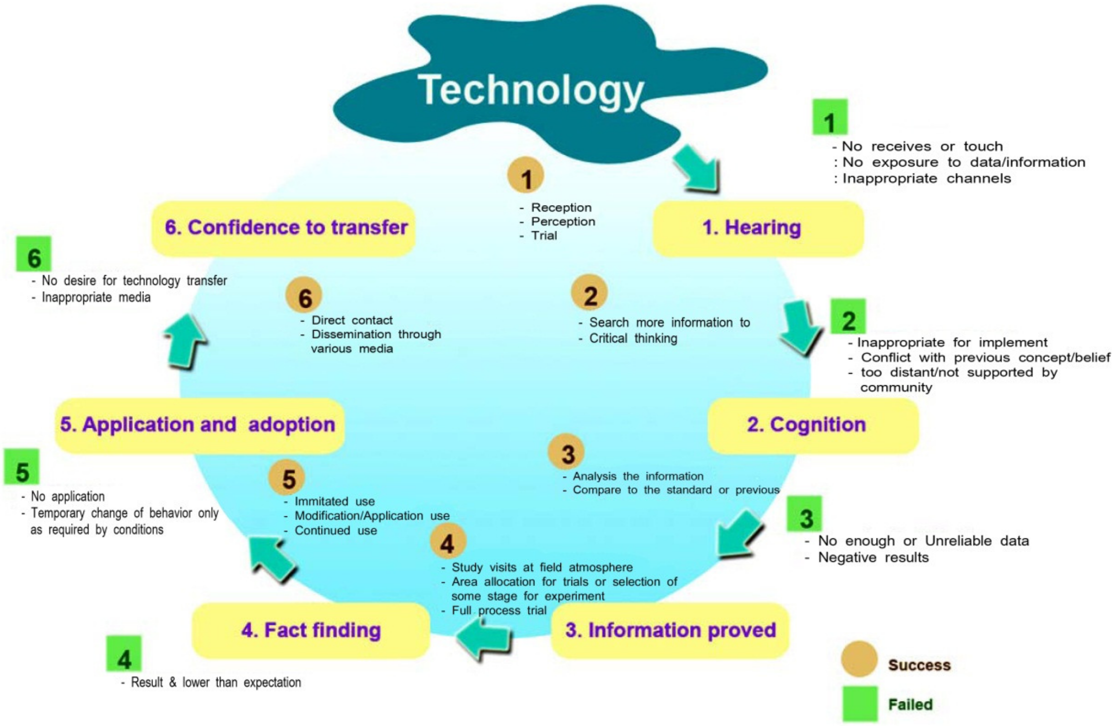

Figure 10 Reception and adoption of soilless culture technology.
Source: Sukprasert (2008)

Rogers stated that adoption process as the mental process through which an individual passes from first hearing about an innovation to final adoption. He likens the process to learning and other type of decision-making. The process by which innovation are adopted by individual was essentially a limited example of how any type of learning take place. In the adoption process, various stimuli about the innovation reach the individual from communication sources. Each ensuing communication about the innovation cumulates until the individual responds to these communication, and eventually adopts or rejects the innovation. Furthermore, he stated the information sources were important stimuli to the individual in the adoption process (Rogers, 1983).

The individual become aware of the innovation mainly impersonal and cosmopolite sources such as the mass media. Then the conclusion of the adoption process was either adoption or rejection of the idea. An innovation may be adopted at the conclusion of the adoption process and may be 1) used continuously, or 2) rejected at a later date, discontinuance. The innovation may be rejected at the end of the adoption process, but adopted at a later. It also possible the innovation will be continuously rejected.

Adoption studies identified and described five categories of adopters in a social system. The categories included innovators, early adopter, early majority, late majority and laggards (Mosher, 1978; Rogers, 1983). Describing the characteristics of these groups a study by Rogers (1983) indicated that the majority of late adopters are expected to be older, less educated, conservative, and not willing to take risks.

He also described the innovation adoption decision process, as the mental process from the first knowledge of an innovation to the decision to adopt or reject.

5. SWOT analysis and its application

SWOT analysis is a method invented by Albert S Humphrey in the 1960s, and is still widely used. A simple icebreaker helping people get together to "kick off" strategy formulation, or in a more sophisticated way as a serious strategy tool. (Anonymous, 2010). The SWOT analysis is an extremely useful tool for understanding and decision making for all sorts of situations in business and organizations. It is a good method both for workshop sessions and in brainstorming meetings. SWOT analysis can be used for strategic planning, product development and research reports. In addition, this 2×2 matrix's method, SWOT analysis is also a widely recognized method for gathering, structuring, presenting and reviewing extensive planning data within project planning process (Anonymous, 2011)

This SWOT analysis is a structured planning method used to evaluate the strengths, weaknesses, opportunities, and threats involved in a project venture and also identifying the internal and external factors that are favorable and unfavorable to achieve that project. This can be applicable to soilless culture in determining suitable crops for each system and vice versa taking into account the inputs, outputs and process of crop growing.

SWOT analysis aims to identify the key internal and external factors seen as important to achieving an objective (Anonymous, 2012). SWOT analysis groups key pieces of information into two main categories :

1. internal factors – the strengths and weaknesses internal of the organization

2. external factors – the opportunities and threats presented by the environment external of the organization.

Analysis may view the internal factors as strengths or as weaknesses depending upon their effect on the organization objectives. What may represent strengths with respect to one objective may be weaknesses (distractions, competition) for another objective. The factors may include all of the 4 Ps ; as well as personnel, finance, manufacturing capability, and so on. The external factors may include macroeconomics matters, technological change, legislation, and sociocultural change, as well as change marketplace or in competitive position. The results are often presented in form of a matrix.

SWOT analysis may be used in any decision making situation when a desired objective has been defined and also be used in creating a recommendation during a viability survey. Setting the objective should be done after the SWOT analysis has been performed. This would allow achievable goals or objectives to be set for the organization.

1. Strengths: characteristics of the business or project that give it an advantage over others.

2. Weaknesses: characteristics that place the business or project at a disadvantage relative to others

3. Opportunities: elements that the project could exploit to its advantage

4. Threats: elements in the environment that could cause trouble for the business or project

Identification of SWOTs is important because they can inform later steps in planning to achieve the objective. First, the decision makers should consider whether the objective is attainable, given the SWOTs. If the objective is *not* attainable a different objective must be selected and the process repeated.

Users of SWOT analysis need to ask and answer questions that meaningful information for each category (strengths, weaknesses, opportunities, and threats) to make the analysis useful and their competitive advantage.

One way of utilizing SWOT is matching and converting. Matching is used to find competitive advantage by matching the strengths to opportunities. Converting to apply conversion strategies to convert weaknesses or threats into strengths or opportunities.

The SWOT analysis template is normally presented as a grid, comprising four sections, one for each of the SWOT headings: Strengths, Weaknesses, Opportunities, and Threats. The free SWOT template below includes sample questions, whose answer are inserted into the relevant section of the SWOT grid. The questions are examples, or discussion points, and obviously can be altered depending on the subject of the SWOT analysis. The SWOT questions are also talking points for other headings – use them as you find most helpful, and make up your own to suit the issue being analyzed. It is important to clearly identify the subject of a SWOT analysis, because a SWOT analysis is a perspective of one thing, be it a company, a product, a proposition, and idea, a method, or option, etc.

SWOT analysis is commonly presented and developed into a 2×2 matrix, which is shown and explained within the SWOT analysis matrix section.

Modern SWOT analysis in business and marketing situations is normally structured so that 2×2 matrix grid can be produced, according to two pairs of dimensions. Strengths and Weaknesses, are 'mapped' or 'graphed' against Opportunities and Threats. To enable this to happen cleanly and clearly, and from a logical point of view anyway when completing a SWOT analysis in most business and marketing situations, Strengths and Weaknesses are regarded distinctly as internal factors, whereas Opportunities and Threats are regarded distinctly as external factors.

Here is the explanation in more detail :

The SWOT analysis in this format acts as a quick decision – making tool, quite aside from the more detailed data that would typically be fed into business planning process for each of the SWOT factors.

Internal factors / **External factors**	**Strengths: S** - - -	**Weaknesses : W** - - -
Opportunities: O - - -	**strengths / opportunities** **obvious natural priorities**	**Weaknesses / opportunities** **Potentially attractive options**
Threats : T - - -	**Strengths / threats** **Easy to defend and counter**	**Weaknesses / threats** **Potentially high risk**

Figure 11 SWOT Matrix.
Source: Putrawat (2003)

CHAPTER III

RESEARCH METHODOLOGY

This research covers the literature review on related research starting from data collecting from the research reference, result from trial work, the collection of primary and secondary data, selection, and evaluation of the best system that can be extended to farmers as the "action research", so that they will be able to produce crops to substitute the import of temperate vegetables and herbs as well as popular local crops with safety and at a reasonable price.

1. Steps in Research

1.1 Review literature on related research starting from collecting data from research reference.

1.2 Study from visits abroad to see present situation of soilless culture in some developed countries, for example, Japan, Australia, New Zealand, Israel, The People's Republic of China, Taiwan, etc.

1.3 Collecting result from trial work at Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan Province, Sai Jai Thai Garden (Vocational Training Center for the Handicaps), Bangkok, Royal Project Foundation, Chiang Mai and H.M. 's Private Development Project, Bangkok.

1.4 Collection of primary and secondary data from research reference, results from trial works, data analysis and identification, selection and evaluation the best system that can be extended to farmers so that they will be able to produce crops to substitute the import of temperate vegetables and herbs as well as popular local crops.

1.5 The situation of soilless culture of vegetable production was studied, so that growers would be able to choose and adopt the soilless culture technology for vegetable production.

1.6 Study on growers acceptance of the new hydroponic technology in order to improve the productivity and increase the income.

2. Research Frame

2.1 Studying and describing hydroponic systems in foreign countries and in Thailand.

2.2 Analyzing the advantage, disadvantage, and problems of each system.

2.3 Synthesizing data and selecting the system suitable for crops, repeating the trial, collecting data to decide if they are feasible at the commercial scale. Using the focus group discussion, consisting of 22 members from the Thai Soilless Culture Forum Committee, experts from Kasetsart University and soilless culture famers held in November 2010.

2.4 Developing and simplifying the hydroponic systems, trial, repeating, collecting data for feasible field study.

2.5 Monitoring the best system that can be extended to farmers.

2.6 Studying the adoption of soilless culture technology that grower accepted as one of the means to achieve the improvement of productivity and increase income.

3. Population and sampling

Population in this research consist of 2 groups.

3.1 Focus Group discussion consisting of 22 members from the Thai Soilless Culture Forum Committee, experts from Kasetsart University, and soilless culture farmers.

3.2 Population in this research are 58 soilless culture or hydroponic farmers chosen as representatives of those in each part of Thailand.

Research tool

1. Collecting soilless culture datas. Datas were obtained from various projects, namely The Royal Northern Project, H.M.'s Private Development Projects at Sapansung, Bangkok, Sai Jai Thai Foundation and Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan. Comparisons were made on the techniques used at those projects and at other farms in Thailand. Datas were also obtained from various research reports presented at seminars on "Development of Soilless Culture for Crop Production" at Kasetsart University, Thailand, National Chung Hsing University, Taiwan, University of Swaziland, Swaziland and the Ministry of Fisheries and Agriculture, Maldives.

2. Conducting focus groups. A focus group discussion was conducted among 22 members from the Thai Soilless Culture Forum Committee, soilless culture farmers, and experts from Kasetsart University, to gather their experiences, problems, and comments which were analyzed using Boston's model to identify the most appropriate system of soilless culture for crop production.

3. Interviewing with farmers to collect information and following up soilless culture technology transfer from soilless culture or hydroponic farmers chosen as representatives from each part of Thailand.

4. Measurement for checking and analyzing data obtained on qualifications, authenticity and trust.

Period of Study

Starting from 2007 until 2014.

Duration of Research

Table 4 Research Plan and data collection using tools collected data as tabulated.

Step	Activities	Data sources and Collection	Time
1. Review literature on related research	1. Collecting data from research reference 2. Analysis of each suitable System on crops production	documentation, related research	July 2007 to March 2009
2. Study visits to see present situation of soilless culture in some developed countries.	1. Visited Japan during 20-27 September,2005 2. Visited Republic of China on Taiwan during 5-12 December,2009 3. Visited Australia and New Zealandduring 22-28 May, 2011 4. Visited People's Republic of China during 20–27 April, 2012 5. Visited Israel during 12 -17 May, 2012	documentation, visit soilless culture farms, university and companies concerned.	September, 2005 to June,2012
3. Collected Result from trial works.	Experiments to collect yields comparebetween each system for some temperate lettuce, herbs and popular local crops at LukPhra Dabos Agriculture Training and Development Center, Sai Jai Thai Garden and H.M.'s Private Development Project.	yield trial and comparison between each system.	June 2008 - June 2013

Table 4 (Continued)

Step	Activities	Data sources and Collection	Time
4. Collection of primary and secondarydata, selection and evaluation of the best system.	Analysis of 5 main soilless culture systems.DRFT, NFT, DFT, aeroponic and substrate culture using Boston's Model.	Focus group. discussions	November, 2010
5. Study on adoption of soilless culture technology that grower accepted some idea, knowledge, method, practice or technique as one of the means to achieve the improvement of productivity and income.	1. Evaluating the competence of agricultural Extension, utilizing the knowledge. 2. evaluating the farmers' adoption of technology.	Questionnaires and interviewing forms	June,2011 – June 2013

Data Analysis

Using statistical method as follows:

1. Quantitative data analysis and presence in descriptive statistics

1.1 Frequency, distributing the frequency by arranging data number in sequence at same interval, number of data in each interval is called frequency

1.2 percentage (%) = $\frac{X}{N}$, × 100,when

X = sampling group

N = number of total group

1.3 Average value ($\overline{X}$) is the value from the total value divided by number of total value:

Formula: $\overline{X} = \frac{\sum x}{N}$ when

$\overline{X}$ = average value of sampling group

$\sum x$ = total of the whole number

N = the number of data in sampling group

1.4 Analysis of IOC index

Formula: $IOC = \frac{\sum R}{n}$, when

$\sum R$ = total score from the amount of experts in each level of the evaluation

n = total number of experts

1.5 Analysis of data gathered from questionnaires, interviewing forms, researchers using statistics ready program to find the percentile value and quartile value

2. Qualitative Analysis

Content analysis is the analysis of the content gathered from group meeting and from review of literature and from document gathered from questions and interviews with experts and analyzing together with Boston's models (Kotler, 2009).

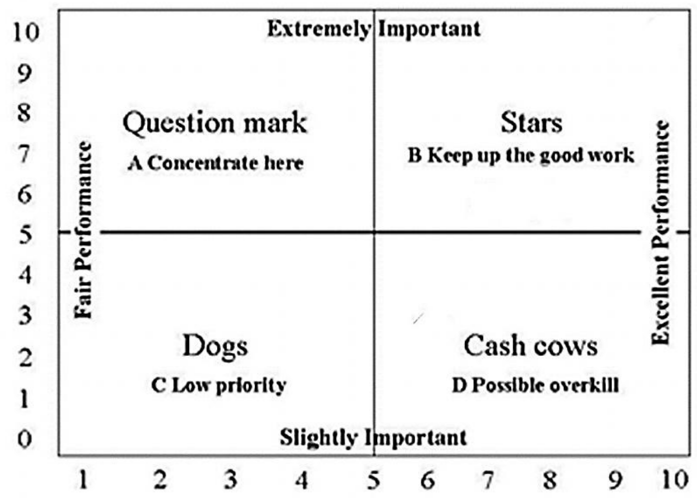

Figure 12 Analysis of a hydroponic system suitable for vegetable production in Thailand using Boston' s Model.

Operation definition

Input = cost of investment : operation cost, life long of equipment cost, cost of water, electricity, transportation, constraint in getting or buying equipment concern.

Process = simplicity or difficulty of growing process, system maintenance cost, easiness or difficulty on taking care starting from seedling, transplanting harvesting, safety period when there are problems on electricity and support systems.

Out put = product quality, yield per crop, number of crops annually, marketing attractive, easiness or difficulty in harvesting, by products or problems from the system.

From comparison, it can be concluded which system should be selected to use in hydroponic vegetable production.

Cash cows, possible overkill

1. Need to be simplified technique, so that the systems will be cheaper.
2. Need to install in availability of electricity and support systems.
3. Can control aerial and root environments.
4. Working condition attractive and easier working.
5. Off season production.
6. Give yield early.
7. Complicate system and need more after service.
8. Need contract market and high demand due to high yield and quality.
9. Grower should have more soilless culture experience.

Stars, keep up the good work.

1. Use local planting materials and equipments.
2. Can produce cash crops all year round with high yield, quality and rapid harvest.
3. No problem caused by continuous cropping.
4. Save cost of water and fertilizer.
5. Use less labor, women, children, senior citizen, handicaps can work.
6. Easy to extend in case of high marketing demand.
7. High demand on marketing of hygienic vegetable.
8. Growers should have more skillful and managing experience in hydroponic.

Question mark, concentrate here

1. Difficult to simplify technique, use high cost of equipment or import set.
2. Unavailability of equipment from local market.
3. Quality of products not attractive.
4. High yield and quality only some season.
5. Suitable to grow only some cash crops.
6. Low number of crops growing annually.

7. Sensitive to crop production when non availability of electricity and support system.
8. Growers should have most skillful and managing experience in hydroponic.

Dogs, low priority

1. Difficult to extend in case of high marketing demand, using only
2. import planning materials and equipments.
3. Need much labor in preparation of plant beds, hard working condition.
4. Give a few yield higher when compare to soil grown.
5. Quality of products not attractive.
6. Growers should have high skillful and managing experience in hydroponic.
7. Worse case to crop production when non availability of electricity and support systems.

CHAPTER IV

RESULTS OF THE STUDY

The results of the study in identification and development of the hydroponic systems suitable to grow cash crops like temperate lettuce and herbs (normally imported from other countries) and the selection of hydroponic systems suitable to produce some popular local crops with food safety technique at a reasonable price, as well as the development of hydroponic equipment using local material for commercial hydroponic production comprises of 5 steps as follows.

Phase I Primary and secondary data are collected both from literature reviews and field works.

Phase II All data and information are analyzed and following synthesized to identify the advantages, and disadvantages, of each systems. The best system suitable to Thailand condition will be selected, followed by carrying out interviewees and focus group discussion.

Phase III Synthesize the data and select the systems suitable for potential crops, replicating the trials, collecting data to evaluate if they are feasible at the commercial scale.

Phase IV Develop the best system using locally produced equipment and conduct the production trial using soilless culture at Chitralada Palace, Bangkok, Sai Jai Thai Garden (Vocational Training Centre for the handicaps) Bangkok, H.M.'s Private Development Project Bangkok, The Royal Northern project, Chiang Mai and Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan.

Phase V Adoption of soilless culture/hydroponic technology.

Phase I Primary and secondary data collection

The basic data from the document have been studied in many research works both inside and outside the country. Results from document analysis and data collection from literature reviews and field works shows that soilless culture was seen as an alternative means for farmers who would like to grow fresh and healthy vegetables to serve the high demand from markets. However, there were still many problems to be solved.

Vegetable growing in soil is still predominant in Thailand. Thai farmers have to face many serious problems such as drought, flood, pests, plant diseases, low quality products and misuse of insecticides causing risks for their income earning. New agricultural technologies have been researched and developed by government agencies, research institutes, universities and importantly, The Royal Development Projects.

Among problems of growing vegetable in soil are soil-borne diseases and high temperature. Growing plant continuously without crop rotation or interruption in production in open field can lead to an excessive build-up of soil pathogens, while high temperature can cause low yield and low quality. Moreover, heavy rain can pave way for secondary infection from fungi and bacteria.

Since 1997, after the country's economic crisis, soilless culture or hydroponics has expanded throughout Thailand. There are five soilless culture systems currently practiced, namely, NFT, DRFT, DFT, areoponics, and substrate culture. However, the existing information, data, and recommendations were considered to still be minimal and inadequate for the interested persons to study and help them make decision before implementing this new technology.

Of the five soilless culture systems in use, growers chose a system depending on their conditions taking the following factors into account: crop size, crop price, varieties, climate, tropical environment, and cost of investment. However, soilless culture was seen as an alternative means for farmers who would like to grow fresh and healthy vegetables to serve the high demand from markets.

In this study, it was necessary to obtain data from previous works: in 1987, from Kasetsart University and Chitralada Palace; and in 1997, from the Royal Northern Project, H.M.'s Private Development Projects in Sapansung, in Bangkok, and the Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan and the Sai Jai Thai Foundation, Bangkok. Some findings and practices on soilless culture from those projects were presented at both local and international seminars.

In the future, it has been anticipated that hydroponics should play a much greater role in food production in developing countries. Food products from hydroponic techniques have a high potential to help improve dietary standards as they are of superior quality and rich in nutrients. Maybe, hydroponics could also become an important tool to eradicate malnutrition problems and certain diseases commonly associated with extreme poverty conditions (Paul, 2000).

Hydroponics is usually claimed to involve a high initial capital cost and complicated operational procedures. However, these problems could be resolved by using new simplified hydroponic methods and simple equipment. In Japan, farmers simply built their own equipment using local materials which were much cheaper than purchasing the same thing (Ratanakosol, 1997).

Thailand, like any other country in the tropics, is influenced by the monsoons. During the rainy season, various crops could be damaged to varying extents due to the heavy rainfall (334 mm in September) followed by diseases. Chemicals used in controlling pests and diseases are very expensive and could leave residues in plant products, while there is growing demand for high quality with minimal or no pesticide residues in vegetables, both for local consumers and for export. Therefore, it became necessary to study alternative methods of plant growing (Wattanapreechanon and Wattanapreechanon, 1997).

1. The advantages of soilless culture

Research results have proved that soilless culture has more advantages over the soil culture as shown in Table 5, which indicate that yield, income, profit, and the number of crops per year of soilless culture were much higher than soil culture.

Table 5 Comparison between soil and soilless production on investment and profit of temperate lettuce, some popular local crops and herb conducted at Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan Province.

Vegetables / Data concern	Lettuce[1] (Soil culture)	Lettuce (NFT Outdoor)	Lettuce (NFT Evaporative cooling house)	Chinese cabbage[2] (DFT)	Chinese cabbage (DRFT)	Rocket Young vegetable (NFT Outdoor)	Rocket Young vegetable (DRFT)
1. Plot size (m)	1.00x5.00	1.60x6.00	1.60x12.00	1.20x4.80	1.00x3.80	1.60x6.00	1.00x3.80
2. No. of plants (plants/ m^2)	9.00	25.00	25.00	70.00	79.00	94 (pots)	79 (pots)
3 Yield (kg/plot)	7.90	28.00	60.00	25.00	18.00	20.00	12.00
4. Average yield (kg/ m^2)	1.58	2.92	3.13	4.34	4. 74	2.08	3.16
5. Wholesale price (baht/kg)	20.00	60.00	60.00	40.00	40.00	100.00	100.00
6. Income (Baht/ m^2)	31.60	175.00	187.80	173.61	189.60	208.00	316.00
7. Average investment (Baht/kg)	6.10	40.00	45.00	25.00	20.00	60.00	55.00
8. Investment (Baht/ m^2)	9.64	116.80	140.85	108.50	94.80	124.80	173.80
9. Profit (Baht/ m^2)	21.96	58.20	46.95	65.11	94.80	83.20	142.20

Table 5 (Continued)

Vegetables / Data concern	Lettuce[1] (Soil culture)	Lettuce (NFT Outdoor)	Lettuce (NFT Evaporative cooling house)	Chinese cabbage[2] (DFT)	Chinese cabbage (DRFT)	Rocket Young vegetable (NFT Outdoor)	Rocket Young vegetable (DRFT)
10. Annual Crops	4.00	14.00	14.00	10.00	12.00	16.00	14.50

Note: [1] Collected from The Royal Northern Projects because most temperate lettuces and herbs can not grow in Bangkok.

[2] Collected from H.M.'s Private Development Projects Sapansung, Bangkok

Source: Phra Dabos Foundation (2009)

Soilless culture was identified as a technique that can solve many problems in unsuitable environments, since growers could control both the aerial and root environments of plants. Plants could grow better, the growing season could be extended, and finally there was an increase in crop yields and income. Advantages can be classified as follows:

1.1 Economic aspects

1.1.1 Time saving. A hydroponic system could drastically reduce the amount of time needed to produce good plants, crops, and fruit. Any vegetables, flowers, shrubs, and even trees could be grown without the need to eradicate weeds and mulch, while watering and fertilizing can be taken care of by automatic systems. Hydroponic gardens can be established anywhere, irrespective of the soil or climate (Dalton & Smith, 2003). In Bangkok, farmers can harvest up to 16 crops of temperate lettuce per year using NFT (Montri and Wattanapreechanon, 2006), which is not possible in soil cultivation. For native vegetables, it is possible to have as many as 12 crops per year using DRFT.

1.1.2 Cost saving. Under a partially controlled environment, a smaller number of seedlings was required while losses from pests and diseases could be greatly reduced, especially if plants are in a greenhouse or some other protected structure. For commercial growers, hydroponic systems were considered ideal. They were highly efficient and required a low capital cost while they could produce maximum yields with less labor inputs.

1.1.3 Better quality and quantity. Fruit and vegetables produced hydroponically had a superb flavor and texture, because they could absorb all kind of necessary nutrients that the growers could provide. Plants grew faster and healthier with more resistance to diseases than plants grown in the soil. Growth could also be sped up by using techniques such as heating or cooling the nutrient solution to the optimum temperature suitable for the plants roots, so that greater yields and better quality could be anticipated. In a hydroponic system, replanting could be done immediately after harvest, as farmers did not have to sterilize the soil, making it possible to have continuous production (Figure 13). Hydroponic vegetables had no toxic substances, no pesticides and no harmful microorganisms, which meets the most stringent catering specifications (Wilson, 2000). In Thailand, most hydroponic growers get Good Agricultural Practice (GAP) certificates as a guarantee to buyers that the product is safe, hygienic and grown using standard techniques. Figure 13 shows the yield and income of temperate lettuce grown by a hydroponic technique in an area of high soil salinity, where temperate lettuce could not normally be grown.

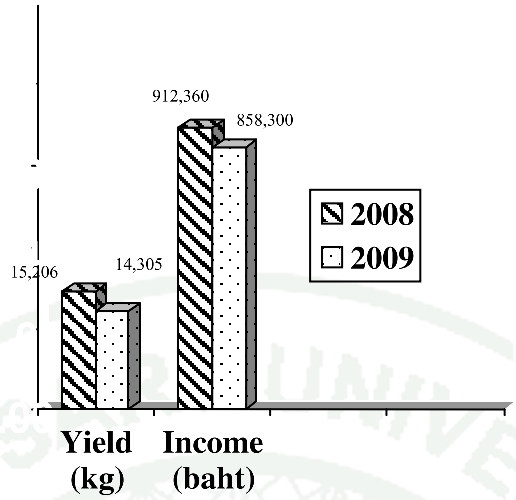

Figure 13 Yield and income of hydroponic vegetable production conducted at Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan, with 60 plots (size 1.6 × 6.0 m), total area = 576m^2.
Source: Luk Phra Dabos Agricultural Training and Development Centre (2009)

1.2 Social aspects

A hydroponic system was considered to require less labor. Women, children, senior citizens, or disabled people could do the tasks without additional help. As there was no dirt in the system, it was easy to keep everything clean and minimize any problems usually caused by soil-borne diseases. Home-grown-quality fruits and vegetables could be produced almost all year-round. It could also be a challenging and exciting family hobby or a means of earning some supplementary income. Where there was a lack of labor, the younger generation could serve as competent growers.

1.3 Environmental aspects

Soilless plant production in a greenhouse was identified as the growing technique most friendly to environment because it could reduce the use of chemical pesticides and encourage the awareness of the efficient use of natural resources. For hydroponic systems such as NFT, DRFT, DFT, and aeroponics, the surplus nutrient solution could be easily recovered and recycled. Moreover, a closed system is highly cost-effective resulting in a low cost of nutrients, efficient use of water, and environmental friendliness.

Below are the comparison of the advantages between soil and soilless cultivation:

Soil cultivation ↓	**Soilless culture/ Hydroponic** ↓	**Advantage/impacts** ↓
Soil-borne diseases.	No problem caused by continuous cropping.	Save cost & save time.
Pesticide and herbicide residue effect.	No insecticide, no herbicide.	Environmental friendly.
Overuse of water and fertilizers.	Watering and fertilizing are automated.	Save cost & save time, environmental friendly
Highly mechanized.	No work using spades, hoes and tractors.	Save cost, save time & save labor.
Environmental limitations. (drought, floods)	Can control aerial and root environments.	Better plant growth, better quality andyield.
Need large land. ➔	Intensive farm, use less land. ➔	Stable yield and minimal water, fertilizer and land.

Figure 14 Advantage / impacts of soilless culture or hydroponic growing.

Dirty, hard work, bad working condition.	Clean, light work, comfortable working condition, attractive and easier working, use less labor, women, children, old citizen and handicaps can do.	Easily produce quality vegetables and fruits all year round with challenging and exciting hobby or vocation.
Full time job.	Once the system is in place, there will be more time.	Happier life.
Seasonal cultivation.	Continuous cultivation/ Off-season production/ give yield early.	Stable supply/Stable price.
Unstable production. (low income)	Stable production. (stable supply of quality products)	Higher income for growers and quality product for consumers.
Consumer : Unstable quality.	High quality production.	Stable price.

Figure 14 (Continued)

Soilless culture or hydroponics was no longer seen as a subject of science fiction or a mysterious form of growing plants in the laboratory. It was considered a well established and fast growing part of modern commercial agriculture. However, growers had to choose the technique suitable for their conditions - climate, plant species, markets, management skills, local material and supplies for the system. The soilless culture techniques used in various countries are different according to their growers' conditions (Table 6).

Table 6 Soilless culture systems for crop production in Thailand and in some other counties.

Countries	NFT	DRFT	DFT	Aeroponic	Substrate culture
Thailand	✓	✓	✓	✓	✓
Singapore	✓	✓	-	✓	✓
China	✓	-	✓	✓	✓
Korea	✓	-	✓	✓	✓
Japan	✓	-	✓	✓	✓
New Zealand	✓	-	-	-	✓
Australia	✓	-	-	-	✓

NFT = Nutrient film techniques, DRFT = Dynamic root floating techniques, DFT = Deep flow techniques.

Source: Data obtained from personal visits and surveys to these countries

The standard method for growing vegetables throughout Thailand was in the soil. Before 1995, following their introduction by the Royal Project Foundation as substitute crops for opium, crisp iceberg lettuce, cos lettuce and red leaf lettuce were grown in soil in the Highlands by hill tribes. However, the produce was not sufficient to meet the demand, especially in the summer and rainy seasons. Moreover, these products could not be grown in other parts of the country because it was too hot there. The fact that Thailand had a high demand for such crops, especially to serve the influx of over 13 million tourists in 2007, meant that substantial amounts had to imported from other countries. Growing numbers of tourists and health-conscious Thai people were an important market for soilless cultural vegetable production. For hydroponic culture, farmers can grow temperate lettuce all year-round and all over Thailand because the environment required for successful crop production, especially the temperature, could be controlled.

2. Development of soilless culture or hydroponics in Thailand

In Thailand, soilless culture was developed more than two decades ago but the product volume was still much lower than the demand. Many problems still remain to be solved. Much attention has been paid to developing a soilless cultivation technique for each crop and to standardize cultivation methods. This effort included careful selection of varieties and the selection hydroponic equipment using local materials, e.g., seeds, growing substrate, water improvement techniques, cooling systems, automatic controlled water sprayers, and nutrient solution controllers.

The five main growing systems work well for vegetable production are as follows:

2.1 Nutrient Film Techniques (NFT)

The Nutrient Film Technique is a water cultural technique, which lets the nutrient solution flow down the channels or gullies and is circulated. The basic principle of the techniques is that the nutrient solution should be maintained as a thin film to provide adequate oxygen for the solution. With proper equipment, a nutrient reservoir together with aeration, electric conductivity and pH level can be automatically adjusted. The NFT is suitable for growing temperate lettuce. The problem for this system is the temperature fluctuation of the nutrient solution which is not easily controlled especially in the hot weather. However, the nutrient reservoir is smaller using less nutrient solution, which is a cooling system can be installed to help control the nutrient solution temperature resulting with higher yield all year round.

2.2 Deep Flow Techniques (DFT)

The principle of DFT is simply to recirculate the nutrient solution. Plants are grown on urethane foam, placed on the holes of polystyrene board. The roots of crops are continuously or intermittently immersed in nutrient solution. The catchments tank of DFT is much bigger than that of the NFT system but is safer in case of possible electricity shock. Also the system can stabilize the temperature better because of bigger catchments tank. It is now expanded to the tropical and subtropical zones by modifying it into a trough system or PVC pipes. The PVC pipes are fitted with plastic pots containing the plants on the same plane. The low density polyethylene (LDPE) bed is 120 cm. wide maximum while the length of planting bed will be adjusted to suit the planting area. This system is very cheap and can be used in growing temperate lettuce, Thai vegetable and watercress as witnessed in the highland area of The Royal Project Foundation.

2.3 Dynamic Root Floating Techniques(DRFT)

The DRFT is the technique modified from the DFT system by putting the air inducer to suck clean fresh air to mix with nutrient to maintain a good supply of oxygen before releasing to plants. The system is also equipped with nutrient adjuster to control the nutrient solution levels as required by each stage of crops. DRFT is designed specially for tropical regions. The culture beds are made from polystyrene plate to protect the high temperature and can keep low temperature during the daytime.

2.4 Aeroponics

It is one of the modified forms of hydroponic culture. It is a method of growing plants where the roots of the plants are suspended in the air within an enclosed chamber to which nutrient is fed in the form of a mist. The nutrient solution intakes will be recirculated by pump. As the roots are suspended in the air, oxygen availability was not a constraint but the system needs good maintenance of pumping system. Only one farm in the Northeast of Thailand has used aeroponics for producing temperate lettuce.

2.5 Substrate culture

By this method, which is most widely used in the world, crops are planted in solid medium instead of soil. Nutrient solution is supplied to the medium by dripping, spraying, and flood fertigation systems. Natural or artificial media, organic or inorganic media are used as growing substrates. It looks like growing in soil but it is free from soil-borne diseases and pests.

In Thailand, using local resources for soilless substrates can effectively reduce costs. Coconut husk is commonly used for orchid production while gravel, sand, saw dust, compost and coconut fiber, individually or mixed are used as substrate for vegetable, flower and ornamental plant production. Some vegetables such as tomatoes, sweet peppers and cucumbers grow very well in substrate culture. Two or three substrates are often mixed to improve physical and chemical properties. Using coconut fiber and rice husk charcoal as growing medium has shown improved yield and growth of sweet peppers, musk melons and tomatoes. Sand mixed with rice husk is commonly used for vegetable production, Drip irrigation is used for vegetables. Mist sprays are applied in orchid production.

Thailand has an abundance of coconut husk and fiber, which is an organic substrate and is now considered one of the best substrates worldwide and is regenerate. The advantages of coconut fiber are good porosity, high available water, good drainage, good absorbability when reused, low volume weight, easy for transport, slow degradation, and good chemical properties.

2.6 Situation of soilless culture production in Thailand. (Figure 15)

2.6.1 System manufacturers and companies

In the past, the soilless cultures or hydroponic expanded throughout the country since the private sector obtained this technology from the developed countries. They also imported planting material and equipment. At present, most system manufacturers and companies can manufacture their own new equipment e.g. plastic gullies, plastic pots, polystyrene as planting bed, urethanes foam as growing media, many hydroponic equipment, different hydroponic sets with many systems suitable for Thailand condition. Those are sold for home garden as well as to commercial growers and exporters. Some companies obtained new ideas and techniques from local research and academic works, Thai soilless culture forum and also carrying out their own R & D. They also carried out an extension work, by introducing new techniques and findings to the growers. Some companies do not only sell hydroponic equipment but also grow vegetables at a commercial scale to advocate products to new growers.

2.6.2 Growers

Most soilless culture growers are well educated but have no agriculture background. Some of them have started hydroponic farm because they lost their job during the economic crisis. However, these people are keen to work with hydroponic, which is considered hygienic, not too hard but challenge. They intend to get stable supply of quality products with stable price and high income. These growers gain knowledge information from system manufacturers and companies, from which they bought the hydroponic system, Thai soilless culture forum and research findings. Most growers choose high value vegetable varieties to grow, which are suitable for their growing system and marketable. Growers organize into groups or small clusters in order to ensure that they can produce stable supply to the wholesalers and retail markets. Some growers have invested in evaporative cooling systems for better quality and yield of product. Many growers prefer net house with plastic roof in order to prevent rain damage and improve pest control with low capital investment. Some growers do not have necessary knowledge about plant growth, pest elimination, maintenance system and harvest system in order to deliver product to meet consumers' expectation, so they need training. Harvesting at correct maturity will reduce postharvest loss, growers must know the age of plant to correctly identify maturity. Most hydroponic farmers grow temperate lettuce because of high price and they do not have to face competitions as in Thailand temperate lettuce cannot grow well in soil. Apart from temperate lettuce and herbs that can grow well in NFT system, some popular local vegetables can also be successfully grown in the different hydroponic system, most hydroponic growers get Good Agricultural Practice(GAP) certificates to guarantee that the product is safe, hygienic and grown with standard technique.

2.6.3 Distributors and exporters

The distribution of perishable commodities is one of the most challenging works. They are particularly susceptible to water loss after harvest.

Hydroponic vegetable is usually harvested with the root system intact in order to prolong shelf life and prevent premature wilting. Most growers now often have the small plastic pot or urethane foam on the root system. It is important that hydroponic vegetable is handled with extreme care, since bruising and leaf damage can easily occur at harvest and result in browning and decay of the leaves. Cool storage facilities are critical in removing field heat, transporting in covered vehicles, and getting to market as quickly as possible should be put in account. Refrigeration at the optimum temperature for the product, combined with high humidity, is the best method of extending storage or shelf life. Most distributors have run packing house with good package to protect and prolong its life. The plastic wrappers, attractive decorated bag are used for gourmet vegetable. Refrigerated cold rooms are needed to store the products before distributing to retailers and customers.

Most distributors also process fresh cut products for customers in order to increase product value. Prepack lettuce leaf mixtures are packed in sealed plastic bags. The distribution system could be improved further by the introduction of more modern postharvest technologies in handling operations. The problem is aggravated during the period of oversupply, which should be solved by expanding markets and developing postharvest facilities as well as processing techniques. Some farmers export their product because of the oversupply in the cold season and cheaper price than the temperate countries. The cost of production is cheaper in terms of labor, energy and others. Crops for export are sweet pepper, musk melon, temperate lettuce, but the volume is still small.

The price of petroleum is getting higher and higher, the cost of transportation and logistics have to be taken into account before starting a new farm, For example, if growers plan to export their products, they have to set up their farms not so far from the international airport.

2.6.4 Marketing

There is much concern about the efficacy of the current marketing system, and the situation is getting more serious. Most growers have to organize good transport to the wholesalers and make sure that there is consistent supply of produce to the markets. Contract market is workable for hydroponic products due to stable yield, continuous cultivation and stable price. Furthermore, consumers are quite happy with high quality product and stable price. In fact, most hydroponic products are sold in modern trade such as supermarkets and high class restaurants. The price of products is not the key factor but the quality and stable supply are more important. However, there are some problems especially in the cold season, when there is a competition with field grown vegetable which give double yield and low price but it happens only for a few months. Mixed salad packages are the new products for supermarket chains, sometimes with a sachet of salad dressing included, which can absorb the surplus supply. A lack of understanding in hydroponic products is another important problem according to the consumer surveys and should be solved as soon as possible. It is recommended to set up an information center to educate consumers and suppliers, and to conduct the consumers' need survey. Feasibility study on the export market of hydroponic vegetable especially during oversupply in the cold season is also a priority. When it is difficult and expensive to grow vegetable in the temperate countries. It is recommended for growers to identify the markets and make contact before starting the cultivation.

Apart from selling the hydroponic systems, some manufacturer and companies also grow vegetables to distribute to supermarkets and sell on farm to convince their new customers to buy their growing systems. Therefore, most growers distribute their product to supermarkets, first class restaurants as well as selling on farm. The reason why they have to develop new packaging and products is to absorb the surplus supply, to keep market share and enable grower cluster to produce stable supply of production to the market. Only small hydroponic farms and part time growers sell their own produce by themselves. Most growers sell to growers cluster in order to reduce possible marketing problem. The hydroponic products can be sold in supermarkets and retail markets through contracts only.

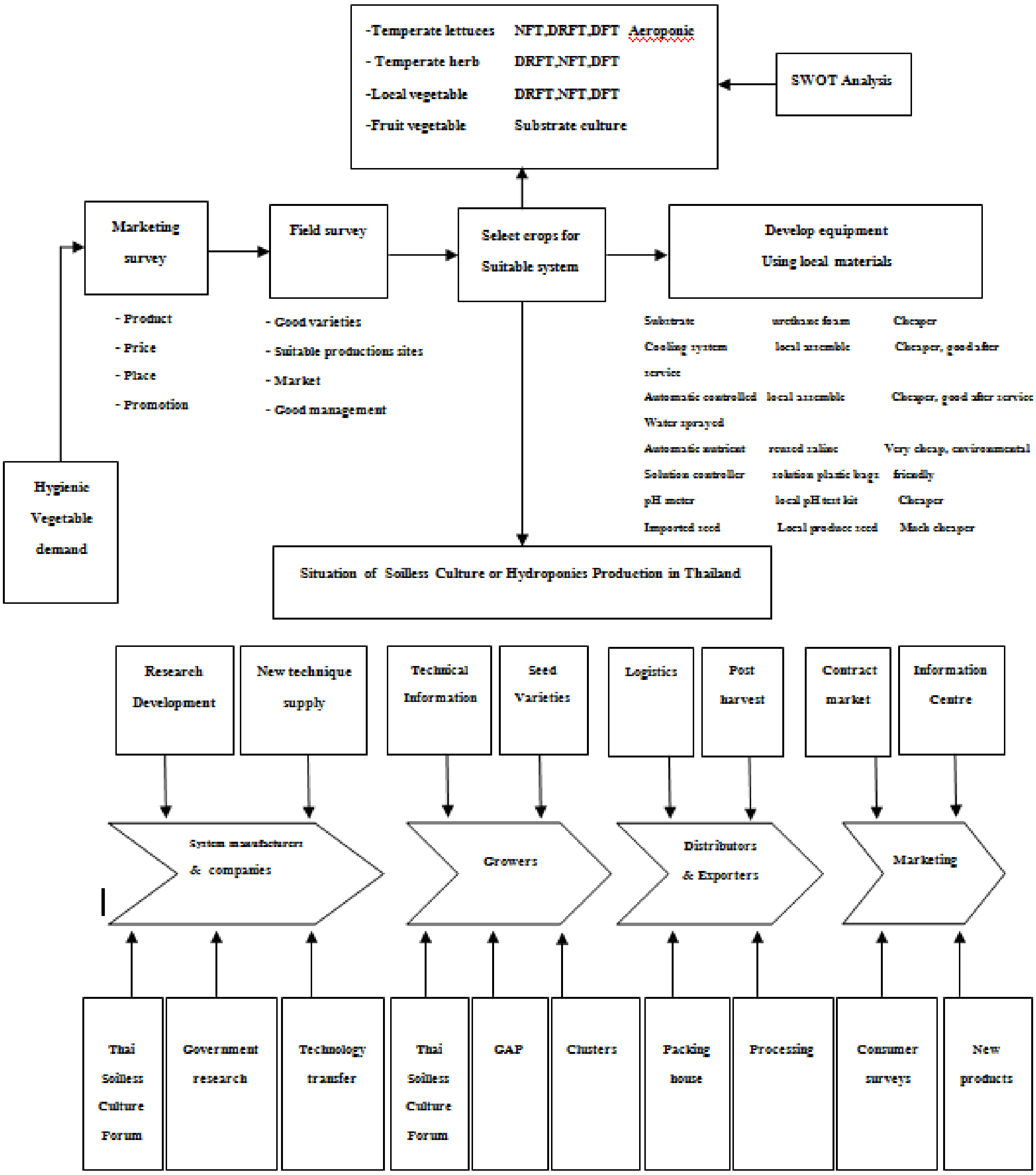

Figure 15 Situation and how to start hydroponic farm.

3. Key factors to successful insoilless culture or hydroponics in Thailand.

Commercial soilless culture or hydroponics production of fresh vegetable in Thailand has been growing steadily. In order to succeed, growers have to take many key factors into account as shown in Figure 16

3.1 Good varieties

The trend of tourism industry and local consumers are on the rise. The tourists, city residents and rural dwellers are more health conscious, so there is growing demand for more high quality fresh vegetables. The soilless culture for vegetable and flower production is becoming more popular. Thai people are consuming more fresh vegetables than before, soilless culture has paved the way for growing new species and varieties. Technology combined with new species could increase food production and income, improve product quality and increase the diversity of food to achieve national food security. Temperate lettuces and herbs are popular for tourists and high incomes, health conscious Thai people but not amongst low-income group. Consumption volume of local vegetables is in fact higher than exotic vegetables. Many local vegetables i.e.: Chinese kale, Chinese cabbage, water convolvulus are routine food for Thai people and can successfully be grown by using many hydroponics systems. Production cost of hydroponic for local varieties are higher than those growing in soil but the number of crops per year is much higher.

Most farms use imported seed, as temperate seed production is still not possible in Thailand. However, it is necessary to do the yield test in Thailand condition before choosing suitable varieties that will give higher yield, good growth in terms of form, color, heat tolerance and high adaptation to local condition. However, research works on seed production has currently been carried on the highland as it has certain period of low temperature probably making seed production feasible.

3.2 Suitable Production Site

Soilless culture or hydroponics farm should be located in appropriate location, with respect to the following requirements namely, availability of water supply, electricity, communications, transportation system as well as market accessibility, as the following:

3.2.1 Water

Normally, we can use rain water as well as water from other sources, like rivers, canals lakes, irrigation system, springs or wells. However, it is a need to have it tested by a reputable laboratory. If there should be any problem, special treatment such as resin deionization system and reverse osmosis system are needed.

3.2.2 Electricity

Consistent power supply is needed in pumping nutrient solution as well as in temperature control of atmosphere and nutrient solution. Solution cooling is particularly effective in reducing crop temperature at stress and is used in many tropical climates. Controlling solution temperature at approximately 25^{o}c, at which 8 ppm of oxygen dissolve is suitable for many crops.

3.3.3 Communication

In the world of trade competition, communication can make one win. Therefore, it is necessary to have modern communication equipment in place such as telephone set, a fax machine, internet, etc.

3.3.4 Logistics

Transport and adequate access to markets is very important as vegetables and flowers are very delicate and perishable. Post-harvest losses especially for leafy vegetable can be reduced significantly if it takes minimal time in transportation. In addition, the price of petroleum in recent years is very high, this is the reason why most of hydroponics farms are set up in Bangkok and metropolitan areas and in tourist provinces. However, hydroponic farming is becoming more popular and expanded throughout the country as the consumption volume is increasing everyday. Both temperate and local varieties of vegetables are produced to serve the market demand.

3.3 Market

Market for perishable commodities is one of the most challenging enterprises. The system of marketing could be improved further by the introduction of more modern post-harvest technologies in handling operations. The problem is aggravated during periods of over supply in the cold season as the weather are suitable for many kinds of vegetable. On the contrary, vegetable yield is quite low in summer and rainy season especially small farms which have no cooling system to control environment for their crops. In this case, most farms collect vegetables from other producers with prepaid orders only. Normally, there is no price guarantee in the buying contract. In order to maintain stable production, some farms have invested in buildings with evaporative cooling systems for better temperature control and pest control and can produce vegetables at an average of 16 crops per year. For hydroponic production, it is recommended that contract between farmers and wholesalers could be made because hydroponic growers can provide stable supply of quality products and convenient for wholesalers to distribute to retailers to sell at high price. Consequently, consumers is able to appreciate high quality products with stable price all year round.

3.4 Good management

At a commercial scale, hydroponics requires both art and science of management. Growers must know what plant eats, how it takes nutrients from its environments, at what amount, under what conditions and how they are used in plant growth and development. The trained personnel are required to supervise the growing operation and the growers must observe their plants every day. In addition, soilless culture system needs steady power supply for many equipment, good quality water, light, good ventilation and growing media.

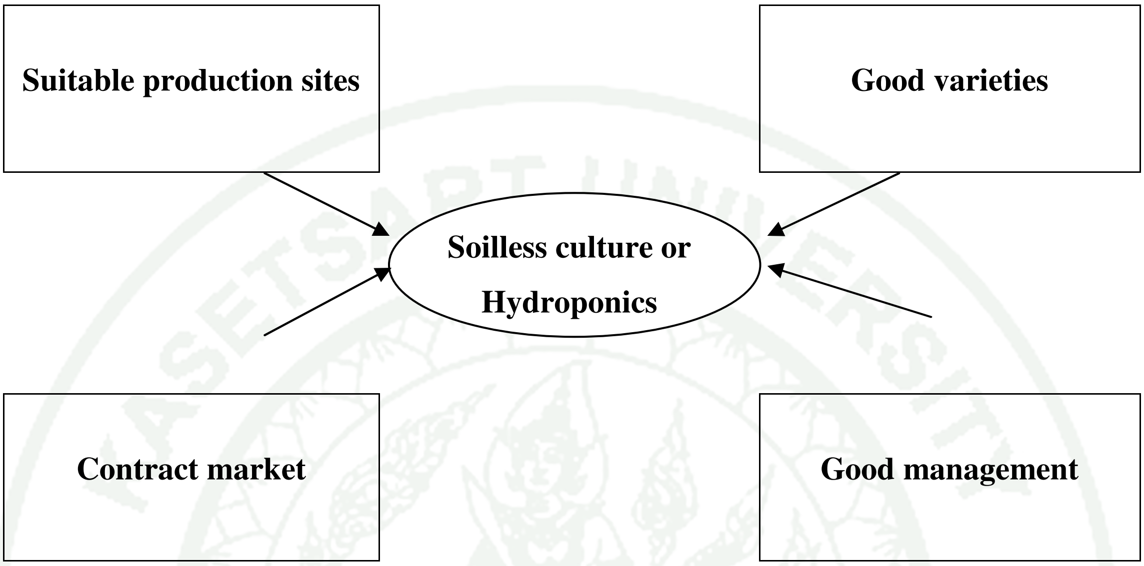

Figure 16 Key factors of soilless culture or hydroponics production.

Phase II The best hydroponic system suitable to Thailand, advantages and disadvantages of each system.

1. Key factors necessary for choosing the best soilless culture / hydroponics suitable system for crops production

The basic data from the document have been studied. The results from document analysis and data collection can be concluded into 3 aspects that could effect the selection forsuitable system for crop production in Thailand. These are economic, social and politic and environment aspects. For each aspect there are various factors concerned: 20 economic factors, 5 social and politic factors, and 10 environmental factors.

The SWOT analysis method and Boston's model have been used in this study. For SWOT analysis, it is an extremely useful tool for understanding and decision making for all sorts of situation in reviewing extensive planning data within project planning process. It is a good method both for workshop sessions and in brainstorming meetings. Boston's model is widely used and involves experts analyzing data and information obtained from SWOT analysis to identify the most appropriate soilless culture system for each crop.

Description of these factors are illustrated in detail in the Table 7, 8 and 9 respectively

Table 7 Economic factors affecting the selection of the soilless culture/ hydroponic system.

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Save cost					
Cost of investment	High initial investment, suitable for cash crops.	Intermediate initial investment.	High initial investment, suitable for cash crops.	Highest initial investment, suitable for cash crops.	Cheap initial investment, simple and easiest management.
Cost of system (material used in the system)	PVC gullies expensive, plastic pot, perlite, vermiculite, single use expensive but urethane foam cube cheaper.	Polyethylene bed cheap, with or without polystyrene plate to protect high temperature, polyethylene board for planting expensive but no need of plastic pots, use cheaper urethane foam cube for planting.	Polystyrene for bed and planting board are expensive, lying with polyethylene sheet but no need plastic pots, use cheaper urethane foam cube for planting.	Polystyrene for bed and planting board are expensive, lying with polyethylene sheet, but no need plastic pots, use cheap urethane foam cube for planting but need high efficiency pumps..	Use polyethylene bag or trough, substrates from agricultural waste e.g. coconut coir, coconut chop, rice husk and sand which is cheap media.
Maintenance of the system	Moderation.	Moderation.	Moderation.	Complication.	Simple.

Table 7 (Continued)

Hydroponic system / Indicator	**NFT**	**DFT**	**DRFT**	**Aeroponic**	**Substrate culture**
Save cost					
Suitable site of production	Can grow well throughout Thailand.	Suitable to grow crops on highland due to no problem of high temperature on nutrient solution and crop environment e.g. Royal Northern Projects.	Can grow well throughout Thailand.	Can grow well throughout Thailand.	Can grow well throughout Thailand.
Catchment tank	Need smaller catchment tank due to used less nutrient solution in the system.	Need the biggest catchment tank due to used deep nutrient solution.	Need medium catchment tank due to used deep nutrient solution but can adjust the nutrient solution levels.	Need smaller catchment tank due to used nutrient solution only intermittent mist.	Need more nutrient solution due to open or run to waste systems.
Installation of chiller	Easy and save energy to install chiller due to need smaller catchment tank to serve many benches.	Easy but consume high energy due to need bigger catchment tank to serve many culture bed.	No need to install chiller due to polystyrene culture bed and board can protect high temperature during day time.	No need to install chiller due to enough oxygen in the nutrient solution.	No need to install chiller, substrates can keep suitable temperature for plant root.

Table 7 (Continued)

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Save cost					
Commercial scale	Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor .	Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor.	the system suitable for small culture bed, use individual small pump and catchment tank. It' s spend a lot of labor to check and adjust nutrient solution.	Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor. However need high quality of mist system.	Large scale needs one set of pump and nutrient solution automatic controller easy and save labor.
Commercial system	Mainly used worldwide and in Thailand.	Popular in Japan and Caribbean Islands.	Popular in Taiwan, Thailand, Singapore .	Not many in commercial scale, needs high attention on the mist system, mainly used for researches.	Mainly used worldwide easy, cheap and use agricultural waste for substrate.
Type of greenhouse	Crops grow well both inside and outside greenhouse, depend on budget. PVC gullies can protect rain water.	Needs plastic roof cover to protect rain which causes the dilution of nutrient solution.	Needs plastic roof cover to protect rain which causes the dilution of nutrient solution.	Recommended to grow crop inside greenhouse to protect rain which causes the dilution of nutrient solution.	Crops grow well both inside and outside greenhouse.

Table 7 (Continued)

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Save cost					
Electricity consumption	Needs high flow rate and large pump, chiller consumes high power supply.	Needs intermediate flow rate but large amount of nutrient solution use large pump.	Needs intermediate flow rate, uses small pump.	Needs high pressure pump for mist system, consumes high power supply.	Feeds solution intermittent run to waste, more nutrient solution, consumes less power supply.
In case of electricity shock	Commercial farm needs spare electric turbine or engine pump.	Still many nutrient solution in the system, no problem with plant.	Still many nutrient solution in the system, no problem with plant.	Commercial farm needs spare electric turbine.	Substrate still keeps many nutrient solution for plant.
System extension of high marketing demand	Easy to extend in case of high marketing demand, can use local planting material and equipments but still expensive.	Easy to extend culture bed, grower can install system which is cheaper than NFT system.	Easy to extend in case of high marketing demand, can use local planting material and equipments but still expensive.	A little bit difficult due to the specification of high efficiency pump and complicate system of mist.	The easiest system, the system just like growing in solid substrate with fertigation or uses slow release fertilizer.

Table 7 (Continued)

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Save time					
Crop annually	High amount of crops per year due to no time lag after harvest crops in the morning, clean and let the sun dry and transplant in the same evening, growing period usually divided into 3 stage : seedling, nursery and growing.	Less amount of crops per year than NFT. growing period usually divided into 2 stages : seedling and growing.	Less amount of crops per year than NFT. growing period usually divided into 2 stages : seedling and growing.	Higher amount of crops per years than NFT. growing period usually divided into 2 stages : seeding and growing.	Lowest amount of crops per year than other soilless system due to time use in preparation of substrates growing period usually divided into 2 stages : seedling and growing.
Crop growth rate	Rapid growth and harvest, high yield due to full time feed nutrient solution.	Rapid growth but slower than NFT due to full time or intermittent feed nutrient solution.	Rapid growth and harvest, high yield due to full time feed nutrient solution.	Rapid growth and harvest, high yield due to full time or intermittent feed nutrient solution.	Slow growth and harvest due to intermittent feed nutrient solution.

Table 7 (Continued)

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Save time					
Time need to clean the system to preparing for the next cropping	PVC gullies easy to clean, harvest crop in the morning, clean and let the sun dry and transplant in the same day in the evening.	Growing on polystyrene board after harvest needs to clean and let the sun dry 1 day before transplant, the cleaning process erodes polystyrene board.	A lot of time consume on cleaning of polystyrene board, culture beds and polyethylene sheet lying.	Need times to clean polystyrene board and nozzles of mist system.	Need a lot of time to clean greenhouse, prepare substrates and fumigation to protect insects and fungus needs high labor intensive.
Time need to transplanting and harvest	Simple.	Simple.	Simple.	Simple.	Moderation.

Table 7 (Continued)

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Better quality and quantity					
Suitable crops	Temperate lettuce, herbs, tomatoes, cucumbers, musk melon.	Temperate lettuce, local crops, water cress, musk melon, aquatic plants.	Temperate lettuce, herbs, local crops.	Temperate lettuce, herbs.	Tomatoes, musk melon, sweet peppers, herbs, orchid.
The spread out of plant diseases	Diseases easy to spread out through the system due to the use of same catchment tank.	Diseases easy to spread out through the system due to the use of same catchment tank.	Individual catchment tank can protect the spread out of diseases.	Diseases easy to spread out through the system due to the use of same catchment tank.	Diseases destroy only spot or plant culture bed, due to feed nutrient solution run to waste.
Better quality and quantity of yield	Excellent.	Excellent.	Excellent.	Excellent.	Excellent.
No toxic substrate and harmful organism	Excellent.	Excellent.	Excellent.	Excellent.	Excellent.

Table 8 Social and politics factors affecting the selection of system.

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Requirement for the beginners	Growers should have some soilless culture experiences.	Growers should have some soilless culture experiences.	Growers should have some soilless culture experiences.	Growers should have many soilless culture experiences.	The soilless culture system recommended for the beginners.
Growers' background and experience	Growers should have more skill and management experiences in hydroponics.	Growers should have more skill and managements experiences in hydroponics.	Grower should have more skill and management experiences in hydroponics.	Growers should have most skill and management experiences in hydroponics including mechanical control of mist system.	No need of skill and experiences in soilless culture. The management just like growing plant in soil.
Kind of the labor, women, children senior citizen, handicaps worker	All mentioned people can work.	All mentioned people can work.	All mentioned people can do.	All mentioned people can do.	Hard work for all mentioned people.
Working condition	Clean, light work, comfortable, attractive working.	Clean, light work, comfortable, attractive working .	Clean, light work, comfortable, attractive working.	Clean, light work, comfortable, attractive working but need attention care.	Clean but quite hard work during preparation and move in and out of the substrate containers.

Table 8 (Continued)

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Politic policy e.g. Promote new innovation for victim (economic crisis, bird flu and Tsunami etc.)	Small and hobby set workable.	Small and hobby set workable.	Small and hobby set workable.	Too complicate to demonstrate.	Not attractive growers.

Table 9 Environment factors affecting the selection of system.

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Season	Plants grow well all year round. In summer, need chiller for nutrient solution.	Plants grow well except in summer. However, plants grow well on the high land all year round.	Plants grow well all season due to culture beds and board made from polystyrene to protect high temperature during day time and provide air inducer and nutrient adjuster.	Plants grow well all year round which nutrient are feed in the form of mist, oxygen availability and high temperature are not constraints.	Plants grow well all year round, no problem of high temperature in summer.

Table 9 (Continued)

Hydroponic system / Indicator	**NFT**	**DFT**	**DRFT**	**Aeroponic**	**Substrate culture**
Supply of optimum oxygen	Thin nutrient film provides adequate oxygen for the solution.	High temperature cause not adequate oxygen dissolve in the solution.	The system putting the air inducer to suck clean air to mix with nutrient to maintain a good supply of oxygen.	Roots are suspended in the air, oxygen availability is not a constraint.	Substrate maintains the adequate temperature and aeration needed for plants' roots.
Substrates (media)	Needs small volume of substrate e.g. perlite mix with vermiculite or small urethane foam cube.	Needs small urethane foam cube.	Needs small urethane foam cube.	Needs small urethane foam cube.	Needs large volume of substrate.
Nutrient solution management	Needs high attention for checking pH and EC.	Needs medium attention for checking pH and EC. due to largest catchment tank.	Needs high attention for checking pH and EC.	Needs high attention for checking pH and EC.	Needs low attention for checking nutrient solution due to buffer action in soilless substrate.

Table 9 (Continued)

Hydroponic system / Indicator	**NFT**	**DFT**	**DRFT**	**Aeroponic**	**Substrate culture**
Temperature of planting bed	Larger greenhouse, high plastic roof, low impact to planting bed.	Large greenhouse high plastic roof, low impact to planting bed.	Small plastic cover with net protection, low ventilation high temperature impact to planting bed during day time.	Large greenhouse high plastic roof, low impact to planting bed.	Large green house high plastic roof, low impact to planting bed.
Insect problems	Growing in evaporative greenhouse and net house have no insect problem.	Growing in net house gets some problem but less than growing in soil.	Growing in plastic roof and net house has no insect problem.	Growing in net house gets some problem but less than growing in soil.	Growing in net house gets some problem but less than growing in soil after harvest needs to clean and fumigate.
Fungus disease protection	Can treat with fungicide e.g. Alietle, *Trichoderma* and needs safety period.	Can treat with fungicide e.g. Alietle, *Trichoderma* and needs safety period.	Can treat with fungicide e.g. Alietle, *Trichoderma* and needs safety period.	Can treat with fungicide e.g. Alietle, *Trichoderma* and needs safety period.	Can treat with fungicide e.g. Alietle, *Trichoderma* and needs safety period.
Heavy storm or gale	Large plastic roof always destroyed by gale.	Large plastic roof always destroyed by gale.	Small plastic roof safe from gale.	Large plastic roof always destroyed by gale.	Large plastic roof always destroyed by gale.

Table 9 (Continued)

Hydroponic system / Indicator	NFT	DFT	DRFT	Aeroponic	Substrate culture
Decrease the use of chemical, pesticide	Needs less insecticide due to rapid harvest.	Needs less insecticide due to rapid harvest.	Needs less insecticide due to rapid harvest.	Needs less insecticide due to rapid harvest.	Fruit vegetables need more insecticide but less than growing in soil.
Recycle, efficiently use of water and fertilizer	Recycled nutrient solution.	Recycled nutrient solution.	Recycled nutrient solution.	Recycled nutrient solution.	Nutrient solution run to waste.

SWOT analysis.

The overall evaluation of a company's strengths, weaknesses, opportunities and threats is called SWOT analysis; it is a way of monitoring the external and internal marketing environment (Kotler, 2009). This can be applicable to soilless culture in determining suitable crops for each system and vice versa taking into account the inputs, outputs, and process of crop growing.

SWOT Analysis of Soilless culture/Hydroponic system Substrate culture

Strength: S

S1 Simple and easier management for growing system than water culture.

S2 Cost of system cheap, use polyethylene bag or trough, substrates from agriculture waste e.g. coconut coir, coconut chop, rice husk and sand which are cheap media.

S3 Crops grow well throughout Thailand.

S4 Plants grow well all year round, no problem of high temperature at roots.

S5 No need to install chiller for nutrient solution.

S6 Substrate maintains the temperature and aeration needed for plant roots.

S7 Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor.

S8 Crops grow well inside greenhouse.

S9 In case of electricity shock, substrates still keep many nutrient solution for plants.

S10 Feed solution intermittent runs to waste, consumes less power supply.

S11 Large greenhouse high plastic roof, low impact to planting bed.

S12 Needs low attention for checking nutrient solution due to buffer action in soilless substrates.

S13 Diseases destroy only spot or each plant culture bed, because feed nutrient solution runs to waste.

S14 Fungus can be treated with fungicide e.g. Aliette, *Trichoderma* and needs safety period.

S15 Used substrate can be recycled to be used for organic fertilizer.

S16 Most of substrate culture grows in net house, less problem from insects.

Weakness: W

W1 Lowest amount of crops per year than other soilless system due to time used in preparation of substrates, growing period usually divided into 2 stages: seedling and growing.

W2 Slow growth and harvest due to intermittent feed nutrient solution.

W3 Needs more nutrient solution due to open or run to waste system.

W4 Needs large volume of substrate.

W5 Needs a lot of time to clean greenhouse, prepare substrate and fumigation to protect insects and fungies, needs high labor intensive.

W6 Large plastics roof sometimes destroyed by gale.

Opportunities: O

O1 Suitable to grow fruit vegetables e.g. tomatoes, musk melons, sweet peppers, cucumbers which are susceptible to insects.

O2 The soilless culture system recommended for the beginners, no need of high skill and experience in soilless culture.

O3 The easiest system, the management of system just like growing in solid substrate with fertigation or use slow release fertilizer.

O4 Mainly used worldwide, easy, cheap and uses agricultural waste for substrate.

O5 Consistently superior quality, high yield, rapid harvest than growing in soil.

O6 Can control aerial and root environments.

O7 Cost of labor, management cheap and no heating or cooling expense, the cost of production is cheap and can be exported.

Threats: T

T1 High initial investment for large net house, plastic roof which are required with shading, ventilation system, fertigation system. etc.

T2 Production cost much higher when compared with growing in soil.

T3 Large volume of substrate needs to manage.

T4 Suitable to grow crop on highland (low temperature).

T5 Most of fruit vegetables are sold only on modern trade, high class restaurants.

Strategies management from SWOT analysis

Substrate Culture

1. Strategies of strength and opportunities. (SO)

1.1 Daily intake of vegetables is essential for healthy life as a result of the increase in safe vegetable demand than before encouraging the growing of safe vegetable. Substrate culture is a technique accepted to grow fruit vegetables e.g. tomatoes, sweet peppers, musk melons, cucumbers which are susceptible to insects but can grow well all year round inside greenhouses throughout Thailand. The damage from diseases and insects is low. Fungus can be protected by using fungicide e.g. Aliette, *Trichoderma* and safety period is needed, in case of disease destroy it happen only spot or each culture bed due to feed nutrient solution run to waste. This system gives consistently superior quality, high yield, rapid harvest than growing in soil. (S3, S4, S8, S13, S14, S16, O1, O5)

1.2 Substrate culture is simple and management is easier for growing system than water culture. The cost of systems is cheap, using polyethylene bag or trough, substrates from agriculture waste e.g. coconut coir, coconut chop, rice husk and sand which are cheap media. There is no need to install a chiller for nutrient solution because substrate maintains the temperature and aeration needed for plant root. For large scale, it needs one set of pump and nutrient solution automatic controller, which is easy and saves labor. In case of electricity shock, substrates still keep many nutrient solution for plants. The system needs low attention for checking nutrient solution due to a buffer action in soilless substrates. These substrate cultures are recommended for the beginners. There is no need of high skill and experience in soilless culture. It is the easiest system and the management of system is just like growing in solid substrate with fertigation or the use of slow release fertilizer. (S1, S2, S5, S6, S7, S9, S12, O2, O3)

1.3 The system feeds solution intermittent run to waste, consumes less power supply and most of substrate culture are growing in large greenhouse high plastic roof, low impact to planting bed, so it can control aerial and root environments. (S10, S11, O6)

1.4 Used substrate from these system can be recycled to be organic fertilizer and mainly used worldwide because it is easy, cheap and use agricultural waste for substrate (S15, O6)

1.5 Cost of systems are cheap, plants grow well all year round. Cost of labor, management are cheap and no heating or cooling expense. The price of production is cheap and it can be exported e.g. sweet peppers, musk melons (S2, S4, O7)

2. Strategies of strength and threats. (ST)

2.1 Most of fruit vegetables are sold on modern trade which is a small market and the price of product is more expensive when compared with local market. It is recommended to select good varieties which give high yield e.g. sweet peppers, musk melons for local market too. (S1, S2, S3, S4, T5)

2.2 High initial investment for a large net house which is required with shading, a ventilation system, fertigation system which the cost of production is higher than growing in soil. It is recommended to choose cheap substrate, reused substrates which decrease cost of management to cut down cost and persuade customers to buy these high quality product with lower price. (S2, S3, S4, S7, S8, S15, T1, T2, T3, T5)

2.3 Environmental limitations (drought, floods, insects, deceases) can be controlled with substrate culture. If management is good, especially on high land with low temperature, the crop are better in quality and yield while the production cost decreases, and they can produce all year round. In addition, consumers are quite happy with high quality product and stable price. (S3, S4, S5, S6, S9, S10, S11, S12, S13, S14, S16, T2, T4)

2.4 Substrate culture mainly uses substrates from agricultural wastes e.g. coconut coir, rice husk and needs large volume of substrate. Furthermore, used substrate can be recycled to organic fertilizer and it is environmental friendly. (S2, S15, S16, T3)

3. Strategies of weakness and opportunities. (WO)

3.1 Substrate culture is suitable to grow fruit vegetables which are susceptible to insects and the system is recommended for the beginners. It is the easiest system. The management of the system is just like growing in solid substrate with fertigation. When growers gain experiences they can improve management skill to get more crops per year and high yield. So turn over of investment is shorter and cheaper. (W1, W2, W3, O1, O2, O3)

3.2 The system is mainly used worldwide, easy, cheap and uses agricultural waste for substrates with consistently superior quality, high yield, rapid harvest than growing in soil but needs large volume of substrate and a lot of time to clean a greenhouse, prepare substrate and fumigation to protect insects and fungus and needs high labor intensive. The net house with large plastics roof is sometimes destroyed by gale. (W4, W5, W6, O4, O5)

3.3 The substrate culture can control aerial and root environments by using large volume of substrate and more nutrient solution run to waste system but cost of labor, management is cheap and no heating or cooling expense, the cost of production is cheap and produce can be exported. (W3, W4, O6, O7)

4. Strategies of weakness and threats. (WT)

4.1 Substrate culture needs high initial investment for a net house with shading, ventilation system, fertigation system. Production cost is much higher when compared with growing in soil, so it needs to decrease cost of investment by increasing numbers of cash crops annually, using and reuse of agricultural waste for substrate, growing cash crops that can not grow in an open field, or trying to grow crops outside a greenhouse in some season (winter) or growing crop only on high land(low temperature). (W1, W4, T1, T2, T3, T4)

4.2 Competition price between crop growing with substrate culture in the open field, it is better to the increase numbers of crops annually due to the decrease of production cost. Substrate culture needs lot of time to clean the greenhouse, prepare substrate and fumigation but it spends less labor than growing in soil and gets less problem of soil borne diseases. The substrate culture still gives consistently superior quality, high yield, rapid harvest and sold in modern trade, simultaneously growing in soil gets uncertain production. (W1, W5, T2, T5)

4.3 Substrate culture needs a large volume of substrate so it needs to be managed by a reuse or recycle for organic fertilizer. (W4, W5, T3)

4.4 Most of fruit vegetables are sold only on modern trade, the price is much higher and substrate culture needs more nutrient solution due to open or run to waste system and needs large volume of substrate. (W3, W4, T5)

	Strength: S S1 … S2 … S3 … S4 … S5 … … S_n	**Weakness: W** W1 … W2 … W3 … W4 … W5 … … W_n …
Opportunities: O O1 … O2 … O3 … O4 … O5 … … O_n	Strategies of strength and opportunities. (SO)	Strategies of weakness and opportunities. (WO)
Threats: T T1 … T2 … T3 … T4 … T5 … … T_n	Strategies of strength and threats. (ST)	Strategies of weakness and threats. (WT)

Figure 17 SWOT Matrix of soilless culture/hydroponic system (Detail of each system see appendix).

Source: Modified from Putrawat, (2003)

Figure 18 Substrate culture**.**

Note: 1 – 3 Tomatoes growing at the Royal Northern Project, Inthanon station, Chiang Mai

4 Sweet peppers growing at the Royal Northern Project, Nonghoi station, Chiang Mai

5 – 6 Tomatoes and musk melon growing at Chitralada Palace, Bangkok

SWOT Analysis of Aeroponic

Strength: S

S1 High amount of crops per year, growing period usually divided in 2 stages: seedling and growing.

S2 Crops grow well inside greenhouse with stable production throughout Thailand.

S3 Rapid growth and harvest, high yield due to full time or intermittent feed nutrient solution.

S4 Needs smaller catchment tank due to used nutrient solution only intermittent mist.

S5 Plants grow well all year round which nutrient is feed in the form of mist.

S6 No need to install chiller for nutrient solution due to enough oxygen in the form of mist.

S7 Roots are suspended in the air, oxygen availability is not a constrain.

S8 Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor, however needs high quality of mist system.

S9 Substrates: need small urethane foam cube.

S10 Large greenhouse high plastic roof, low impact to planting bed.

S11 Fungus can be treated with fungicides e.g. Aliette, *Trichoderma* and needs safety period.

Weakness: W

W1 Highest initial investment, suitable for cash crops.

W2 Cost of system expensive, needs high efficiency pumps for mist system, consumes high power supply.

W3 Recommended to grow crops inside greenhouse to protect rain which causes the dilution of nutrient solution.

W4 Electricity shock: commercial farm needs spare electric turbine.

W5 Needs time to clean polystyrene board and nozzles of mist system.

W6 Needs high attention for checking pH and EC for nutrient solution.

W7 Diseases easy to spread out through the system due to use of same catchments tank

W8 Large plastic roof sometime destroyed by gale.

W9 Needs trained personal to supervise the growing operation.

Opportunities: O

O1 Suitable for temperate lettuce and herbs.

O2 Stable production of quality products.

O3 Challenging and exciting production.

O4 Can control aerial and root environment.

O5 Suitable for research work and exciting landscape.

Threats: T

T1 Growers should have many soilless culture experiences.

T2 Growers should be most skillful in management of hydroponics including mechanical control of mist system.

T3 System extension: quite difficult due to the specification of high efficiency pump and good maintenance of mist system.

T4 Not many in commercial scales, due to high initial investment, mainly used for research.

T5 Needs suitable production site e.g. good water supply, electricity.

Strategies management from SWOT analysis

Aeroponic

1. Strategies of strength and opportunities. (SO)

1.1 Aeroponic is a technique suitable to grow temperate lettuce and herbs with stable production of quality products, high amount of crops per year and grow well inside a net greenhouse with stable production throughout Thailand. The system gives rapid growth and harvest, high yield, needs smaller catchment tank due to used nutrient solution only intermittent mist, plants grow well all year round, no need to install a chiller for nutrient solution. The damage from disease and insects is low.Fungus can be protected by using fungicide. e.g. Aliette, *Trichoderma*. Safety period is needed. (S1, S2, S3, S4, S5, S6, S11,O1, O2)

1.2 Aeroponic is challenging and exciting production, the system can control aerial and root environment which roots are suspended in the air, oxygen availability is not a constrain. Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor, however needs high quality of mist system, (S7, S8, O3, O4)

1.3 The technique is suitable for research work and exciting landscape because crops will grow well, with roots suspended in the air. Oxygen availability is not a constrain and substrates needs only small urethane foam cube growing in large greenhouse, high plastic roof, are low impact to planting bed. (S7, S9, S10, O5)

2. Strategies of strength and threats. (ST)

2.1 Aeroponic needs suitable production site e.g. good water supply, electricity and grower should have many soilless culture experiences and have most skillful management in hydroponics including mechanical control of mist system. However, aeroponic has high amount of crops per year, rapid growth and harvest, with high yield and crops grow well throughout Thailand. These can overcome the high cost of investment. (S1, S2, S3, T1, T2, T5)

2.2 Aeroponic farm is not many in commercial scales, due to high initial investment and mainly used for research. However, if a grower has many soilless culture experiences, it is a challenge for growers to choose aeroponic for cash crops production due to high amount of crops per year, rapid growth and harvest with high yield throughout Thailand. In addition, nutrients are feed in the form of mist to roots suspended in the air, oxygen availability is not a constrain, so the system gives stable production all year round. (S1, S2, S3, S5, S7, T1, T4)

2.3 To extend aeroponic is quite difficult due to the specification of high efficiency pump and good maintenance of mist system. However, grower who has most skillful management in hydroponic including mechanical control of mist system can choose aeroponic for their growing system because high amount of crops per year, crops grow well, rapid harvest throughout Thailand can overcome the high initial investment. (S1, S2, S3, T3)

3. Strategies of weakness and opportunities. (WO)

3.1 Aeroponic is a technique suitable to grow temperate lettuce and herbs with stable production of quality products. However, the system has the highest initial investment, cost of system is expensive and needs high efficiency pumps for mist system and consumes high power supply. It is recommended to grow crop inside a greenhouse and a spare electric turbine is needed. In order to make up amount of crops annually with stable production all year round which gives good opportunities for the market and consumers' need. (W1, W2, W3, W4. O1, O2)

3.2 Aeroponic is challenging and exciting production, the system can control aerial and root environment. However, it needs the highest initial investment, needs time to clean board and mist system, needs high attention for checking pH and EC, diseases easy to spread out through the system due to the use of the same catchment tank and needs trained personal to supervise the growing system.Thus it is considered by growers to be suitable for research work and exciting landscape. (W1, W5, W6, W7, W9, O3, O4, O5)

4. Strategies of weakness and threats. (WT)

4.1 Aeroponic needs the highest initial investment and production cost of system is expensive, needs high efficiency pumps for mist system and consumes high power supply. Growers should be most skillful in management of hydroponic including mechanical control of mist system but production is stable, high yield, rapid harvest all year round. If growers challenge to grow some popular local crops which high amount of crops annually and local market is much bigger than exotic crops,the areoponic is possible. The system can be extended to commercial scale. (W1, W2, T2, T3)

4.2 Aeroponic is recommended to grow crops inside a net greenhouse with the plastic roof to prevent rainwater. It also needs a spare electric turbine, good maintenance of mist system, high attention in checking pH and EC of nutrient solution. If growers have the most skillful management it can give high yield and rapid harvest with maximum yield per year. Growers should not only grow temperate lettuce and herbs but also some popular local crops. These products can supply the market especially in summers and rainy season.However, the system needs to be simplified to use local hydroponic equipments which are cheap with good after service. (W3, W4, W5, W6, W8, T2)

Figure 19 Aeroponic.

Note: 1 – 4 Temperate lettuce at Phurua, Loei

5 – 6 Sweet basil and hot basil at Luk Phra Dabos Agricultural training and Development center, Samut Prakan

SWOT Analysis of DRFT

Strength: S

S1 Crops grow well throughout Thailand which are produced 10.5 – 12 crops annually.

S2 Rapid growth and harvest, high yield due to full time feed nutrient solution.

S3 Needs medium catchment tank due to used deep nutrient solution but can adjust the nutrient solution levels.

S4 Plants grow well all season because the system can provide air inducer and nutrient adjuster to maintain a good supply of oxygen.

S5 No need to install chiller because polystyrene culture bed and board can protect high temperature during day time.

S6 Substrate: needs small urethane foam cube and sold with root system intact for postharvest.

S7 Electricity shock; still has many nutrient solution in the system, no problem with plants.

S8 Needs intermediate flow rate, using small pump.

S9 Individual catchment tank can protect the spread out of diseases.

S10 Growing in plastic roof and net house have no insect and rain problem.

S11 Fungus can be treated with fungicide e.g. Aliette, *Trichoderma* and safety period is needed.

S12 Small plastic roof safe from gale.

S13 Simple system easy to maintenance, and extend production set by growers.

S14 High efficiency use of water and fertilizer.

Weakness: W

W1 High initial investment, suitable for cash crops.

W2 Cost of system expensive, polystyrene for ridge culture bed and planting board are expensive, lying with polyethylene sheet, provide with air inducer and nutrient adjuster.

W3 Less amount of crops per year than NFT, growing period usually divided in 2 stage: seedling and growing.

W4 The system suitable for small culture bed, use individual small pump and catchment tank. It spends a lot of labor to check and adjust pH and EC of nutrient solution.

W5 Small plastic cover with net protection, low ventilation, high temperature impact to planting bed during day time.

W6 A lot of time consumed on cleaning of polystyrene board, culture bed and polyethylene sheet lying.

W7 Some equipments easy to be destroyed e.g. polyethylene boards are cracked, bitten by mice and ants.

Opportunities: O

O1 Suitable for some popular local crops, temperate lettuce, herbs.

O2 Easy to extend in case of high marketing demand, each planting set has individual catchment tank.

O3 Popular in Taiwan, Thailand and Singapore.

O4 Consistently superior quality, high yield, rapid harvest.

O5 Can control aerial and root environment.

Treats: T

T1 Growers should have many soilless culture experiences.

T2 Growers should have most skillful management in hydroponic

T3 Some equipments e.g. polystyrene ridge culture bed, air inducer etc. are expensive.

T4 In summer, some problems happen e.g. it is too warm due to small plastic roof, bad ventilation which has impact on plant.

Strategies management from SWOT analysis

DRFT

1. Strategies of strength and opportunities. (SO)

1.1 The health conscious Thai people with high demand for safe vegetables are the important market for vegetable production. DRFT system is suitable system for growing some popular local crops, temperate lettuce and herbs and it is quite a popular system in Taiwan, Thailand and Singapore. Using DRFT, growers can grow vegetables well throughout Thailand and can produce 10.5 – 12 crops annually with rapid growth and harvest, high yield due to full time feed nutrient solution. Vegetables grow well all season due to the ability of the system in provide air inducer and nutrient adjuster to maintain a good supply of oxygen. There is no need to install a chiller due to polystyrene culture bed and board can protect high temperature during day-time. In case of electricity shock, the system can still keep many nutrient solution and has no effects on plants. All vegetables are growing in plastic roof and net house which will keep insects and rainwater away. Fungus can be treated with fungicide e.g. Aliette, *Trichoderma* and needs safety period. Most of DRFT is done in small plastic roof which is safe from gale. (S1, S2, S4, S5, S7, S10, S11, S12, O1, O3)

1.2 DRFT gives consistently superior quality, high yield, rapid harvest which is a simple system and easy to maintenance and can extend production by growers because the system needs medium catchment tank due to used deep nutrient solution but can adjust the nutrient solution levels. DRFT uses small urethanes foam cube for substrate and sold with root system intact. The DRFT system needs intermediate flow rate, uses small pump and individual catchment tank which can protect the spread of diseases. (S3, S6, S8, S9, S13, O4)

1.3 DRFT is easy to extend in case of high marketing demand, each planting set has individual catchment tank which can control aerial and root environment and high efficiency use of water and fertilizer. (S14, O2, O5)

1.4 Some popular local crops e.g. Chinese cabbage, Chinese celeries, Chinese kales, water convolvulus etc. which have bigger market than temperate lettuce. They can grow well in DRFT which is a simple system, easy to maintenance and extend production by growers in case of high marketing demand. Each planting set has individual catchment tank and gives high efficiency use of water and fertilizer which gives consistently, superior quality, high yield and rapid harvest. (S13, S14, O2, O4)

2. Strategies of strength and threats. (ST)

2.1 DRFT require growers who have a lot of soilless experiences, most skillful management in hydroponics. However, the system allows crop to grow well throughout Thailand and can produce 10.5 – 12 crops annually with high yield due to full time feed nutrient solution. Plants grow well all season because the system can provide air inducer and nutrient adjuster to maintain a good supply of oxygen. (S1, S2, S4, T1, T2)

2.2 DRFT requires growers who have many soilless experiences and most skillful management in hydroponic but the system can grow crop well, high yield rapid harvest and stable throughout Thailand. The system needs medium catchment tank due to the use of deep nutrient solution and can adjust the nutrient solution levels, needs intermediate flow rate, uses small pump with individual catchment tank which can protect the spread of diseases and fungus can be treated with fungicide e.g. Aliette, *Trichoderma* and needs safety period. The system also gives high efficiency use of water and fertilizer which is a simple system easy to maintenance and can extend production set by growers. (S1, S2, S3, S8, S9, S11, S13, S14, T1, T2)

2.3 In summer, some problems happen e.g. temperature is too warm due to small plastic roof, bad ventilation which has impact on plants. However, the system has no need to install a chiller because polystyrene culture bed and board can protect high temperature during day-time and recommended to make shading with slan only in summer period. Growing crops in plastic roof and net house can help prevent insects and rain problems and most small plastic roof is safe from gale. (S5, S10, S12, T4)

2.4 DRFT needs some equipments e.g. polystyrene ridge culture bed, air inducer which are expensive but there is no need to install a chiller which is much expensive and requires good maintenance.It needs small urethane foam cube and plants are sold with root system intact for postharvest. In case of electricity shock, the system still has many nutrient solutions in the system, no problem with plants. (S5, S6, S7, T4)

3. Strategies of weakness and opportunities. (WO)

3.1 The demand of some popular local crops is much higher than temperate lettuce and herbs especially in summer and rainy season. It gives DRFT system an opportunity to grow some popular local crops (e.g. Chinese cabbages, Chinese celeries, Chinese kales, water convolvulus). The system is popular in Taiwan, Thailand and Singapore, but it needs the high initial investment, cost of system is expensive, gives less amount of crops per year than NFT and the system suitable for small culture bed, use individual small pump and catchment tank. It also spends a lot of labor to check and adjust pH and EC of nutrient solution. (W1, W2, W3, W4. O1, O2)

3.2 DRFT system is easy to extend in case of high marketing demand and can control aerial and root environment. These give opportunity to DRFT. However, planting set has individual catchment tank, use individual small pump and spend a lot of labor to check and adjust pH and EC of the nutrient solution and also time consuming on cleaning of polystyrene board, culture bed and polyethylene sheet lying.(W4, W6, O2, O5,)

3.3 DRFT give consistently superior quality, high yield, rapid harvest but cost of system is expensive and some equipments can be easily destroyed e.g. polyethylene boards are cracked, or bitten by mice and ants. (W2, W7, O4,)

4. Strategies of weakness and threats. (WT)

4.1 DRFT requires growers who have a lot of soilless experiences and most skillful management in hydroponics. Simultaneously, the system needs high initial investment. Cost of system is expensive and spends a lot of time in cleaning polystyrene board, culture bed and polyethylene sheet lying. However, DRFT can produce some popular local crops 10.5 – 12 crops annually with stable production for local market in much bigger volume than the temperate lettuce and herbs. (W1, W2, W6, T1, T2)

4.2 Some equipments e.g. polystyrene ridge culture bed, air inducer etc. are expensive and the system is suitable for small culture bed, uses individual small pump and catchment tank, It spends a lot of labor to check and adjust pH and EC of nutrient solution. However, this system is easy for growers to install. In case of high marketing demand, growers can expand the growing set and extend production by themselves. (W4, T3)

4.3 In summer, some problems happen with the DRFT system e.g. the air is too warm due to small plastic roof, bad ventilation. However, it can decrease the problem with cheap shading using slan only in summer period and a net house will help prevent insects and rain problem. Vegetables grown in DRFT have rapid growth and harvest, high yield and stable production which the economic turn over is quit quickly. (W5, T4)

Figure 20 Dynamic Root Floating Technique; DRFT.

Note: 1 – 2 DRFT nursery, final stage and how it works

3 Hobby set

4 Temperate lettuce at the Royal Northern Project, Nonghoi station, Chiang Mai

5 Chinese cabbage grown in a modified vacant chicken house in Chachoengsao after birdflu damage

6 Temperate lettuce growing in Samut Prakan

SWOT Analysis of DFT

Strength: S

S1 Intermediate initial investment.

S2 Cost of system cheap, use polyethylene bed, with or without polystyrene plate to protect high temperature, polystyrene board for planting expensive but no need of plastic pots, use cheaper urethane foam cube for planting.

S3 Rapid growth but slower than NFT due to full time or intermittent feed nutrient solution.

S4 Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor.

S5 Substrate: use small urethane foam cube for planting and sale with root system intact.

S6 Electricity shock: still many nutrient solutions in the system, no problem with plants.

S7 Large green house, high plastic roof, low impact to planting bed.

S8 Needs medium attention for checking pH and EC due to the largest catchment tank.

S9 Growing in net house gets some problem less than growing in soil.

S10 Fungus can be treated with fungicide e.g. Aliette, *Trichoderma* and needs safety period.

S11 Simple system, easy to maintenance and extend production by growers.

S12 High efficiency use of water and fertilizer.

Weakness: W

W1 Less amount of crops per year than NFT; growing period usually divided in 2 stage: seedling and growing

W2 Suitable to grow crops on highland due to no problem of high temperature on nutrient solution and crop environment e.g. Royal Project Foundation.

W3 Needs the biggest catchment tank due to used deep nutrient solution.

W4 Plants grow well except summer. However plants grow well all year round only on the high land.

W5 Easy but consumes high energy due to bigger catchment tank to serve many culture beds.

W6 High temperature causes not adequate oxygen dissolve in nutrient solution.

W7 Needs plastic roof cover to protect rain which cause the dilution of nutrient solution.

W8 Needs intermediate flow rate but large amount of nutrient solution use large pump.

W9 Growing on polystyrene board, after harvest needs to be cleaned and sun-dried 1 day before transplanting, the cleaning process erodes polystyrene board.

W10 Diseases easy to spread out through the system due to the use of same big catchment tank.

W11 Large plastic roof sometimes destroyed by gale.

W12 Some growing equipment easy to be destroyed e.g. polystyrene board is cracked, bitten by mice and ants.

Opportunities: O

O1 The water culture recommended for the beginner.

O2 Suitable for temperate lettuce, some popular local crops, watercress, muskmelon and aquatic plants.

O3 Easy to extend culture bed, growers can install system which is cheaper than NFT system.

O4 Popular in Japan.

Threats: T

T1 High initial investment for large net house, which is required with shading, ventilation system, large catchment tank.

T2 Growers should have some soilless culture experience.

T3 Growers should have more skill in management in hydroponics.

T4 Nutrient solution temperature too high in summer, low yield.

Strategies management from SWOT analysis

DFT

1. Strategies of strength and opportunities. (SO)

1.1 DFT is a water culture recommended for the beginners and suitable for temperate lettuce, some popular local crops, watercress, musk melons and aquatic plants. It is intermediate initial investment, cost of system cheap, uses polyethylene bed with or without polystyrene plate to protect high temperature, polystyrene board for planting are expensive but no need of plastic pots, uses cheaper urethane foam cube for planting. The system gives rapid growth but slower than NFT due to full time or intermittent feed nutrient solution. (S1, S2, S3, O1, O2)

1.2 DFT is popular in Japan and used in many vegetable factories. The system is easy to extend culture bed, growers can install system by themselves, which is cheaper than NFT system. Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor. Substrates use small urethane foam cube for planting and sold with root system intact, in case of electricity shock, it still has many nutrient solution in the system and no problem with plants. (S4, S5, S6, O3, O4)

1.3 DFT is a water culture recommended for the beginners. Plants are grown in large green house, high plastic roof, low impact to planting bed, needs medium attention for checking pH and EC due to largest catchment tank. It is a high efficiency use of water and fertilizer, simple system, easy to maintain and extend production set by growers. (S7, S8, S11, S12, O1)

1.4 DFT is a water culture recommended for the beginners. Plants are grown in net house, plastic roof, getsless problem than growing in soil, fungus can be treated with fungicide e.g. Aliette, *Trichoderma* and needs safety period. (S9, S10, O1)

2. Strategies of strength and threats. (ST)

2.1 DFT is a system that growers should have some soilless culture experience, more skill in management in hydroponics. However, it is intermediate initial investment, cost of system cheap but the system gives rapid harvest with easy and save labor in control nutrient solution for large scale. Substrate uses small urethane foam cube for planting and sold with root system intact. (S1, S2, S3, S4, S5, T2, T3)

2.2 DFT is a system that growers should have some soilless culture experience and more skill in management in hydroponics. However, it is a simple system, easy to maintain and extend production set by growers with high efficiency use of water and fertilizer. Growing DFT in net house get less problem than growing in soil, fungus can be treated with fungicides and needs safety period incase of electricity shock, it still has many nutrient solution in the system and no problem with plants. (S6, S9, S10, S11, S12, S, T2, T3)

2.3 DFT is high initial investment for large net house.It requires shading, ventilation system, large catchment tank. However, the cost of system cheap, use polyethylene bed with or without polystyrene plate to protect high temperature, no need to use plastic pots, uses cheaper foam cube for planting. Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor. Substrate uses small urethane foam cube for planting and sold with root system intact. (S2, S4, S5, T1)

2.4 For DFT system, the nutrient temperature is too high in summer, as a result of low yield. However, if growers use polyethylene bed with polystyrene plate to protect, high temperature, grow in large green house, high plastic roof, low impact to planting bed and use large catchment tank or use the DFT system to install on the highland (low temperature) the problem of high nutrient temperature will decrease. (S2, S7, S8, T4)

3. Strategies of weakness and opportunities. (WO)

3.1 DFT is a water culture recommended for the beginners and suitable for temperate lettuce, some popular local crops, watercress, muskmelon and aquatic plants. However, the system gives less amount of crops per year than NFT and suitable to grow crops on highland due to no problem of high temperature on nutrient solution and crop environment e.g. Royal Project Foundation. Plants grow well all year round except summer. (W1, W2, W4, O1, O2)

3.2 DFT is popular in Japan and used in many vegetable factories. The system is easy to extend culture bed, growers can install system by themselves which is cheaper than NFT system. The system needs the biggest catchment tank due to used deep nutrient solution and serve many culture beds which is easy but consumes high energy for intermediate flow rate but large amount of nutrient solution and uses large pump. (W3, W5, W8, O3, O4)

3.3 DFT is a water culture recommended for the beginners. However, high temperature in summer causes inadequate oxygen dissolves in nutrient solution, and needs plastic roof cover to protect rain which causes the dilution of nutrient solution but large plastic roof sometimes destroyed by gale. (W6, W7, W11, O1,)

3.4 DFT is a water culture recommended for the beginners. However, plants growing on polystyrene board, after harvest need to be cleaned and let the sun dry before transplanting, the cleaning process erodes polystyrene board. Furthermore, some growing equipment easy to be destroyed. e.g. polystyrene board is cracked, bitten by mice and ants. In addition, diseases easy to spread out through the system due to the use of same big catchment tank. (W9, W10, W12, O1,)

4. Strategies of weakness and threats. (WT)

4.1 DFT is a system that growers should have some soilless culture experience and more skill in management in hydroponics. However, the system is suitable for growing crops on highland due to no problem of high temperature on nutrient solution and crop environment. Plants grow well all year round only on highland (low temperature) and give less amount of crops per year than NFT. (W1, W2, W4, T2, T3)

4.2 DFT is high initial investment for large net house, which requires shading, ventilation system, large catchment tank, gives less amount of crops per year than NFT and suitable for growing on highland which plants grow well all year round without chiller for nutrient solution. It challenges growers to grow some popular local crops which local market is much bigger than temperate crops especially in summer. In addition, DFT system is an efficiency use of water which is the biggest problem on highland. (W1, W2 W4, T1)

4.3 DFT system has limitation on nutrient solution when temperature is too high in summer. It gives low yield. However, DFT is suitable for growing crops on highland, plants grow well, gives high yield, rapid harvest all year round because no problem of high temperature causing inadequate oxygen dissolve in nutrient solution and needs intermediate flow rate for plants. (W2, W4, W8, T4)

Figure 21 Deep Flow Technique; DFT.

Note: 1 Chinese celery at H.M.'s Private Development Project, Bangkok

2 Local herb at Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan

3 - 4 Temperate lettuce at the Royal Northern Project, Ang khang station, Chiang Mai

5 Temperate lettuce at the Royal Northern Project, Inthanon station, Chiang Mai

6 Watercress at the Royal Northern Project, Nonghoi station, Chiang Mai

SWOT Analysis of NFT

Strength: S

S1 High number of crops per year due to no time lag, after harvest crops in the morning can transplant seedling in the same evening, growing period usually divided in 3 stages: seedling, nursery and growing.

S2 Crops grow well throughout Thailand which are produced 12-16 crops annually.

S3 Rapid growth and harvest, high yield due to full time feed nutrient solution, no need intermittent controller.

S4 Needs smaller catchment tank due to used less nutrient solution in the system.

S5 Plants grow well all year round. But in summer needs chiller for nutrient solution.

S6 Easy and save energy to install chiller due to use smaller catchment tank to serve many benches.

S7 Thin nutrient film provides adequate oxygen for the plant.

S8 Large scale needs one set of pump and nutrient solution automatic controller, easy and save labor to check pH and EC of nutrient solution.

S9 Crops grow well both inside and outside greenhouse depend on budget, PVC gullies can protect rain water.

S10 Substrate: need small volume of substrate e.g. perlite mix with vermiculite or small urethane foam cube and sold with root system intact.

S11 Large greenhouse, high plastic roof or open field low impact to planting bed.

S12 Time need: PVC gullies easy to clean, harvest crop in the morning, clean and let the sun dry and transplant in the same evening.

S13 Growing in evaporative greenhouse or net house have no insect problem.

S14 Fungus can be treated with fungicide through nutrient solution e.g. Aliette, *Trichoderma* and safety period is needed.

S15 Simple system, easy to maintenance and expand production set by growers.

S16 High efficiency use of water and fertilizer.

Weakness: W

W1 High initial investment, suitable for cash crops e.g. temperate lettuce & herbs.

W2 Cost of system expensive, PVC gullies expensive, plastic pot, perlite, vermiculite single use expensive but urethane foam cubes cheaper.

W3 Electricity shock: needs spare electric turbine or engine pump.

W4 High electricity consumption: commercial farms need high flow rate and large pump, chiller consumes high power supply.

W5 Needs high attention for checking pH, EC to control nutrient solution.

W6 Disease easy to spread out through the system due to the use of same catchment tank.

W7 Large plastic roof sometime destroyed by gale.

W8 Need chiller for cooling nutrient solution especially in summer.

Opportunities: O

O1 Suitable for temperate lettuce, herbs.

O2 Easy to extend in case of high marketing demand, can use local planting materials and equipments.

O3 Opportunities to produce crops substitute the import of temperate lettuce and herbs.

O4 Mainly used worldwide and in Thailand.

O5 Consistently superior quality, high yield, rapid harvest.

O6 Can control aerial and root environment.

Threats: T

T1 Grower should have many soilless culture experiences.

T2 Grower should be most skillful in management of hydroponics.

T3 Nutrient solution temperature is too high in summer, low yield, so need chiller.

T4 Some equipments are expensive e.g. PVC gullies, iron benches, evaporative cooling houses etc.

Strategies management from SWOT analysis

NFT

1. Strategies of strength and opportunities. (SO)

1.1 NFT is a water culture suitable to grow temperate lettuce and herbs which are given opportunities to produce crops substitute the import of temperate lettuce and herbs. The system can give high number of crops per year due to no time lag, after harvest crops in the morning, growers can transplant seedling in the same evening, crops grow well throughout Thailand which are produced 12 – 16 crops annually, rapid growth and harvest, high yield due to full time feed nutrient solution, no need intermittent controller, plant grow well all year round but in summer need chiller for nutrient solution, crops grow well both inside and outside greenhouse depend on budget. (S1, S2, S3, S5, S9, O1, O3)

1.2 NFT can produce consistently superior quality, high yield, rapid harvest which are mainly used worldwide and in Thailand, because it is simple system, easy to maintain and expand production set by growers with high efficiency use of water and fertilizer. (S15, S16, O4, O5)

1.3 NFT is a system easy to extend in case of high marketing demand, can use local planting materials and equipments. Furthermore, the system need smaller catchment tank due to use less nutrient solution in the system, easy and save energy to install chiller. Thin nutrient solution provide adequate oxygen for the plant, large scale needs one set of pump and nutrient solution automatic controller, easy and save labor to cheek pH and EC of nutrient solution. For substrate, it needs small volume of substrate e.g. perlite mix with vermiculite or small urethane foam cube and sold with root system intact. (S4, S6, S7, S8, S10, O2)

1.4 NFT system can control aerial and root environment because the system is easy and save energy to install chiller for nutrient solution. Growing in large greenhouse, high plastic roof or open field, low impact to planting bed, save time to clean PVC gullies and harvest crops. In addition, growing in evaporative greenhouse or net house have no insect problem, fungus can be treated with fungicide through nutrient solution. (S6, S11, S12, S13, S14, O6)

2. Strategies of strength and threats. (ST)

2.1 NFT is a system that growers should have a lot of soilless culture experiences and most skillful management in hydroponics. However, it gives high number of crops per year due to no time lag, crop grow well throughout Thailand which are produced 12 – 16 crops annually, rapid growth and harvest, high yield, plants grow well all year round but in summer needs chiller for nutrient solution and crops grow well both inside and outside greenhouse depend on budget. (S1, S2, S3, S5, S9, T1, T2)

2.2 NFT system in the tropic gets problem of high nutrient solution temperature in summer and give low yield, so the system needs chiller in summer period. However, NFT need smaller catchment tank due to used less nutrient solution in the system, it is easy and save energy to install chiller and used smaller catchment tank to serve many benches. (S4, S6, T3)

2.3 Some equipments of NFT system are expensive e.g. PVC gullies, iron benches, evaporative cooling house etc. However, NFT can grow crops well both inside and outside greenhouse, thin nutrient solution provides adequate oxygen for the plant, use small volume of substrates and plants are sold with root system intact. It need less time in cleaning PVC gullies and transplanting seedling in the same day, it is a simple system, easy to maintain and expand production set by growers. (S7, S9, S10, S12, S15, T4)

2.4 Some equipments of NFT system are expensive such as PVC gullies, evaporative cooling house. Although plants grow well all year round but in summer, it needs to cool crops environment. In order to produce crops with stable production all year round, it is better to grow crops in large evaporative cooling house and it need one set of pump and nutrient solution automatic controller with easy and save labor to check pH and EC of nutrient solution, large greenhouse with high plastic roof gets less impact to planting bed, no insect problem, fungus can be treated with fungicide and high efficiency use of water and fertilizer. (S5, S8, S11, S13, S14, S16, T4)

3. Strategies of weakness and opportunities. (WO)

3.1 NFT is a water culture suitable to grow temperate lettuce and herbs which are given opportunities to produce crops substitute the import of temperate lettuce and herbs which NFT are mainly used worldwide and in Thailand, the system gives consistently superior quality, high yield, rapid harvest. However, it is a high initial investment, cost of system expensive, high electricity consumption for large pump and chiller, need high attention for checking pH and EC to control nutrient solution. (W1, W2, W4, W5, O1, O3, O4, O5)

3.2 NFT is easy to extend in case of high marketing demand, can use local planting materials and equipments. However, the cost of system expensive, high initial investment. In case of electricity shock, it need spare electric turbine or engine pump and need chiller for cooling nutrient solution in summer. (W1, W2, W3, W8, O2)

3.3 NFT can control aerial and root environment. However, the system consumes high power supply for pump and chiller, needs high attention for checking pH, EC to control nutrient solution, disease easy to spread out through the system due to the use of same catchment tank, and large plastic roof for rain protection, sometimes destroy by gale. (W4, W5, W6, W7,O6,)

4. Strategies of weakness and threats. (WT)

4.1 NFT requires growers who have a lot of soilless culture experiences and most skillful management in hydroponics. Simultaneously, the system needs high initial investment. Cost of system is expensive, commercial farm consumes high power supply for chiller or evaporative cooling house, needs high attention for checking pH, EC to control nutrient solution. However, NFT can produce temperate lettuce and herbs 12 – 16 crops annually with stable production for modern trade and high class restaurant which can substitute the import. (W1, W2, W4, W5, T1, T2)

4.2 NFT have some problems of nutrient solution temperature is too high in summer, with a result of inadequate of oxygen for plants and give low yield, it is recommended to install chiller and operate only high temperature during day-time in summer, so it consumes high power supply. However, NFT can produce temperate lettuce 12 – 16 crops annually with stable production, high quality products with stable price all year round which the economic turn over is very quickly. (W4, W4, T3)

4.3 Some NFT equipments are expensive e.g. PVC gullies, iron benches, evaporative cooling house etc., cost of system expensive, consumes high power supply, needs high attention for checking pH, EC to control nutrient solution, diseases easy to spread out through the system due to use same catchment tank. However, if growers have many soilless culture experience and most skillful in management of hydroponics, they can produce 12 – 16 crops annually of temperate lettuce and herbs which are very high price. It is a good business to implement in Bangkok and tourist area. (W2, W4, W5, W6, T1, T2, T4)

Figure 22 Nutrient Film Technique; NFT.

Note: 1-2 Temperate lettuce growing outdoor at Sai Jai Thai Garden, Bangkok

3 In evaporative cooling house at Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan

4 In evaporative cooling house at H.M.'s Private Development Project, Bangkok

5 Under plastic roof at Kaoko, Phetchabun

6 Outdoor growing in Pathum Thani

Boston's model

This model is widely used and involves experts analyzing data and information obtained from SWOT analysis to identify the most appropriate soilless culture system for each crop (Sukprasert, 2008).

Operation definition

Input = cost of investment : operation cost, life long of equipment cost, cost of water, electricity, transportation, constraint in getting or buying equipment concern.

Process = simplicity or difficulty of growing process, system maintenances cost, easiness or difficulty of taking care starting from seedling, transplanting, harvesting, safety period when there are problems on electricity and support system.

Out put = product quality yield per crop, number of crops annually, easiness or difficultly in harvesting, by products or problems from the system.

In comparison, it can be concluded which system should be selected to use in hydroponic vegetable production.

The focus group discussion, consisting of 22 members from the Thai Soilless Culture Forum Committee, experts from Kasetsart University, and soilless culture farmers was held in November 2010. From the brainstorming sessions involving SWOT analysis on the inputs, outputs, and processes of soilless culture, it was evident that only 5 main soilless culture systems are used—DRFT, NFT, substrate culture, DFT and aeroponics. The DRFT, NFT, and DFT systems worked well for vegetable production, but substrate culture was suitable for fruit vegetables (sweet peppers, tomatoes, etc.)due to the limitations of crop size, crop price, variety, climate, tropical environment and the cost of investment (Figure 2). These results were similar to a previous study by Montri and Wattanapreechanon (2006), as shown in Table 3. However the high initial capital cost and mechanical complexity could be reduced by using newly simplified local materials and simple equipment as recommended by Ratanakosol (1997).

Figure 23 showed that DRFT, NFT, Substrate culture and Aeroponic worked well for vegetable production respectively. However, it is possible to use aeroponic but the technique should be simplified to make it easy to maintain and cut the cost.

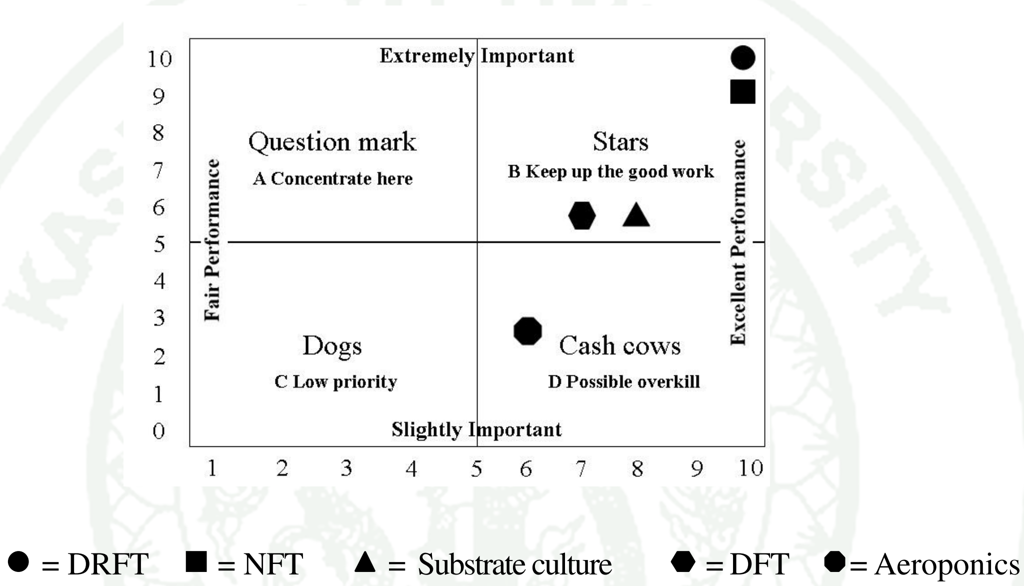

Figure 23 Analysis of a hydroponic system suitable for vegetable production in Thailand using Boston's Model.

Cash cows, Possible overkill (Aeroponic)

1. Needs to simplify technique, so that the systems will be cheaper.
2. Needs to install where electricity and support systems are always available.
3. System provides enough oxygen for plants
4. Needs contract market and high demand of hygienic vegetables due to high yield and quality.
5. Growers should have more soilless culture experiences.

Stars, keep up the good work (DRFT, NFT, Substrate culture, DFT)

1. Easy to extend in case of high market demand, also local planting material and equipment can be used.
2. Can produce cash crops all year round with high yield, quality and rapid harvest.
3. Use less labor; women, children, senior citizen, handicaps can work.
4. Easy to extend in case of high market demand.
5. Plants grow well all year round.
6. High demand of hygienic vegetable market.
7. Growers should have more management skill in hydroponics.

Phase III Selection of the soilless culture systems suitable for commercial scale of some potential crops.

From the brainstorming sessions involving SWOT analysis on the inputs, outputs, and processes of soilless culture, the results showed that DRFT, NFT, and DFT systems worked well for leafy vegetables production, but substrate culture was suitable for fruit vegetables (sweet peppers, tomatoes, etc.) These results were checked in hydroponic growers to find out the commercial level. Many organization had provided information, facilities and areas to carry out experiment. The results of yield trial are as fallow:

In rainy season, temperate lettuce could be damaged due to the heavy rainfall followed by diseases, but these crops and herbs give high yield when grown in evaporative cooling house (Table 10).

Table 10 Soilless production of temperate lettuce varieties, herb in NFT with PVC gullies in evaporative cooling house conducted at Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan Province during rainy season (October, 2013).

Vegetables / Related Data	Green Oak	Red Oak	Red Coral	Butter Head	Cos	Frillice Iceberg	Rocket (young)
1. Plot size (m)	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	.60x12.00
2. No. of plants (plants/ m^2)	25	25	25	25	25	25	250
3. Yield(kg/plot)	60.00	56.00	48.00	64.00	68.00	55.00	38.00
4. Average yield (kg/ m^2)	3.13	2.92	2.50	3.33	3.54	2.86	1.98
5. Wholesale price (baht/kg)	65	65	65	65	65	65	100
6. Income (baht/ m^2)	203.45	189.80	162.50	216.45	230.10	185.90	198
7. Annual Crops	14	14	14	14	14	14	14

Soilless culture was identified as a technique that can solve many problems in unsuitable environments. Plants could grow better, the growing season could be extended, and finally there was increase in crop yield and income (Table 11, 12, 13 , 14 and 15)

Table 11 Soilless outdoor production of temperate lettuce varieties, herb in NFT with PVC gullies under slan shading conducted at Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan Province during the cold season (December, 2013).

Related Data \ Vegetables	Green Oak	Red Oak	Red Coral	Butter Head	Cos	Frillice Iceberg	Rocket (young)
1. Plot size (m)	1.60x6.00	1.60x6.00	1.60x6.00	1.60x6.00	1.60x6.00	1.60x6.00	1.60x6.00
2. No. of plants (plants/ m^2)	25	25	25	25	25	25	250
3. Yield(kg/plot)	36.20	34.40	30.40	38.40	39.20	35.20	20.20
4. Average yield (kg/ m^2)	3.77	3.58	3.17	4.00	4.08	3.67	2.10
5. Wholesale price (baht/kg)	65	65	65	65	65	65	100
6. Income (baht/ m^2)	245.05	232.70	206.05	260.00	265.20	238.55	210.00
7. Annual Crops	14	14	14	14	14	14	14

Table 12 Soilless outdoor production of temperate lettuce varieties in NFT under slan shading conducted at Sai Jai Thai Garden, Bangna, Bangkok during the cold season (December, 2013).

Related Data \ Vegetables	Green Oak	Red Oak	Red Coral	Butter Head	Cos	Frillice Iceberg
1. Plot size (m)	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00
2. No. of plants (plants/ m^2)	25	25	25	25	25	25
3. Yield(kg/plot)	72.60	70.50	60.50	78.20	79.50	72.00
4. Average yield (kg/ m^2)	3.78	3.67	3.15	4.07	4.14	3.75
5. Wholesale price (baht/kg)	65	65	65	65	65	65
6. Income (baht/ m^2)	245.70	238.55	204.75	264.55	269.10	243.75
7. Annual Crops	14	14	14	14	14	14

Table 13 Soilless production of temperate lettuce, some popular local crops conducted at H.M.'s Private Development Projects, Sapansung, Bangkok during the cold season (December, 2013).

Vegetables / Related Data	Green Oak (NFT Evaporation cooling house)	Red Oak (NFT Evaporation cooling house)	Butter Head (NFT Evaporation cooling house)	Cos (NFT Evaporation cooling house)	Chinese cabbage (DFT with plastic cover)	Amaranthus (DFT with plastic cover)	Chinese celery (DFT with plastic cover)
1. Plot size (m)	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	1.20x4.80	1.20x4.80	1.20x4.80
2. No. of plants (plants/ m^2)	25	25	25	25	25	25	25
3. Yield(kg/plot)	51.80	49.90	55.70	60.90	20.70	21.60	26.50
4. Average yield (kg/ m^2)	2.70	2.60	2.90	3.17	3.60	3.75	4.60
5. Wholesale price (baht/kg)	65	65	65	65	50	50	50
6. Income (baht/ m^2)	175.50	169.00	188.50	206.05	180.00	187.50	230.00
7. Annual Crops	14	14	14	14	12	12	12

Table 14 Soilless outdoor production of temperate lettuce varieties, herb in NFT under slan shading conducted at Chitralada Palace during the cold season (December, 2013).

Related Data \ Vegetables	Green Oak	Red Oak	Red Coral	Butter Head	Cos	Frillice Iceberg	Rocket (young)
1. Plot size (m)	1.60x6.00	1.60x6.00	1.60x6.00	1.60x6.00	1.60x6.00	1.60x6.00	1.60x6.00
2. No. of plants (plants/ m^2)	25	25	25	25	25	25	250
3. Yield(kg/plot)	37.50	35.50	30.70	43.20	44.20	37.50	16.40
4. Average yield (kg/ m^2)	3.90	3.70	3.20	4.50	4.60	3.90	1.70
5. Wholesale price (baht/kg)	65	65	65	65	65	65	100
6. Income (baht/ m^2)	253.50	240.50	208.00	292.50	299.00	253.50	170.00
7. Annual Crops	14	14	14	14	14	14	14

Table 15 Soilless indoor production of temperate lettuce varieties in DFT under plastic cover greenhouse conducted at Royal Northern Project, Chiang Mai during the cold season (December, 2013).

Related Data \ Vegetables	Green Oak	Red Oak	Butter Head	Cos	Frillice Iceberg
1. Plot size (m)	12.00x6.00	12.00x6.00	12.00x6.00	12.00x6.00	12.00x6.00
2. No. of plants (plants/ m^2)	24	24	24	24	24
3. Yield(kg/plot)	30.00	27.00	38.00	39.00	34.00
4. Average yield (kg/ m^2)	4.16	3.75	5.27	5.41	4.72
5. Wholesale price (baht/kg)	65	65	65	65	65
6. Income (baht/ m^2)	270.40	243.75	342.55	351.65	306.80
7. Annual Crops	12	12	12	12	12

Table 16 Average yield of temperate lettuce grown by various systems at different housing, and sites.

	Royal Northern projects DFT under plastic cover greenhouse	Chitralada Palace NFT under slan shading	Sai Jai Thai NFT under slan shading	Luk Phra Dabos NFT under slan shading	H.M.'s Private Development Projects NFT in EVAP cooling house	Luk Phra Dabos NFT in EVAP cooling house
1. Average yield (kg/ m2)	4.62	3.96	3.76	3.71	2.84	3.04

From the trial works, it was revealed that:

1. The average yield of temperate lettuce grown by NFT in PVC gullies in the evaporative cooling house was less than those grown under slan shading (Table 16) due to the lower quality and intensity of light for photosynthesis. However, the quality of vegetable produce harvested from evaporative cooling house was better because there was less damage from rain and fungus diseases in the rainy reason and the temperature could be controlled in the summer.

2. The yield of temperate lettuce harvested in December was much higher than in October as the weather in December was much cooler and the temperate lettuce originated from the temperate zone.

3. It could be concluded that each individual varieties of lettuce yields differently as follow:

3.1 October : Cos > Butter Head > Green oak > Red oak > Frillice > Red coral

3.2 December : Cos > Butter Head > Green oak > Frillice >Red oak > Red coral

3.3 Frillice was particularly sensitive to hot temperature. If grown in cooler temperature, it's performance was much better.

4. The yields of temperate lettuce were not different significantly if grown in different locations but not far apart. Luk Phra Dabos Agricultural Training and Development Center and Sai Jai Thai Garden could yield at the same level, which was higher than H.M.'s Private Development Projects, possibly because of the growers' experience. However, the Chitralada Palace and Royal Northern projects could yield higher than those three mentions farms due to the higher efficiency of chillers for nutrient solution at Chitralada Palace and lower temperate at Royal Northern Project (Table 16).

Substrate culture was suitable for fruit vegetables as shown in Table 17. However, yield of tomatoes conducted at hill tribes farmers in Royal Northern projects when compare with growers at Camelon High land, Malaysia (30 kg/m^2) is nearly the same (Senadee, 2014)

Table 17 Soilless substrate culture of fruit vegetables under plastic cover greenhouses conducted at hill tribes farmers in Royal Northern Projects, Chiang Mai during cold season (December, 2013).

Vegetables / **Data concern**	**Tomatoes**	**Cucumbers**	**Sweet peppers**
1. Average yield (kg/ m^2)	27.60	21.80	15.20
2. Wholesale price (baht/kg)	30	25	75
3. Income (Baht/ m^2)	828	545	1,140
4. Annual Crops	2	2	2

Research results showed that soilless culture had more advantages over soil culture as shown in Table 18 which indicated that yield, income, and the number of crops per year of soilless culture were much higher than that of soil culture.

Table 18 Comparison between soil and soilless production of temperate lettuce varieties, herbs in NFT with PVC gullies in evaporative cooling house conducted at Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan Province during 2013.

Vegetables / Data concern	Lettuce[1] (Soil culture)	Green oak	Red oak	Red Coral	Butter Head	Cos	Frillice Iceberg	Rocket Young vegetable
1. Plot size (m)	1.00x5.00	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00	1.60x12.00
2. No. of plants (plants/ m2)	9	25	25	25	25	25	25	250
3. Yield(kg/plot)	7.90	60	56	48	64	68	55	38
4. Average yield (kg/ m2)	1.58	3.13	2.92	2.5	3.33	3.54	2.86	1.98
5. Wholesale price (bath/kg)	20	65	65	65	65	65	65	100
6. Income (Bath/ m2)	31.60	203.45	189.80	162.50	216.45	230.10	185.90	198
7. Annual Crops	4	14	14	14	14	14	14	14

Note: [1]Collected form The Royal Northern Project because most temperate lettuces and herbs cannot grow in Bangkok.

In a hydroponic system, replanting could be done immediately after harvesting, as farmers did not have to sterilize the soil, making it possible to have continuous production (Figure 24). Hydroponic vegetables had no toxic substances, no pesticides and no harmful microorganisms, which meets the most stringent catering specifications (Wilson, 2000). In Thailand, most hydroponic growers get Good Agricultural Practice (GAP) certificates as a guarantee to buyers that the product is safe, hygienic and grown by using standard techniques. Figure 24 shows the yield and income of temperate lettuce grown by a hydroponic system in an area of high soil salinity, where temperate lettuce could not be normally grown.

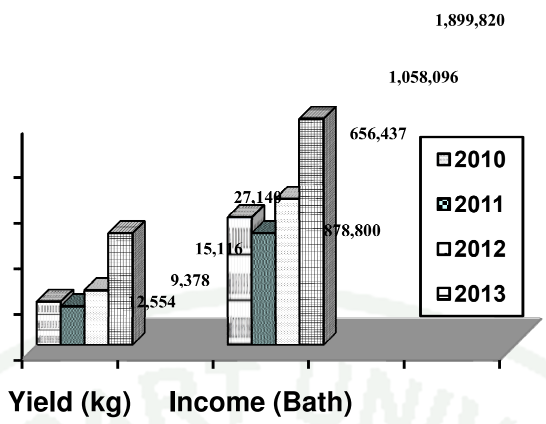

Figure 24 Total farm yield and income of hydroponic vegetable production conducted at Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan, with 90 plots (size 1.6 × 6.0 m) under slan shading and 24 plots (size 1.6× 12.0 m.) in evaporative cooling house, total area = 1,324.8 m^2.
Source: Luk Phra Dabos Agricultural Training and Development Centre (2014)

From the research results the researchers have been working on how to reduce costs and improve the production of hygienic vegetables. The research could identify which hydroponic systems were suitable for growing each cash crop and some popular local crops with appropriate food safety techniques at reasonable price (Table 19). So we can synthesize data and select the systems suitable for potential crops as shown in table 19.

Table 19 Suitable systems for crop production in Thailand.

Crops	Suitable system
Temperate lettuces	NFT > DRFT > DFT (Highlands) > aeroponics.
Temperate herbs (rocket, sweet basil)	NFT > DRFT > DFT (Highlands)
Local vegetables (Chinese cabbage, Chinese celery, Chinese kale, water convolvulus etc.)	DRFT >NFT > DFT
Fruit vegetables	Substrate culture

Phase IV Trials of crop productions using local produced materials and equipment for hydroponic system

The best hydroponic system using locally produced equipment were conducted at Chitralada Palace, Bangkok, Sai Jai Thai Garden (Vocational Training Centre for the handicaps) Bangkok and Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan.

In order to reduce production costs and improve product quality on hydroponic farms, it was necessary to develop equipment using local materials. The results from experiments conducted at the Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan, are shown in Table 20.

Table 20 Comparison of imported and locally made hydroponic equipment.

	Imported	**Locally made**	**Advantage of locally made**
Substrate	Perlite + vermiculite	Urethane foam, sand, coconut fiber, rice husk etc.	Cheaper
Cooling system	Cooling set	Local assembly	Cheaper and good after-sales service
Automatic controlled mist sprayed	Set	Local assembly	Cheaper and good after-sales service
Automatic nutrient solution controller	Set	Reused saline solution plastic bags	Very cheap and environmentally friendly
pH meter	Set	Local pH test kit	Cheaper
Gullies	PVC	PVC, Polystyrene board, asbestos sheeting etc.	Cheaper and easy to buy
Seeds	Pelleted seeds	Raw seeds	Very cheap

Imported Vermiculite+ Perlite → local urethane foams

Imported cooling set → local assembly

Local assembly automatic controlled water sprayed set

Imported automatic nutrient solution controller set → Reused saline solution plastic bags

Figure 25 Equipment made of local materials.

Locally made pH test kit to substitute imported pH meter

Polystyrene board cover on PVC or asbestos sheet, which is cheaper
Than the PVC gullies and easy to buy at local hardware shops

Using local raw seeds to substitute imported pelleted seeds

Figure 25 (Continued)

Figure 26 Raw temperate lettuce seeds seeding.

Note: 1. Line the clear plastic box with wet cotton pad, have the lid on to keep the moisture.

2. Lay the seeds on one side of the cotton pad and fold the other side to cover them, put the lid on, and place it in the refrigerator at 4 – 10 °C for about 38 hours (to stimulate germination).
3. Open the box, roots coming out of the seeds should be seen.
4. Wet the urethane foam, lay it on the plastic tray, use lightly the forceps to move the geminated seeds in to the urethane foam but not too deep.
5. Transplant the seeds in the urethane foam to grow on the dim light for 1 – 2 days.
6. Move the plantlets to the soft sunlight to let them grow strong.

Substrate or media

Many types of substrate or media can be used for seed germination e.g. perlite, vermiculite, gravel, coarse washed river sand, rockwool, with small plastics pots as container. For best results, the media selected has to allow air to reach the roots, and supply the oxygen requirement of the plant. It must also retain sufficient water and nutrient long enough between watering cycles, to keep the plant stress-free and provide support for the seedling. Another importance criteria of any media is that it is disease free. In Thailand, perlite mixed with vermiculite is very popular and normally used but it is imported and expensive. Urethane foam cube can be substituted, which the price is much cheaper and locally made. In addition, it can be widely used in NFT system without plastic pots. Other alternative substrates from agricultural waste are coconut fiber, rice husk etc. and sand.

Cooling system

In warmer climate, NFT permits an economical cooling of plant roots, avoiding the more expensive cooling of the entire greenhouse. Problems occur in hydroponics when the temperature of nutrient solution exceeds 20 °C, as this causes "bolting" in lettuce crops. Cooling the nutrient solution for lettuce production not only reduces bolting but lessens the incidence of the damping off fungus Pythium, which causes plant damage and death, particularly of small seedlings. Normally, it needs to import cooling set but it is very expensive. Modify of cooling set, by using local assembly which is cheaper with good after-sales service is another solution as widely used at Royal Development projects Chitralada Palace, Bangkok, Luk Phra Dabos Agricultural Training and Development Centre, Samut Prakan, Sai Jai Thai Foundation, Bangkok etc. These cooling sets can maintain stable temperate lettuce production all year round.

Automatic controlled mist sprayed

The rates of photosynthesis, transpiration, respiration and hormone production are all affected by temperature. The physiology of the plants may be changed by growing at higher temperature. If the temperature at which lettuces are grown is too high articular varieties will bolt without hearting. Higher temperature in Thailand can be trouble to grow plant without soil. The use of an automatic controlled water spray not only decreases approximately 3-5 °C of temperature but also increases humidity and provides better ventilation for good supplies of O_2 and CO_2 during sunny day from 9.00-4.00 PM. In the past, imported set is normal imported. Using local assembly which is cheaper with good after-sales service is alternative solution.

Automatic nutrient solution controller

One of the most interesting advantages of hydroponics is labor saving by adopting highly mechanized methods. Adjustment of nutrient solution is generally carried out automatically by means of electric conductivity meter and pH meter. Generally, it needs to import automatic nutrient solution controller set but it is very expensive and after-sales service is not good. Using reused saline solution plastic bags for semiautomatic control nutrient solution to substitute the import set is very cheap (free from hospitals) and environmentally friendly.

pH meter

There are many options of the equipment available and it is important to know the accuracy and handing of the meter. For most growing application, the meter needs only be accurate at + 0.2 of a pH point. It is necessary to control the solution pH, because pH strongly affects mineral nutrient absorption and growth of plants. Addition of acid or alkali solution to control the suitable pH level of the solution is essential in soilless culture. Practically, pH is measured by the pH meter or pH test kit. However, pH meter needs to import but pH test kit can be locally produced. The use of pH indicator drop test kit is recommended because it is very cheap and accurate enough for most purposes. To find the pH of a solution, take about a tablespoon of nutrient solution put in a small white cup, add 1 drop of the indicator solution and read off the corresponding pH value from the color developed with printed standard color chart. The whole operation takes less than 30 seconds.

PVC gullies

PVC gullies supported by benches, in both outdoor and greenhouse situation are used in NFT system. Most large commercial growers purchase PVC gullies in bulk and can reduce costs but it is difficult to buy where the farm is far from Bangkok. The most commonly used type of PVC gulliesare the rectangular, white 50 × 100 mm. channel. These small types of channels have been developed, designed specifically for lettuce and other small crops such as herbs. The choice of gully system or material is often based on availability, cost and growers' preference. Using asbestos sheeting as rigid multi-channel sheeting has found used in hydroponics, for small sized crops such as lettuce. There requires greater support from the bench structure, but has the advantage of providing a number of small channels per sheet, cheap, easy to buy at local hardware shops and are easier to clean.

Seeds

Normally, we need to import pelleted seed of most lettuce varieties. Pelleted seed consists of raw seed, coated with a layer of inert material and clay. As the pellet absorbs water it splits open, allowing immediate access to oxygen for more uniform germination, and better emergence. Some coated seeds are also primed to extent both the temperature range and speed of germination. Lettuce seed pelleting improves the shape, size and uniformity of raw lettuce seeds for more accurate seedling and easier handling. Most farms use imported seeds but they are very expensive and sometimes out of order. However, research works on seed production has currently been carried out in the high land as it has certain period of low temperature making seed production feasible. Normally, freshly lettuce seeds will not germinate at high temperature until thermo dormancy is broken. Thermo dormancy is a common cause of failure to germinate in summer condition. Germination of lettuce seed in above 4 °

C refrigerator is common for local produce seeds. Lettuce raw seeds are much cheaper when compare to import seeds.

Phase V Adoption of soilless culture technology

From the primary data collection and in-depth interviews with 58 soilless culture growers, the research revealed that

1. Most soilless culture growers are male (69 %). They preferred using NFT, DRFT and DFT for leafy vegetable, but substrate culture for fruit vegetable. They chose NFT the most (48.3%) for their growing system(Table21), because the investment cost of NFT system (1,052 Baht/m^2) is cheaper as compare to DRFT (1,890 Baht/m^2) (Sirinupong, 2013).

Table 21 Growers and their preference of soilless culture systems.

			soilless culture systems								
			DRFT	NFT	DFT	Substrate Culture	NFT+ Sub	DRFT NFT DFT	DRFT NFT	DRFT DFT	Total
sex	male	Count	2	18	4	11	1	1	2	1	40
		Expected Count	3.4	19.3	4.1	7.6	.7	1.4	2.8	.7	40.0
		% of Total	3.4%	31.0%	6.9%	19.0%	1.7%	1.7%	3.4%	1.7%	69.0%
	female	Count	3	10	2	0	0	1	2	0	18
		Expected Count	1.6	8.7	1.9	3.4	.3	.6	1.2	.3	18.0
		% of Total	5.2%	17.2%	3.4%	0.0%	0.0%	1.7%	3.4%	0.0%	31.0%
Total		Count	5	28	6	11	1	2	4	1	58
		Expected Count	5.0	28.0	6.0	11.0	1.0	2.0	4.0	1.0	58.0
		% of Total	8.6%	48.3%	10.3%	19.0%	1.7%	3.4%	6.9%	1.7%	100.0%

2. For temperate lettuce, they preferred imported seed (53.44%) because of this pellet seed originated from Europe and thus could allow better convenience in the seeding process. It germinated well on cheaper and locally produced of urethane foam cubes as substrate (Table 22).

Table 22 The choosing of seed.

			Seed			Total
			Imported seed	Local seed	Both	
sex	male	Count	21	11	8	40
		Expected Count	21.4	11.0	7.6	40.0
		% of Total	36.2%	19.0%	13.8%	69.0%
	female	Count	10	5	3	18
		Expected Count	9.6	5.0	3.4	18.0
		% of Total	17.2%	8.6%	5.2%	31.0%
Total		Count	31	16	11	58
		Expected Count	31.0	16.0	11.0	58.0
		% of Total	53.4%	27.6%	19.0%	100.0%

3. Most growers held bachelor's degrees (69.0%). About (79.3%) of grower chose soilless culture occupation, while the remaining (20.7%) as supplementary income as Table 23.

Table 23 Education and occupation.

			occupation		Total
			main	supplement	
education	Non-degree	Count	9	2	11
		Expected Count	8.7	2.3	11.0
		% of Total	15.5%	3.4%	19.0%
	Bachelor's degree	Count	31	9	40
		Expected Count	31.7	8.3	40.0
		% of Total	53.4%	15.5%	69.0%
	Higher than bachelor's degree	Count	6	1	7
		Expected Count	5.6	1.4	7.0
		% of Total	10.3%	1.7%	12.1%
Total		Count	46	12	58
		Expected Count	46.0	12.0	58.0
		% of Total	79.3%	20.7%	100.0%

4. Most of growers preferred growing temperate lettuce only (51.7%) because temperate lettuce was a new cash crop, no competition from soil grown, sold at stable high price but still cheaper than the import (Table 24). In addition, this crop was suitable for their growing system and marketable.

Table 24 Vegetable varieties used in soilless culture systems.

education		Crops								Total
		Temperate lettuce, herb,local vegetable	Temperate lettuce, herb	Temperate lettuce, local vegetable	Temperate lettuce, fruit vegetable	Temperate lettuce	Temperate herb	local vegetable	fruit vegetable	
Non-degree	Count	0	3	0	0	4	0	0	4	11
	Expected Count	.2	1.5	.9	.2	5.7	.2	.2	2.1	11.0
	% of Total	0.0%	5.2%	0.0%	0.0%	6.9%	0.0%	0.0%	6.9%	19.0%
Bachelor's degree	Count	0	5	3	1	22	1	1	7	40
	Expected Count	.7	5.5	3.4	.7	20.7	.7	.7	7.6	40.0
	% of Total	0.0%	8.6%	5.2%	1.7%	37.9%	1.7%	1.7%	12.1%	69.0%
Higher than chelor's degr	Count	1	0	2	0	4	0	0	0	7
	Expected Count	.1	1.0	.6	.1	3.6	.1	.1	1.3	7.0
	% of Total	1.7%	0.0%	3.4%	0.0%	6.9%	0.0%	0.0%	0.0%	12.1%
Total	Count	1	8	5	1	30	1	1	11	58
	Expected Count	1.0	8.0	5.0	1.0	30.0	1.0	1.0	11.0	58.0
	% of Total	1.7%	13.8%	8.6%	1.7%	51.7%	1.7%	1.7%	19.0%	100.0%

5. Most hydroponic growers intended to get stable supply of quality products with stable price and high income, 56.9 % could earn approximately 100,000 – 500,000 Baht/year (Table 25).

Table 25 Soilless culture incomes.

			Income				Total
			Below than 100000	**100000-500000 Baht**	**500000-1000000 Baht**	**Over than 1000000**	
education	Non-degree	Count	1	8	2	0	11
		Expected Count	1.9	6.3	2.5	.4	11.0
		% of Total	1.7%	13.8%	3.4%	0.0%	19.0%
	Bachelor’s degree	Count	9	21	9	1	40
		Expected Count	6.9	22.8	9.0	1.4	40.0
		% of Total	15.5%	36.2%	15.5%	1.7%	69.0%
	Higher than bachelor’s degree	Count	0	4	2	1	7
		Expected Count	1.2	4.0	1.6	.2	7.0
		% of Total	0.0%	6.9%	3.4%	1.7%	12.1%
Total		Count	10	33	13	2	58
		Expected Count	10.0	33.0	13.0	2.0	58.0
		% of Total	17.2%	56.9%	22.4%	3.4%	100.0%

6. Most growers (55.2%) had working experience(1-5 years) and organized into groups or small clusters in order to ensure that they could provide stable supply for the wholesale and retail markets, (Table 26).

Table 26 Growers and soilless culture experience.

			experience				Total
			Less than 1 year	**1-5 years**	**6-10 years**	**Over 10 years**	
Age	21-30	Count	1	7	2	0	10
		Expected Count	1.0	5.5	2.6	.9	10.0
		% of Total	1.7%	12.1%	3.4%	0.0%	17.2%
	31-40	Count	0	13	8	1	22
		Expected Count	2.3	12.1	5.7	1.9	22.0
		% of Total	0.0%	22.4%	13.8%	1.7%	37.9%
	41-50	Count	1	6	1	3	11
		Expected Count	1.1	6.1	2.8	.9	11.0
		% of Total	1.7%	10.3%	1.7%	5.2%	19.0%
	51-60	Count	2	4	1	0	7
		Expected Count	.7	3.9	1.8	.6	7.0
		% of Total	3.4%	6.9%	1.7%	0.0%	12.1%
	More than60	Count	2	2	3	1	8
		Expected Count	.8	4.4	2.1	.7	8.0
		% of Total	3.4%	3.4%	5.2%	1.7%	13.8%
Total		Count	6	32	15	5	58
		Expected Count	6.0	32.0	15.0	5.0	58.0
		% of Total	10.3%	55.2%	25.9%	8.6%	100.0%

7. Some growers (8.6%) invested in evaporative cooling systems for better quality and higher yield of product (Senadee and Kusakul, 2013) and some of them (34.5%) preferred net house with plastic roof in order to prevent damages from rain and improve pest control measures at low capital investment (Table 27).

Table 27 The types of house for soilless culture systems.

			house							Total
			EVAP house	**Net house**	**Net house with plastic roof**	**Sunshade net**	**Net house with plastic and sunshade**	**Plastic roof house**	**EVAP+ sunshade net**	
education	Non-degree	Count	0	0	5	5	0	1	0	11
		Expected Count	.9	.6	3.8	3.4	1.3	.8	.2	11.0
		% of Total	0.0%	0.0%	8.6%	8.6%	0.0%	1.7%	0.0%	19.0%
	Bachelor's degree	Count	4	3	14	8	7	3	1	40
		Expected Count	3.4	2.1	13.8	12.4	4.8	2.8	.7	40.0
		% of Total	6.9%	5.2%	24.1%	13.8%	12.1%	5.2%	1.7%	69.0%
	Higher than bachelor's degree	Count	1	0	1	5	0	0	0	7
		Expected Count	.6	.4	2.4	2.2	.8	.5	.1	7.0
		% of Total	1.7%	0.0%	1.7%	8.6%	0.0%	0.0%	0.0%	12.1%
Total		Count	5	3	20	18	7	4	1	58
		Expected Count	5.0	3.0	20.0	18.0	7.0	4.0	1.0	58.0
		% of Total	8.6%	5.2%	34.5%	31.0%	12.1%	6.9%	1.7%	100.0%

8. Most of them (96.28%) heard, received and tried appropriate technologies. All growers (100%) searched more information from training courses, books and internet etc. However, most growers (76.3%) imitated, modified and continued to use but 2.8% failed (resulted lower than standard) and 20.9% of growers did not apply (only temporary change of behavior) as shown in Figure 27. Much attention was paid to developing a cultivation for hydroponic condition for each crop and standardization of cultivation method. This included production cost reduction, product improvement and also equipment development using local material for their farms.

9. Most growers learnt soilless culture techniques form short training courses organized by government universities and private companies, textbooks and internet then accepted / received and adopted as in Figure 27.

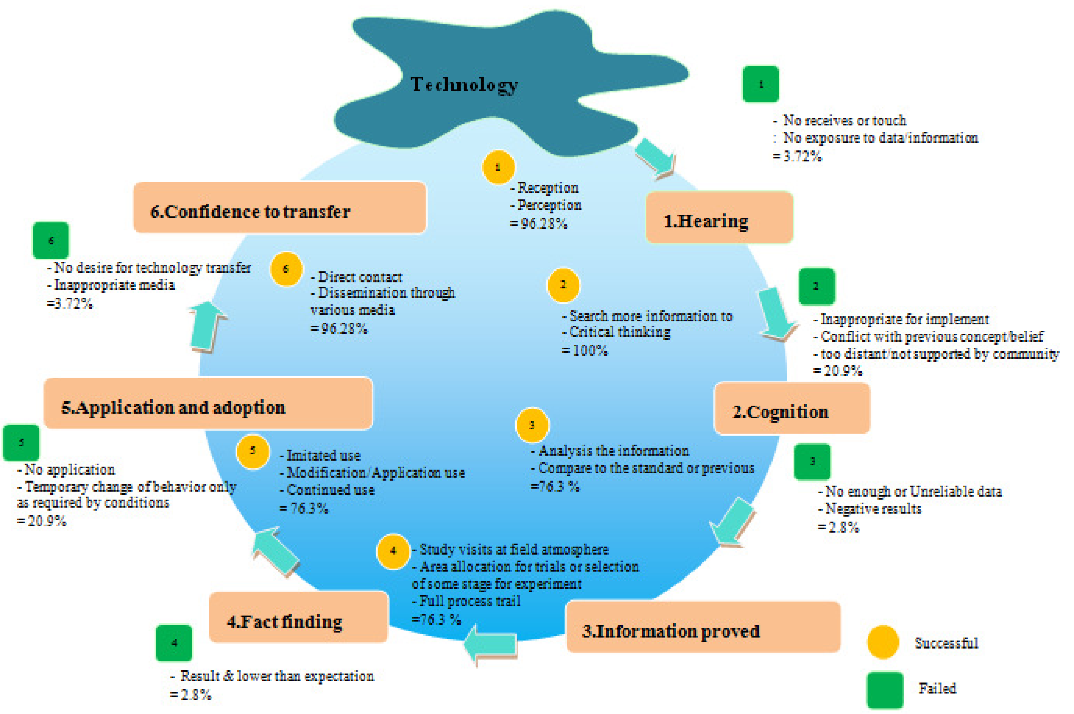

Figure 27 Reception and adoption of soilless culture technology.

Source: Modified from Sukprasert (2008)

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

This research covers the identification and development of the hydroponic system suitable for growing cash crops like temperate lettuce and herbs normally imported from other countries and to select the hydroponic systems suitable for producing some popular local crops with food safety techniques at a reasonable price. Similar to any other investment projects, a feasibility study should be done before getting started. In this study, the results revealed that in conducting a feasibility study and choosing suitable hydroponic systems there were 3 dimensions to be considered called IPO model as shown in Figure 28.

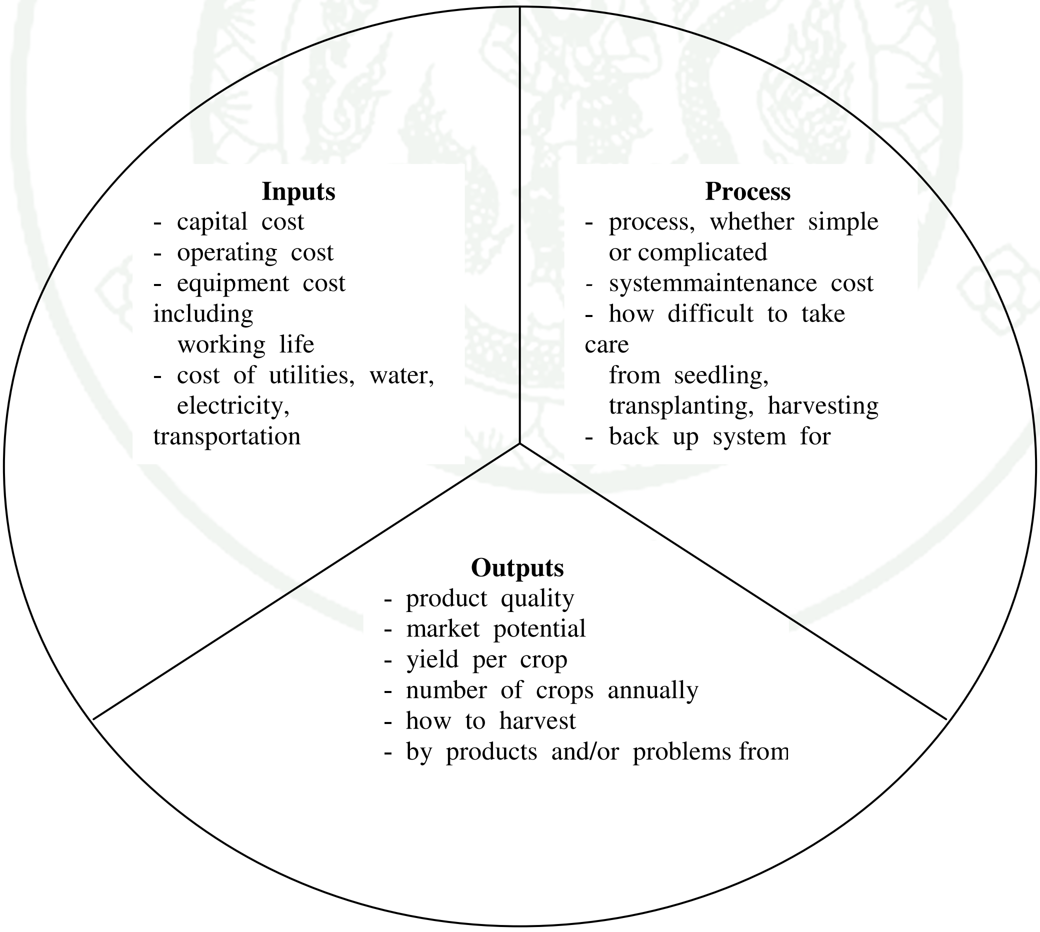

Figure 28 IPO model of hydroponic system.

With the aim to identify and develop the hydroponic system suitable for growing crops with research experts, the focus group discussion and brainstorming sessions involving SWOT analysis on the inputs, outputs, and process of soilless culture were organized. It was found that only 5 main soilless culture systems were used - DRFT, NFT, substrate culture, DFT and aeroponics. The DRFT, NFT and DFT systems worked well for leafy vegetable production, but the substrate culture was proved to be suitable for fruit vegetable (sweet peppers, tomatoes, etc.) depending on the limitations of crop size, crop price, variety, climate, tropical environment and the cost of investment.

1. Inputs for hydroponic systems

All hydroponic systems need many kinds of inputs before starting a hydroponic farm. These inputs consist of :

1.1 Capital cost

This consists of land, construction of the chosen system for example: investment cost of NFT = 1,052 baht/m^2 , DRFT = 1,890 baht/m^2 (Sirinupong,2013). If it was too high, it might not be cost-effective and growers might not be able to afford. However, the hydroponic system could yield a very high quality produce, rapid harvest, and did not cause problem in continuous cropping, therefore it was an ideal system for all growers. For example : NFT system can produce up to 16 crops of leafy vegetable with consistently superior quality, high yield, and rapid harvest all year round.

1.2 Operating cost

The operating cost should not be too high, otherwise, it would take longer time for turn over. Such cost includes the management skill, labor, utilities of water, electricity, transportation, and constraints in getting or buying equipment to be used, complexity and difficulty in the operating process. For example : NFT system required 1/4 of the labor cost, 1/10 water for recirculation, float valve for make up water, use on demand nutrient controller, so the operating cost would be lower than the soil grown.

1.3 Working life of the equipment

The longer the equipment could be use, the lower would be the cost of investment. Fortunately, most of hydroponic equipment likes PVC gullies, PVC piping, polyethylene sheet, polystyrene board , etc. were made from petro – chemical material which lasted longer. Although the capital cost is rather high, the greater return from better quality produce, and frequent harvest plus longer period of depreciation of the equipment, the profit margin is still high. For example NFT systems can use PVC gullies and electric pumps for more than 15 years (15 × 16 crops/year = 240 crops).

2. Process

Each hydroponic system had its own advantage and disadvantage and could work particularly well with certain crop varieties. The following were factors to be considered how to choose appropriate ones.

2.1 Complexity of the growing process. Most hydroponic system were clean, easy to work on and involved less labor, thus it could easily be done by women, children, aged people and handicaps alike. It had definite process to follow, which can easily be learnt by new starters. In Japan, growers were used machine and robot help in seeding, transplanting and harvesting to replace the expensive labor.

2.2 Maintenance all systems and equipment regular maintenance to prolong there working life. The cost depends on the material they used. For example : if it make from first grad material like PVC or iron coating with zinc, its may use last longer, PVC gullies should be made of food grade standard to make sure that the system is good hygienic with standard of growing technique and spend less time and labor to take care after use for some period of production.

2.3 Complexity of handling. Each hydroponic system as well as the growing plant needs different way of handling from seedling to harvesting. For example, one croppingsequence of NFT lettuce production consists of 3 stages of operation namely :

2.3.1 1 week for germination and seedling stage (7-10 days).

2.3.2 2-4 weeks for nursery stage (14-28 days).

2.3.3 2-4 weeks for final planting stage (14-28 days).

Total of 45-50 days of plant growth duration.

The more crop harvested from the final gullies per year means the better returns from the system. In this undertaking, even though it required more labor (two moves) the productivity increased by 30% compared with the one omitting the nursery gullies stage (one move).

3. Outputs of hydroponic system

Hydroponic systems did not only allow for continuous cultivation but also gave stable supply of quality product as outputs :

3.1 Stable yield of quality product. For example : lettuce production in NFT system always gave stable supply of high quality product with only 10% crop loss, compared to 25% from soil grown lettuce. Product is cleaner and no grit.

3.2 Yield per cropping area was much higher than the soil grown due to no water and nutrient stress, less weed and pest. Growers can control both aerial and root environments of plants. Plant can grow better and the growing season can be extended.

3.3 Number of crops harvested annually was much higher. NFT lettuce production could be harvested 16 crops a year rather than 3-4 crops growing in the ground. There were no problem caused by continuous cropping and off-season production and give yield early.

3.4 Complexity in harvesting. Most hydroponic system were placed on benches, so it was very convenient and easy to harvest. Workers did not have to suffer from backache and easy to carry.

3.5 By products or problems from the system. The hydroponic nutrient solution after being used for some period of time should be changed because the proportion and quality of nutrient were no longer suitable for plant. However, it was still useful for fruit trees on soil. It is recommended to reuse it for other crops. It is recovered and recycled system. Some substrate (perlite, vermiculite, urethane foam, coconut fiber etc.) could be reused to grow other crops on soil. This was how hydroponic was environmental friendly.

4. Research process and Result

The research results were considered a break through for hydroponic technology and extension in Thailand. This situation, it could reduce the production cost and improve the production process of hygienic vegetable as well as low-cost equipment. However, further study and experiment must be carried on in line with the above objectives. The research findings could be summarized as shown in Table 28.

Table 28 Research process and results.

Methods	Research system	
	Tasks	Results
1. Studying and identifying hydroponic systems in foreign countries and in Thailand.	1. Review literature on related research, collecting data from research reference 2. Study visits abroad to see current situation of soilless culture in some developed countries, for example, Japan Australia, New Zealand, Israel etc.	1. 5 main soilless culture system were used in Thailand namely, DRFT, NFT, Substrate culture, DFT and aeroponics.Page. 64
2. Analyzing the advantages disadvantages, and problems of each system.	1. Group discussion with hydroponic growers on training at Luk Phra Dabos Agricultural Training and Development Center 2. Results of trialworks at Luk Phra Dabos Agricultural Training and Development Center	1. Conclusion of advantages, disadvantages, and problems of each system. Page. 73-80
3. Synthesizing data and selecting the system suitable for crops, repeating the trials, data processing to decide which systems suitable at the commercial scale.	1. Using focus group discussion and brainstorming session involving SWOT analysis on the inputs, outputs, and processes of soilless culture.	1. DRFT, NFT and DFT systems worked well for leafy vegetable production. 2. Substrate culture was suitable for fruit vegetables. (sweet peppers, tomatoes, etc.) Page. 81-107
4. Developing and simplifying the hydroponic systems, trial, repeating, collecting data for feasible field study.	1. Collecting result from trials works at Luk Pra Dabos Agricultural Training and Development Center, Sai Jai Thai Garden, Royal Project Foundation and H.M's Private Development Project.	1. Good quality products, high yield, rapid harvest and high number of crop annually. Using locally made hydroponic equipments.Page.107-121
5. Study on growers' acceptance of the new hydroponic technology.	1. Interview schedule to collect primary and secondary data and in depth interview.	1. Obtaining data and recommendations for future development. Page.121-127

5. Adoption of soilless culture technology

From the primary data and the in-depth interview with 58 soilless culture growers, it was found that most of them (96.28%) heard, received and tried appropriate technology. All growers (100%) search more information from training courses, books, internet etc. However, most growers (76.3%) imitated, modified and continued to use but 2.8% failed (result lower than standard) and 20.7% of growers did not apply as shown in Figure 29.

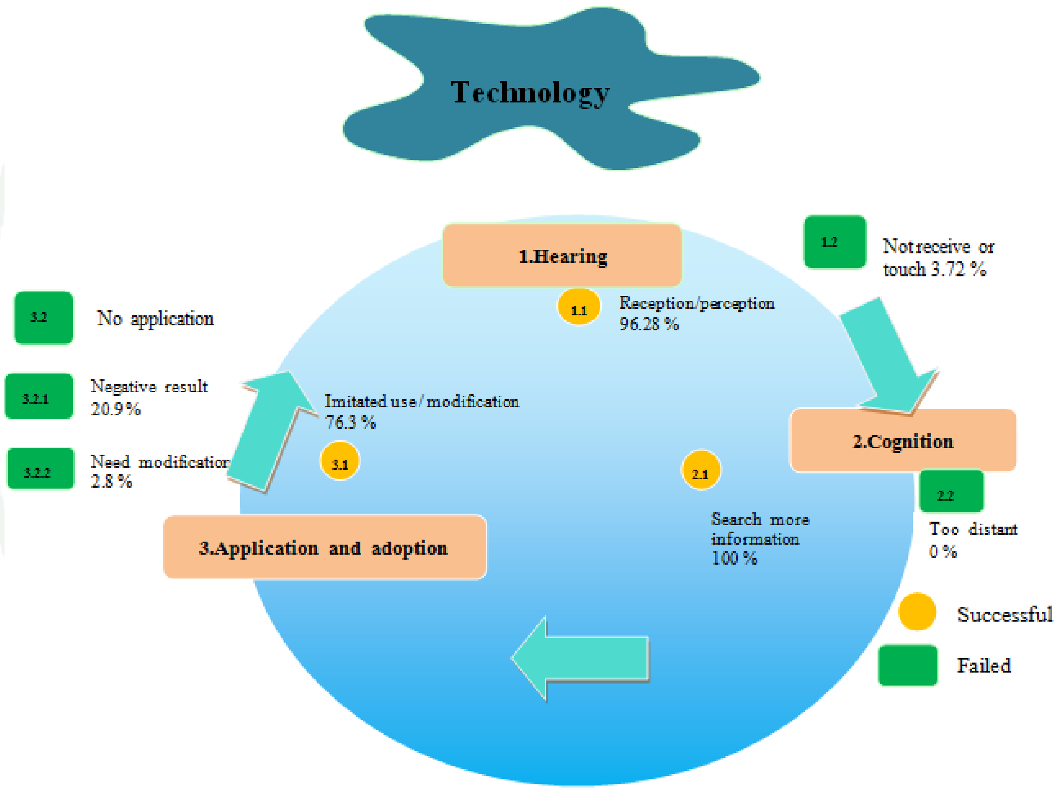

Figure 29 Adoption of soilless culture technology.

Source: Modified from Figure 10

Conclusion

In Thailand, soilless culture has developed steadily over the last two decades. Many commercial hydroponic farms have been set up in Bangkok and in the provinces with tourist attractions. Plants grown by hydroponic techniques had consistently superior quality, high yield, rapid harvest, and high nutrient content. There was a high demand for hygienic vegetable especially to serve the incoming tourists and health conscious Thai people, creating important market for hydroponic vegetable production. Hydroponic farm became more popular and was expanded throughout the country as the consumption volume was increasing everyday. Temperate and some local varieties of vegetables were produced to serve the market demand both with the similar phenomenon as described by Rest (1993) and Paul (2000).

Soilless culture could be applied to growing some popular local crops with the application of food safety standards and at a reasonable price (Paul, 2000). The advantages and impacts of soilless culture or hydroponic growing were nearly the same as in Japan (Ikeda, 2007b). However, it was necessary to gather more knowledge and gain more experience of soilless culture systems. Those who decided to grow vegetable using hydroponic method need to do local market survey, field survey, to select crops and suitable system and to study the situation of hydroponic production in Thailand and how to reduce the production cost especially by using local hydroponic equipment before starting their hydroponic farm.

From the focus-group discussion, it could be concluded that there were only 5 main soilless culture systems in use, namely DRFT, NFT, substrate culture, DFT, and aeroponics. While the DRFT, NFT, and DFT systems were appropriate for vegetable production. Substrate culture was appropriate for fruit vegetables due to the limitations of crop size, crop price, varieties, climate, the tropical environment, and the cost of investment. The results were similar to those from a previous study (Montri and Wattanapreechanon, 2006). However, the volume of soilless crop production was still found to be lower than that in the developed countries. Although many species of vegetables including temperate lettuce and herbs could easily be grown under all climates and in all locations using suitable processes and maintenance, many problems still remained to be solved.

Soilless culture production in Thailand originated from orchid production, one of its major agricultural export items. In order to develop hydroponic production, many key factors should be taken into account. For example, growers need to have better understanding of the technology, good management practices, good varieties, how to choose suitable production sites, and how to establish the contract markets. Production should not be limited to temperate lettuce and herbs only but should also cover some popular local crops for sale at a reasonable price. There were some hydroponic systems suitable for leafy vegetable such as NFT, DRFT, DFT. With those systems, temperate lettuce and herbs could be grown about 10-16 crops per year. The DRFT, DFT, and NFT were good for some popular local crops, and could produce about 10.5 – 12 crops annually. Lastly the substrate culture was suitable for fruit vegetable.

To expand the hydroponic industry in Thailand, it was necessary to develop hydroponic equipment using local materials for commercial hydroponic farms, and to effectively disseminate the technology, as has been accomplished in Japan (Ratanakosol, 1997).

Furthermore, growers need to familiarize themselves with the hydroponic culture principles and basic requirements of planting and caring, which could contribute towards successful establishment and operation of highly productive and rewarding hydroponic unit. Hydroponic development was the ongoing process. Growers had to think of the techniques that were suitable for their condition. In addition, management skill and contract market were needed.

From the in-depth interviews and the research it was found that most of soilless culture growers were educated persons, growing temperate lettuce in NFT, learnt and accepted all appropriate technology through the phenomenon as explained by Sukprasert (2008). Much attention was paid to develop a cultivation for hydroponic condition for each crop and standardization of cultivation method. This included production cost reduction, product improvement and also equipment development using local material for their farm (Wattanapreechanon, 2014).

Recommendations

In order to develop commercial soilless culture hydroponics production, many key factors had to be taken into account as follow:

1. Growers should study and better understand hydroponics technology before they could start their hydroponic farm. They should know about the good varieties of the crops they wanted to grow. Soilless culture has paved the way for growing new species and varieties. Technology combined with new species could increase food production and income, improve product quality, and increase the diversity of food to achieve the national food security targets. Temperate lettuces and herbs were popular among tourists and the rich, health-conscious Thai people but not among the low income groups. The consumption of local vegetable was in fact higher than that of the exotic vegetable.

2. On the commercial scale, hydroponic growers should have more experience in management skills and how to grow their crops well. They had to take care of their plants every day.

3. The important factors to be considered in choosing suitable production site were the availability of water supply, electricity, communications, and transportation system.

4. Growers need to have contract market. For perishable commodities market was one of the important challenges. Appropriate modern post-harvest technologies could be an effective solution. However, as hydroponic techniques could control product stability, high yield, and could produce vegetable at an average of 16 crops per year, contract market could promise steady income for growers.

5. Soilless production should not be limited only to temperate lettuce and herbs but should also cover some popular local crops at a reasonable price. As Thai people consumed more fresh vegetables than before of local vegetables consumption volume was higher than the exotic vegetables. Many local vegetables were staple food for Thai people and could successfully be grown by using many kinds of hydroponic systems.

6. In order for the hydroponic industry to be successful, it was necessary to develop the hydroponic equipment using local material for commercial hydroponic farms, and to effectively disseminate the technology, as has been accomplished in Japan.

7. On a commercial scale, hydroponics required both art and science of management. Growers must know and continue to learn the technology from time to time because new technology has been developed everyday. Therefore, education and training on new hydroponic know- how should be done continuously. Further research should be done on climate control and crop environment, integrated pest management and improved agricultural practices.

8. Hydroponic production of fresh vegetable has been increasing steadily since it was first introduced in 1990s. Many species of vegetables including temperate vegetables can easily be grown in Thailand under all climate and location with uncomplicated processes and simple maintenance. The NFT, DRFT, DFT and substrate culture had great potential for vegetable production and also for ornamentals including orchids.

9. Hydroponic could allow for optimum and efficient use of resources (light, water, CO_2, fertilizer, labor) and simultaneously give high quality and high yield produce. In addition, the design of the work place which reduce workers' moving distance and enabled for handicapped and aged people to work without difficulties.

10. High labor cost and decreasing farm labors become serious problems at the present and in the future. Hydroponic agriculture was another possible in supplying stable vegetable to consumers all year-round with maximum yield and minimum inputs of resource and energy.

11. Biological insecticides are recommended to control insect pests. The specific activity of B.t. generally is considered highly beneficial. Unlike other insecticides, B.t. insecticides do not have a broad spectrum of activity, so they do not adversely affect beneficial insects. This includes the natural enemies of insect (predators and parasitoids) as well as beneficial pollinators, such as honeybees. Therefore, B.t. can be integrated well with other natural approaches of pest controls. The major advantage is that B.t. is essentially nontoxic to people, pets and wildlife. Therefore, it can be used on food crops or in other sensitive sites where pesticide possibly cause adverse effects.

12. Aquaponics was another alternative for crop growing with food safety at a reasonable price for the health-conscious groups, home garden or hobbies, and small farmers in the areas with soil problems. At Luk Phra Dabos Agricultural Training and Development Center, there were many different models of aquaponics for interested groups to study and learn. This would a new challenge and alternative for environment friendly horticulture systems in the near future (See appendix).

13. As hydroponics and aquaponics were important alternatives for agriculture in current and future time of growing consumers, less arable land, and labor shortage, it was recommended that research and development as well as technology transfer in terms of training should be emphasized and supported by related agencies, both in the public and private sectors. To name a few, Luk Phra Dabos Agricultural Training and Development Center organized training for 1,591 people from 2009 up to the present (See appendix).

REFERENCES

Anonymous. 2009. **The population of Thailand** (Online). http://th.wikipedia.org/wiki/%E0%B8%88%Eo%B8%B1%E0%..., September 23, 2009.

______. 2010. **SWOT analysis-strategy Tools from Mind Tools.com** (Online). www.mindtools.com/pages/artiele/new TMC_os. Htm, September 23, 2009.

______. 2011. **SWOT analysis template and method** (Online). www.businessballs.com/swotanalysisfreetemplate.htm, September 23, 2009.

______. 2012. **SWOT analysis** (Online). http://en.wikipedia.org/wiki/SWOT_analysis, September 23, 2009.

______. 2013. "Hydroponic vegetable to strengthen the community of Ban NeunSumran village" **Dailynews.** Issue (January 9th) :19 (in Thailand).

Bangchaud, T. 2001. **An Economic Analysis of Hydroponic Vegetable Farm**. (Unpublished master thesis) Kasetsart University, Bangkok.

Barry, C. 1996. **Nutrients: The Handbook to Hydroponic Nutrient Solutions**. Australia: Casper Publication Pty Ltd.

Benoit, F. and N. Ceustermans. 1995. "Horticultural aspects of ecological soilless growing methods". **Acta Horticulture** 396: 11-24.

BÖkme, M. 1995. Effects of closed system in substrate culture for vegetable production in greenhouse. **Acta Horticulture** 396: 45-54.

Chamsawang, J. 2008. "Using *Trichoderma* to control root rot in hydroponic farms" **Agricultural Progressive Journal**. 1: 29-44. (in Thailand).

Chamsawang, J. . 2013. " The use of *Trichoderma*, *Bacillus* for bio-control in hydroponics". **Home Agricultural Magazine**. 8: 146-149. (in Thailand).

Chanpaisaeng, J. 2011. **B.t. : *Bacillus thuringiansis*, microbial insecticide**. Bangkok: New tammada printing (Thailand) Co.Ltd.

Chiumchaisri, Y. 1973. **"Water and its application for orchid".** paper for summer training at Kasetsart University. 16-30 March. 39-46. (in Thailand).

______. 2007. "safety in soilless culture vegetables facts that you should know." **House Agricultural Magazine**. 2: 170-174. (in Thailand).

______. 2011. **"Nutrient solution"** Paper for training in Development of Hydroponic Agriculture in the Maldives held at Luk Phra Dabos Agricultural Training and Development Centre, June 8, supported by Thailand International Development Cooperation Agency (TICA)

Collins, C. 1993. **Essential English Dictionary**. London: Collins Publishers.

Cooper, A.J. 1982. **Commercial applications of NFT**. London UK: Grower Books.

Dalton, L. and R. Smith. 1999. **Hydroponic Crop Production**. New Zealand: NZ Hydroponics International Ltd.

______. 2003. **Hydroponics Gardening: A practical guide to growing plant without soil.** New Zealand: Hydroponic Development Ltd.

Department of agriculture (DOA). 2014. **GAP DOA** (Online). http://122.155.190.187/gapold/SearchQaspx, September 23, 2009.

Douglas, J.S. 1975. **Hydroponics: The Bengal system with notes on other methods of soilless cultivation**. 5th ed. England: Oxford university Press.

Eastwood, T. 1947. **Soilless Growth of Plants**. 2nd ed. New York: Reinhold Publishing.

Fuangpreechawai, S. 2005. **Hydroponic Control System**. A report submitted in partial fulfillment of the requirements to MES 404 senior project Department of Mechanical Engineering Sirindhorn International Institute of Technology Tammasart University. 28 February 2005.

Fukuda, N., H. Ikeda and M. Nara. 1993. "Effects of light quality on the uptake of water and minerals of lettuce plants grown under controlled environment". **The Journal of the Society of Agricultural Structures** 24(1): 57.

Hornby, A.S. 1999. **Oxford Advanced Learner' Dictionary of Current English**. Fifth edition. Oxford University Press.

Ikeda, H. and T. Osaka. 1984. **"**Lettuce growth as influenced by N source and temperature of the nutrient solution**"**. **Sixth International Congress on Soilless culture Lunteren** 273-284.

______. 1988. "Effects of CO_2 concentration in the Air and shading on the utilization of NO_3 and NH_4 by vegetable crops". **Journal of the Japanese Society for Horticultural science** 57(1): 52-61.

Ikeda, H. 2005. **Soilless crop production in the world**. Graduate school of life and environment Science. Osaka, Japan: Osaka Prefecture University.

Ikeda, H. 2007a. **Environment-Friendly Soilless Culture and Fertigation Technique**. Paper presented to the seminar on soilless culture in the International Horticultural Exposition for His Majesty the King Royal Flora Ratchaphruek 2006 Chiang Mai January 5-6 organized by Department of Agriculture and the Thai soilless culture forum.

______. 2007b. **Soilless Production of Horticultural Crops**. Paper presented to the seminar on soilless culture in the International Horticultural Exposition for His Majesty the King Royal Flora Ratchaphruek 2006 Chiang Mai January 5-6 organized by Department of Agriculture and the Thai soilless culture forum.

______. 2011a. **"Closed system soilless culture and greenhouse waste management".** Presented to the seminar on soilless culture at Faculty of Agriculture. Kasetsart University Bangkok, August 5, organized by Faculty of Agriculture and the Thai Soilless Culture Forum.

______. 2011b. **"What is the advanced plant production?".** Presented to the seminar on soilless culture at Faculty of Agriculture. Kasetsart University Bangkok, August 5, organized by Faculty of Agriculture and the Thai Soilless Culture Forum.

______. 2013. **Present situation and foresight of plant factories in the world.** Paper presented at the seminar, Held at Faculty of Agriculture Kasetsart University, July,11,organized by Faculty of Agriculture and the Thai Soilless Culture Forum.

Ito, T. 1994. "Hydroponics". **Horticulture in Japan** 247: 124-131.

Jarujareet, W. 2013. " The use of LED for future horticulture". **Home Agricultural Magazine** 8: 183-189. (in Thailand).

Jarujareet, W. and S. Oshita. 2013. "Micro and Nano – bubble technology and its application to agriculture". **Home Agricultural Magazine** 11: 183-185. (in Thailand).

Jarvis, B. 2001. "Don't stress your plant… you' ll make them sick". **Practical Hydroponic & Greenhouse** 58(5-6) :70-75.

Jeong , B.R. 2006. **Current Status & Concern in Hydroponic Crop Production in Korea**. Korea: COEX Convention Center.

Jiang , W. 2006. **Twenty Years Development of Soilless Culture in Mainland China.** Korea: COEX Convention Center.

Jones, J. and Jr. Benton. 1997. **Hydroponics: A Practical Guide for the Soilless Grower**. U.S.A.: st Lucie Press.

Jongjairuk, J. 2005**. A Comparative Cost and Return Analysis on Investment in Hydroponic Vegetable Production Using Dynamic Root Flow Technique (DRFT) and PC Technique.** Kasetsart University, Bangkok.

Kao, T. 1997. **The Dynamic Root Floating Hydroponic Techniques: year-round Production of Vegetable in ROC on Taiwan**. Paper presented to the Royal Project Foundation seminar. August 15-16. Chiang Mai.

Kim, S. 2006. **Impact of Environmentally-Friendly Horticulture Systems in the Coming Decades : Vision and Agenda.** Korea: COEX Convention Center.

Kotler, P. 2009. **Marketing management.** 13^{th} ed. New Jersey: Pearson Education Inc.

Leagans, J.P. 1971. **Behavioral Change in Agriculture**. Ithaca London: Cornell University Press.

Luangna, S. 2006. **Study of lettuce (*Lactuca sativa* Linn.) under hydroponic systems.** Ubon Ratchathani: Ubon Ratchathani Rajabhat University.

Luk Phra Dabos Agricultural Training and Development Centre. 2009. **Annual report 2009**. Thailand: Luk Phra Dabos Agricultural Training and Development Centre.

Maruo, T. 1999. **Quantitative Nutrient Management of Low concentrate condition in NFT spanich culture**. Faculty of Horticulture, Chiba University: 648 Matsudo chiba. 271-8510 Japan.

Montri, N and E. Wattanapreechanon. 2006. **Soilless culture in Thailand.** Korea: COEX Convention Center.

Morgan, L. 1999. **Hydroponic lettuce Production**. Australia: Casper Publication Ply Ltd.

Morgan, L. and S. Lennard. 2000. **Hydroponic Capsicum Production**. Australia: Casper Publication Pty Ltd.

Mosher, A.T. 1978. **An Introduction of Agricultural Extension**. Singapore: Singapore University Press.

Muckle, M.E. 1993.**Hydroponic Nutrients: Easy ways to make your own**. British Colombia: Princeton Growers press Inc.

Nantakit, I. 2012. "Design and management of commercial NFT lettuce farm". **Agricultural Progressive Journal**. 3: 8-46. (in Thailand).

Noomnu, C. 2013. "Open up the new prospective of Israel agriculture". **Home Agricultural Magazine**. 10: 139-142. (in Thailand).

Pimkot, W. 2003. **Growth, Nitrate Accumulation and Pre-harvest Nitrate Reduction in Hydroponic-grown Lettuce (*Lactuca sativa* L.).** Bangkok: Kasetsart University.

Pomrit, P. 2013. "Modern technology of vegetable cultivation in Japan". **Home Agricultural Magazine**. 5: 182-185. (in Thailand).

Pual, C. 2000. "Health and Hydroponic". **Practical Hydroponic & Greenhouse**. 53(7-8): 28-30.

______. 2001. **"**Cultivating Orchids Hydroponically". **Practical Hydroponics & Greenhouse**. 59(7-8): 40-46.

Pumhirun, J. 2004. **Growing and Cultural Practice**. Orchid Department of Agriculture Document No 15/2004 Agricultural and Cooperative press: 31-46. (in Thailand).

Putrawat, I. 2003**. Handbook in planning for Co-operative strategies**. Bangkok: Co-operative and administration Bureau.

Radulovich, R. 2012**. "Aquaponics : aquaculture with hydroponic or just low trophic-level aquaculture."** Presented to the seminar at Faculty of Agriculture. Kasetsart University.

Ratanakosol, P. 1997. "Soilless culture not complex as we think". **Kasikorn** 6(11-12): 587-592. (in Thailand).

Reablerthirun, N. 2007**. Soilless culture.** Bangkok: Suweeriyasan.

Resh, H.M. 1993. **Hydroponic Food Production**. California: Woodbridge Press Publishing Company.

Reungruk, E., S. Taowan, S. Maneepong and M. Isarakaisil. 2011. "The use of coconut coir to substitute peat moss in tomato seedling production" **Home Agricultural Magazine**. 8: 214-215. (in Thailand).

Rogers, E.M. 1983. **Diffusion of Innovations.** 3rd edition. New York: Macmillan Publishing Co. Inc.

Romer, J. 1997. **Hydroponic Gardening in Australia**. Australia: Reed Books.

Sakuma, H. and K. Suzuki. 1997. "Development of energy-saving to hydroponic systems without requiring electricity". **JIRCAS Journal** 4: 73-77.

Salisbury, F.B. and C. Ross. 1969. **Plant physiology**. Belmont. Calif: Wadsworth.

Sangruksawong, C. 2004. **Orchid**. Department of Agriculture. Document no 15/2004. Agricultural and Cooperative press: 1. (in Thailand).

Satiensawas, W. 1998. **Development on Hydroponics Technology**. P J B Research and Development Co. Research Project Supported by The Notional Research Council of Thailand December 1998: pp13. (in Thailand).

______. 2003. "Hydroponics". **Thai junior encyclopedia project by Royal Command of H.M. the King**. 27: 132-163. (in Thailand).

Schwaz, M. 1968. **Guide to commercial hydroponic**. Jerusalem: Israel University Press.

Senadee, W. 2012a. "ACK Hydroponic farm : new vegetable business for health conscious groups". **Home Agricultural Magazine**. 1: 115-119. (in Thailand).

______. 2012b. "Salad Station : new hydroponic farm for young generation". **Home Agricultural Magazine** 12: 151-156. (in Thailand).

Senadee, W. 2013. “Chinese kales and celeries from Siam Hydro Farm”. **Home Agricultural Magazine** 7: 177-180. (in Thailand).

Senadee, W., R. Suntikul and S. NaSongkla. 2013. “Green house for agriculture in tropical climate”. **Home Agricultural Magazine** 12: 148-153. (in Thailand).

Senadee, W. 2014. “Vegetable industries in Cameron High Land, Malaysia”. **Home Agricultural Magazine** 5: 83-105. (in Thailand).

Senadee, W. and A. Suboonsun. 2013. “New design of evaporation cooling house for hydroponic vegetable production”. **Home Agricultural Magazine** 4: 143-146. (in Thailand).

Senadee, W. and P. Kusakul. 2013. “Greenhouse : another solution when the world is facing climate change”. **Home Agricultural Magazine** 9: 180-182. (in Thailand).

Shinohara, Y. and Y. Suzuki. 1988. “Quality Improvement of Hydroponically Grown Leaf Vegetables”. **Acta Horticulture** 230: 1988.

Shinohara, Y. 1999. **Possibility of Hydroponics Application in Thailand**. Paper presented to the seminar during 21-23 September 1999. Bangkok organized by Department of Industry Technology. King Mongkut’s. Institute of Technology North Bangkok and Ministry of University Affairs.

Shinohara, Y., T. Hata, T. Maruo, M. Hohjo and T. Ito. 1999. Chemical and physical properties of the coconut-fibre substrate and the growth and productivity of tomato*(Lycopercicones culentum* Mill) Plants, Proc Int. sym Growing media and Hydroponics Ed. A. P. Papadopoulos **Acta Hort.** 481, ISHS 1999.

Sirinupong, M. 2013. **Practical for soilless culture in Thailand.** second edition. Nontaburi: Siam color print Com.Ltd.

Smith, D.L. 1987. **Rockwool in Horticulture**. London: Grower Books.

Solan, N. 2013. "Greenhouse for agriculture in tropical climate". **Home Agricultural Magazine** 12: 148-153. (in Thailand).

Somchaiwong, N. and N. Thampanya. 2008. **Development of planting controller in hydroponics culture**. Final report to the National Research Council of Thailand.

Srinuanjun, P. 2008. **Feasibility study for growing vegetable by using hydroponic system in Chiang Mai Province**. Chiang Mai: Chiang Mai University.

Stanley, D. 1998. "Hydroponic strawberries avoid soil pests". **Agricultural Research** 98(11): 10.

Suboonsun, A. 2012. "How to grow Chinese kales with bigger stem in hydroponic". **Home Agriculture Magazine** 11: 205-208. (in Thailand).

Sukprasert, P. 2008. **Paradigm in Thai Agricultural Extension and Adoption of Technology**. Bangkok: Faculty of Agriculture, Kasetsart University.

Sundstrom, A.G. 1985. **Simple Hydroponics for Australian Gardeners**. Singapore: Tien Wah Press.

Taporn. 1999. "Food for world demand: Thai opportunity". **Matichon** 976(6): 24. (in Thailand).

Tongaram, D. 2003. **Soilless culture**. second edition. Rach buri: Tammaruk printing. (in Thailand).

Tongkete, T. and W. Senadee. 2013. It is the suitable time for greenhouse technology". **Home Agricultural Magazine** 11: 85-108. (in Thailand).

Tsuneyoshi, T., Y. Jiro and S. Takashi. 2006. "Hydroponic Cultivation Offers A Practical Means of Producing Selenium Enriched Garlic". **Journal of Nutrition** 136: 870S-872S.

Tuncho, A. 2005. **Soilless Culture in Tropics.** Chiangmai: Trio Advertising & Media Co. Ltd. (in Thailand).

Waters, W, J. Nesmith, C. Geraldson and S. Woltz. 1972. **The Interpretation of Soluble Salt Test and Soil Analysis by Different Procedures.** AREC Mimeo Report GC-1772-4 Bradenton, FL.

Wattanapreechanon, K. and E. Wattanapreechanon. 1991. **Growing muskmelon by soilless culture III**. Comparative study on four varieties of muskmelon growing in NFT. Paper presented to the 9th conference on techniques of Methodology in Biological Science Central Laboratories and Experimental Greenhouse, Research and Development Institute, Kasetsart University, Kampangsaen campus, Nakornpathom province November 19-21,1991 pp7 (Thai with English abstract).

Wattanapreechanon, K., E.Wattanapreechanon and A. Samart. 1991a**. Growing muskmelon by soilless culture I Growing muskmelon in different substrates**. Paper presented to the 10th conference on Thai national vegetable crops Udonthani Agricultural college March 19-22, 1991 pp9 (Thai with English abstract).

______. 1991b. **Growing muskmelon by soilless culture IIGrowing muskmelon in NFTPaper presented to the 10th conference on Thai national vegetable crops**. Udonthani Agricultural college March 19-22, 1991 pp.9 (Thai with English abstract).

Wattanapreechanon, K., E.Wattanapreechanon and A. Samart. 1992. **Growing Tomatoes in Agricultural waste**. Paper presented to the 11th conference on Thai national vegetable crops Mae Jo Agricultural technology Institute Chiang Mai 15-19 January 1992. pp12 (Thai with English abstract).

______. 1993. **Growing lettuce and chinese celery in hydroponic system**. Paper presented to the 12th conference on Thai national vegetable crops Songkla nakarind University Songkla 31 March - 3 April 1993 pp.10 (Thai with English abstract).

Wattanapreechanon, K. 1993. **Development of soilless culture for crops production inChitralada 1987-1992**. Paper presented to the 3th seminar on Vegetable for Health 20 June Sermmitr restaurant Bangkok pp.2 (in Thailand).

Wattanaprechanon, K. and E. Wattanapreechanon. 1997. "**Development of soilless Culture for crop Production at Chitralada Palace**". Towards the year 2000: Technology for Rural Development. Proceeding of the international conference. Chulalongkorn University August 25-26 1997, Bangkok Thailand.

Wattanapreechanon, E. 2007. **Development of soilless culture for crops production in Thailand**. Paper presented to the seminar on soilless culture in the International Horticultural Exposition for His Majesty the King Royal Flora Ratchaphruek 2006 Chiang Mai January 5-6 organized by Department of Agriculture and the Thai Soilless Culture Forum.

______. 2011. "Hydroponic vegetable production in New Zealand**".** **Home Agricultural Magazine** 12: 134-140. (in Thailand).

______. 2012. "Hydroponic vegetable production in Australia**".** **Home Agricultural Magazine** 1: 171-173. (in Thailand).

Wattanapreechanon, E and P. Sukprasert. 2012. "Development of soilless culture for crops production in Thailand". **Kasetsart Journal Soc. Sci.** 33(3): 475 – 486.

Wattanapreechanon, E. 2014. "Hydroponics in Kaoko, Petchaboon province". **Home Agricultural Magazine** 7: 143-146. (in Thailand).

Wilson, G. 2000. "Olympic Victory for Hydroponics". **Practical Hydroponics & Greenhouse** 53(7-8): 19-23.

Yuktanun, S. 2012. "Mae bua Luang hydroponic farm". **Agricultural progressive Journal** 3: 53-69. (in Thailand).

APPENDICES

Traditional soil grown vegetable

Appendix Figure 1 Present situation of vegetable production in Thailand

Note: 1-4 Temperate lettuce growing at the Royal Northern Project, Ang khang station, Chiang Mai

5-6 Chinese kales and pumpkins growing in Ang Thong

Appendix Figure 2 Hydroponic home garden hobby sets.

Note: 1 Hobby sets at Srisangwan School for handicap students, Pathumthani

2 Hobby sets demonstration at Chitralada Palace, Bangkok

3 – 9 Hobby sets demonstration at Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan

Appendix Figure 3 Aquaponics: alternative of aquaculture with hydroponics.

Note: 1 Chitralada Palace

2 – 6 Luk Phra Dabos Agricultural Training and Development Center, Samut Prakan

Appendix Table 1 Number of trainees undergone 1 day training program on soilless culture conducted at Luk Phra Dabos Agricultural Training and Development Center.

No.	Day/ Month / Year	Trainees	Remark
1	20 April 2009	14	
2	5 March 2010	42	
3	4 March 2011	71	
4	1 July 2011	62	
5	9 September 2011	84	
6	2 March 2012	155	
7	2 August 2012	52	
8	7 September 2012	68	
9	5 March 2013	61	
10	26 March 2013	49	
11	22 April 2013	29	soldiers wounded from field services hospitalized at Phra Mongkutklao Hospital
12	3 June 2013	65	
13	2 August 2013	52	
14	6 September 2013	80	
15	1 November 2013	76	
16	9 December 2013	19	soldiers wounded from field services hospitalized at Phra Mongkutklao Hospital
17	24 December 2013	70	
18	7 January 2014	67	
19	15 January 2014	4	soldiers wounded from field services hospitalized at Phra Mongkutklao Hospital
20	21 February 2014	62	
21	4 March 2014	73	
22	4 July 2014	74	
	total	**1329**	

Appendix Table 2 Number of trainees undergone 5 days training programs for SME support by Office of small and medium enterprises promotion ministry of Industries.

No.	Day/ Month / Year	Trainees	Remark
1	26-30 June 2013	39	
2	5-9 July 2013	34	
3	7-11 May 2013	38	
4	7-11 May 2014	38	
5	26 May - 4 June 2014	45	undergone 10 days training program for SME from the south
6	26 June -8 July 2014	57	
	total	251	

Appendix Table 3 Number of trainees undergone 5 days training programs for participants from the Maldives supported by Thailand International Development Cooperation Agencies (TICA) Ministry of Foreign Affairs.

No.	Day/ Month / Year	Trainees	Remark
1	5-25 June 2011	6	
2	3-23 June 2013	5	
	total	11	

Questionnaire 1

Vegetable Soilless Cultivation Methods Suitable to Thailand

Name of informant…………………, given on … month………B.E. 2553

Please rate according to following definitions:

Strength: Advantages or benefits of the vegetable soilless cultivation (actual condition)

Weakness: Problems or inferiority of the vegetable soilless cultivation (actual condition)

Opportunity: External environment, which could be beneficial or advantageous to the vegetable soilless cultivation like market (expectation)

Threats: External environment, which could limit or obstruct the vegetable soilless cultivation (expectation)

Inputs: All production inputs e.g. capital cost, depreciation, power and water supply cost, system maintenance, and the convenience in procuring equipment

Process: Production process e.g. system maintenance, complication of operation, convenience in cultivation, harvesting and plant safety in case there is power supply problems

Outputs: Product e.g. product volume in each crop, number of crop production per year, product quality, and by-product

Scale of scores:

1 = lowest, 2 = low, 3 = medium, 4 = high, 5 = highest

SWOT	Weighting Scale	NFT	DFT	DRFT	Aeroponic	Substrate Culture
Strength	Input					
	Process					
	Output					
Weakness	Input					
	Process					
	Output					
Opportunity	Input					
	Process					
	Output					
Threats	Input					
	Process					
	Output					

Additional comments ……………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

SUPPLEMENT

Name of Experts

1. Professor Dr. Sorasith Vacharotayan (Ph.D) Kasetsart University.

2. Professor Dr. Tusanee Autanan (Ph.D) Kasetsart University.

3. Associate Professor Dr. Pattana Sukprasert (Ph.D) Kasetsart University.

4. Associate Professor Dr. Jariya Chanpaisaeng (Ph.D) Kasetsart University.

5. Assistant Professor Dr. Yongyut Chiumchaisri (Ph.D) Thai Soilless Culture Forum.

6. Assistant Professor Dr. Thammasak Tongkate (Ph.D) Kasetsart University.

7. Associate Professor Dr. Ittisoontorn Nantakit (Ph.D) King Mongkut Institute of Technology.

8. Assistant Professor Dr. Nattaya Montri (Ph.D) King Mongkut Institute of Technology.

9. Mr. Weerapol Niyomthai (MSc.) Thai Soilless Culture Forum.

10. Ms. Pravalpat Kuptarak (BA.) Thai Soilless Culture Forum.

11. Mr. Prem Na Songkhla (MPa.) Home Agricultural Magazine.

12. Ms. Wannapa Senadee (BSc.) Home Agricultural Magazine.

13. Mr. Prasert Anukulprasert (BSc.) Soilless Culture Farmer.

14. Ms. Warangkana Nokyoo (MSc.) Soilless Culture Farmer.

15. Mr. Auttaporn Suboonsan (BSc.) Soilless Culture Farmer.

16. Mr. Ruampol Thepmuchkapol (BA.) Soilless Culture Farmer

17. Ms. Kanjana Yakinee (BSc.) H.M.'S. Private Development Projects, Bangkok.

18. Ms. Ruchadawul Titi-atirut (BSc.) Fresh Garden Company.

19. Mr. Tanachat Klinhomruen (MSc.) Royal Development Projects Bureau of the Royal Household.

20. Ms. Linchong Jaraksabhakdi (MBa.) Royal Palace Ground Affairs Division Bureau of the Royal Household.

21. Mr. Samarnmitr Pattana (MSc.) Luk Phra Dabos Agricultural Training and Development Centre.

22. Ms. Darika Musikul (MSc.) Luk Phra Dabos Agricultural Training and Development Centre

BIOGRAPHICAL DATA

NAME:	Mr. Ekasit Wattanapreechanon
DATE OF BIRTH:	February 19, 1951
PLACE of BIRTH:	Phra Nakhon Si Ayutthaya
GRADUATION:	1974 B.Sc. Kasetsart University
	1983 M.Sc. University of Reading U.K.
	1985 M.Sc. Kasetsart University
PLACE OF WORK:	Bureau of the Royal Household
	1974 : Agricultural subject specialist
	1989 : Head of Service sub-Division
	1996 : Director of Royal Palace Ground Affairs Division
	2011 : Senior Expert in Agricultural Analysis Advisory Level