A Thesis

for the Degree of Master of Science

Determination of Citrus Nutrient Uptake by Spray Hydroponic Culture System

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DEPARTMENT OF AGRICULTURAL CHEMISTRY
GRADUATE SCHOOL
CHEJU NATIONAL UNIVERSITY

2001.12.

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(Supervised by Prof. Dr Zang Kual U.)

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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This thesis has been examined and approved.

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ABSTRACT

Since it was difficult to determine nutrient and water uptake by citrus in soil condition, we designed an air tight system in which citrus tree could grow in nutrient solution under the accurate observation of nutrient uptake. The system functioned successfully so that we could conduct this research to determine amount of nutrient uptake by citrus and nutrient requirement for citrus growth and development, using three levels of nutrient solution concentration under the spray hydroponic cultivation.

The uptake amounts of nutrient were significantly different depending on the concentration of supplied nutrient solution, the higher concentration, the greater uptake by citrus tree. NO_3-N, K, and Ca with total uptake amount (16670, 3553, 2954 mg) were found as major nutrient elements with their higher uptake amount comparing with other elements. But NH_4-N, P, Mg and S with total uptake amount (2425, 2559, 715, 2982 mg) were found the secondary major nutrient elements. The uptake amounts of nutrient were also much changed by the seasons. The highest uptake of most elements were occurred in July due to rapid growth of citrus trees and in September for fruiting.

The highest water uptake amount by citrus (in the range of 400 to 500 ml) was found in July and September. Water uptake at the high concentration of nutrient solution was lower than at the medium and low concentration, due to its higher osmolarity in the concentrated solution. More amount of nutrient was needed to produce one kg of fresh weight at the high concentration level (for example requirement of NO_3-N was 9359 mg) than at the medium (6756 mg) and the low (5094 mg). This fact was observed from all the elements examined, therefore, it can be suggested that supplying too high concentration culture solution should be avoided to save the nutrition or fertilizers. But the optimum amount of each element for natural growth of citrus tree should be figured out by further investigation. It can also be suggested that the spray hydroponic system used in this study will be suitable for research purpose of nutrient and water absorption by other perennial crops as well as citrus.

I. INTRODUCTION

As citrus growers, we need to make several decisions before applying fertilizers to the trees, thus, we also need to know which nutrient elements are needed as major and secondary elements, decide which commercial fertilizers are the most suitable, how much of each to apply and when to apply to citrus trees?. Getting these decisions right will affect citrus orchard profitability, tree health will be improved, fruit quality and yield increased, and wasteful fertilizer applications avoided.

Meanwhile, citrus is the main fruit crop and being commonly grown in all most areas of Jeju Island. Its productions has been also known over the domestic as well international markets since the past years and being contributed as main income of Jeju farmer. However, after a decay of cultivation, Jeju citrus growers have been facing with so many factors that damagingly effected to citrus quality and production. In addition, the quality of citrus recently being strictly considered by customer. thus, how to improve both quality and production was very difficulty given questions for citrus grower here in Jeju. One of this identified effect factors was fertilization, this includes fertilizer application timing, fertilizer composition, major and secondary elements.

In fact, there are 16 nutrient elements essential to citrus growth and development. A deficiency of any essential element will limit growth (Tucker., Alva., Jackson., Wheaton. 1995). In addition, Jeju soils are quite fertile and contain ample levels of most elements to sustain optimum citrus growth and development. However, it has been considered as really difficult to determine nutrient absorption by citrus and nutrient requirements in the soil condition here in Jeju. In addition, there have been no any research conducted here in Korea since so far to know amount of nutrient absorption of citrus (except N) and also nutrient requirement for timing of fertilizer application, particularly in the subtropical weather of Jeju Island. For this reason, Jeju citrus growers did not know when and which fertilizer should be applied for their citrus orchard and this was not only caused waste of fertilizer application but also affected to citrus quality and productions.

In addition, to the knowledge of the authors, no studies of like nature have been conducted for citrus, although with reference to seasonal requirements of these trees (including major nutrient elements uptake, increases of fresh weight, water uptake, growth rate etc.). American scientists had made an hydroponic system to measure nutrient absorption of citrus (Chapman and Parker. 1945). However, the system was very simple one and the researchers determined nitrate absorption only. In 1946 there was another related research conducted by Roy and Gardner, 1946 to determine nutrient absorption of citrus in sand culture. It is reported as difficult to measure accurate amount of nutrient uptake by citrus grown in sand culture system. The disadvantage was that the supplied nutrient solution was stored in sand so that they could not estimate how much water was stored, this might cause an error on calculation of nutrition uptake. In 1968, a research on nutrient absorption of citrus in soil condition was reported by Hirobe and Ogaki, 1968. Within this research, they had to sacrifice a lot of trees during their experiment to measure nutrient uptake at a certain time intervals. For those mentioned reasons, the authors had constructed an air tight spray hydroponic system in which accurate amount of nutrient and water uptake by citrus trees could be measured and also the main objectives of this research therefore were

1. To determine amount of nutrient uptake by citrus, major and secondary elements and nutrients requirements depending seasonal changes.

2. To study the affect of related factors on citrus growth and development depending on seasonal changes.

3. To develop a new nutrient research method and culture techniques for citrus and other perennial crops.

II. MATERIAL AND METHODS

1. Plants

Nine citrus trees (*Citrus unshiu Marc. cv. Miyagawa Wase*), three years old tree grown widely in Jeju Island were used.

2. Construction of spray hydroponic culture system

The basic method of citrus cultivation was a spray hydroponic system with air tight nutrition supplying design bottle in which citrus trees were planted. An air tight is essentially required to prevent water evaporation from the nutrient solution, consequently accurate water uptake measurement can be possible. The system supplied nutrient solution directly to root zone of citrus trees using spray jets (nozzle). After nutrition uptake by citrus, the remained solution was automatically drained back to the nutrient solution bottle for the next supply. The spray hydroponic culture system consists of electric control part, nutrient supply part, temperature control part, and air (oxygen) supply part as shown in Fig.1. The system was constructed on the iron angled standing under natural condition (outdoor).

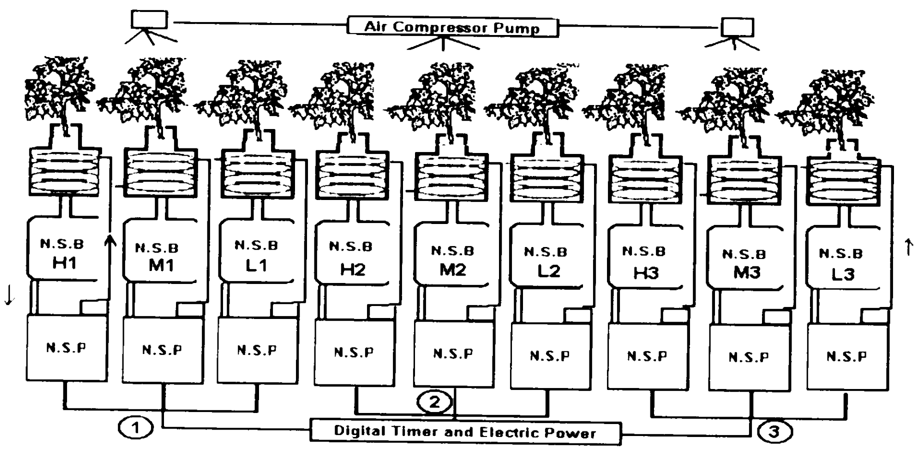


Figure 1. Overview of the spray hydroponic system (H is high, M is medium, and L is low nutrient concentration level. 1,2, and 3 being replications of treatment. N.S.B: nutrient solution bottle. N.S.P: nutrient solution pump)

2.1 Nutrient solution supplying part

Nine plastic bottles (20L) were used for containing nutrient solution (this is called **nutrient solution bottles N.S.B**). Nine other plastic bottles (10L) have been used to contain citrus trees (this is called **citrus tree bottle C.T.B**), and three nozzles were inserted inside **C.T.B** to spray nutrient solution around citrus roots. There were holes in bottom of **C.T.B** for draining solution back to N.S.B, and this could help remain nutrient solution automatically drain back to **N.S.B**. Also, a digital timer was attached to control time interval for supplying and draining.

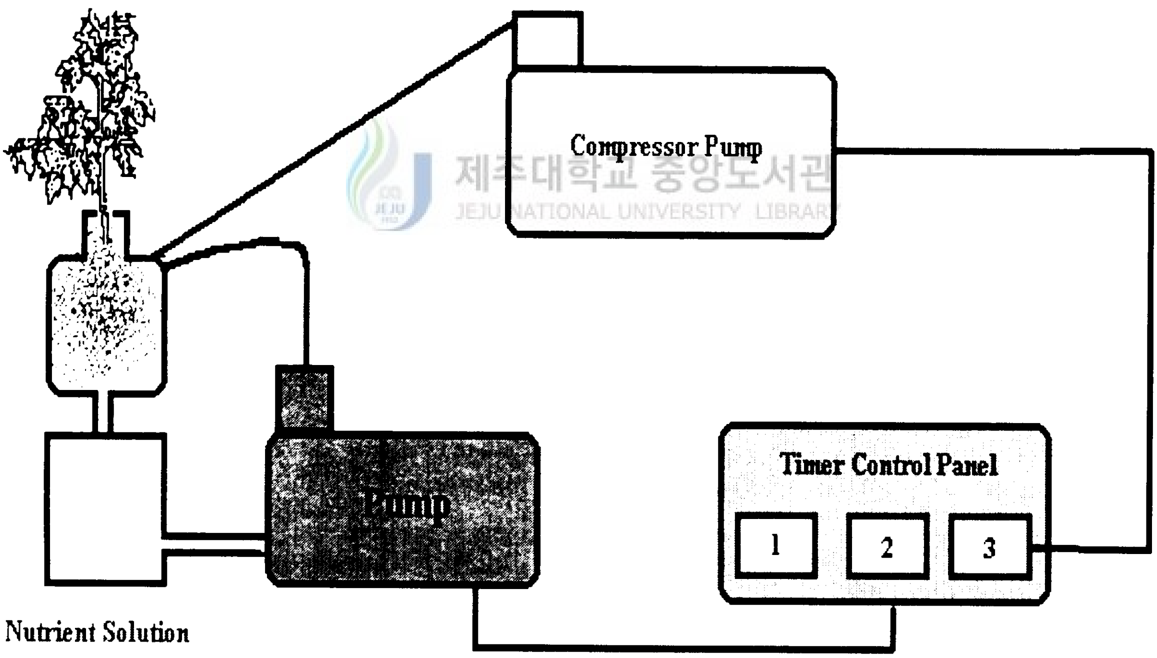


Figure 2. Nutrient solution supplying part (Timer 1: control of supply interval, Timer 2: control of supply time, Timer 3: control of oxygen supplying)

2.2 Oxygen supplying part

Since the system was an air tight one, oxygen supply to the root zone of citrus was required for root respiration. By inserting plastic tubes connected to air compressor into **C.T.B** oxygen could be directly supplied to citrus root surfaces after nutrient solution supplying. The oxygen supplying time was 30 seconds in each supply period and also controlled by digital timer.

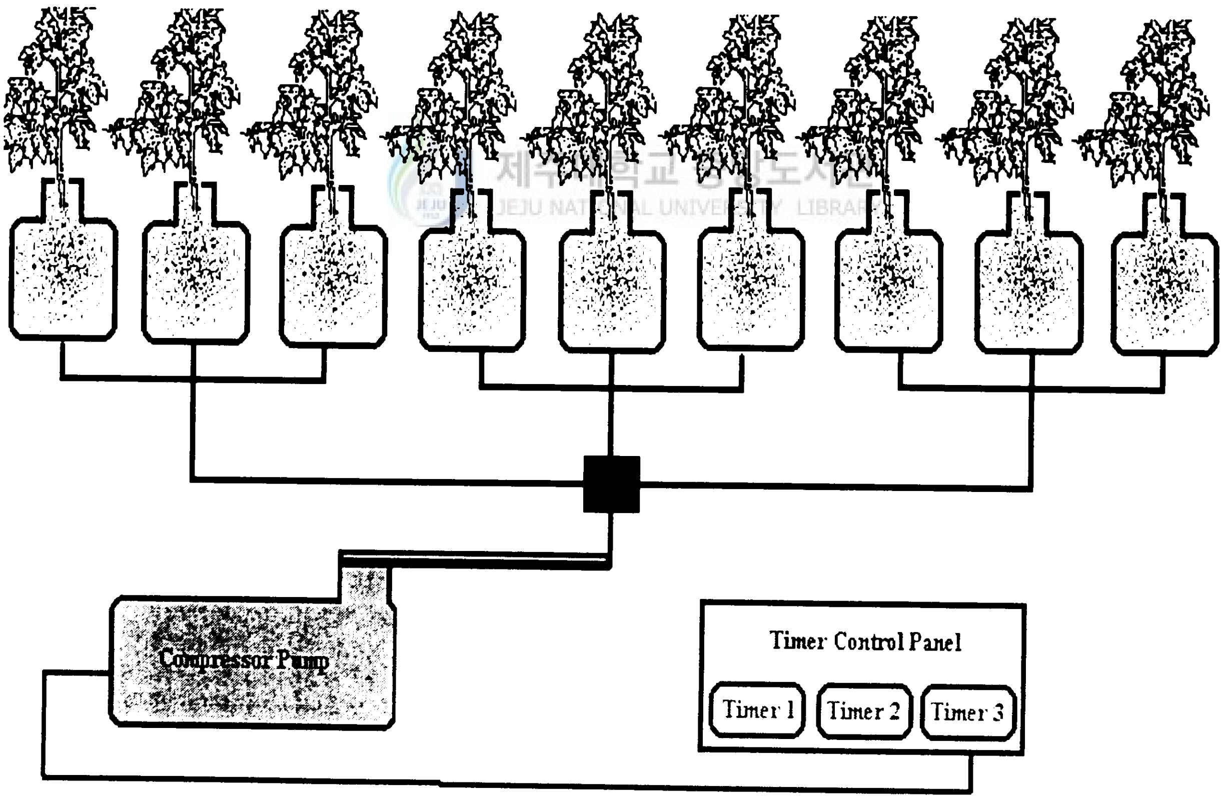


Figure 3. Oxygen supplying part (Timer 3: control of oxygen supplying time)

2.3 Temperature controlling part

Soil temperature at the depth of 20 cm in citrus field was preliminary measured, and the result showed that temperature in soil condition was very constant during one month of measurement. According to the result from preliminary measurement of soil temperature, a temperature control part was made to control temperature around the root environments of citrus trees. Copper tubes were wound up around **C.T.B** in which citrus tree was planted. Supplying water from water bath through copper tubes could control the temperature of system so that intended temperature was kept by using heater and cooler in water bath. The temperature sensor was connected with digital timer and pump to continuously supply water to copper tubes whenever temperature in root environment was lower or higher than the temperature set in the water bath.

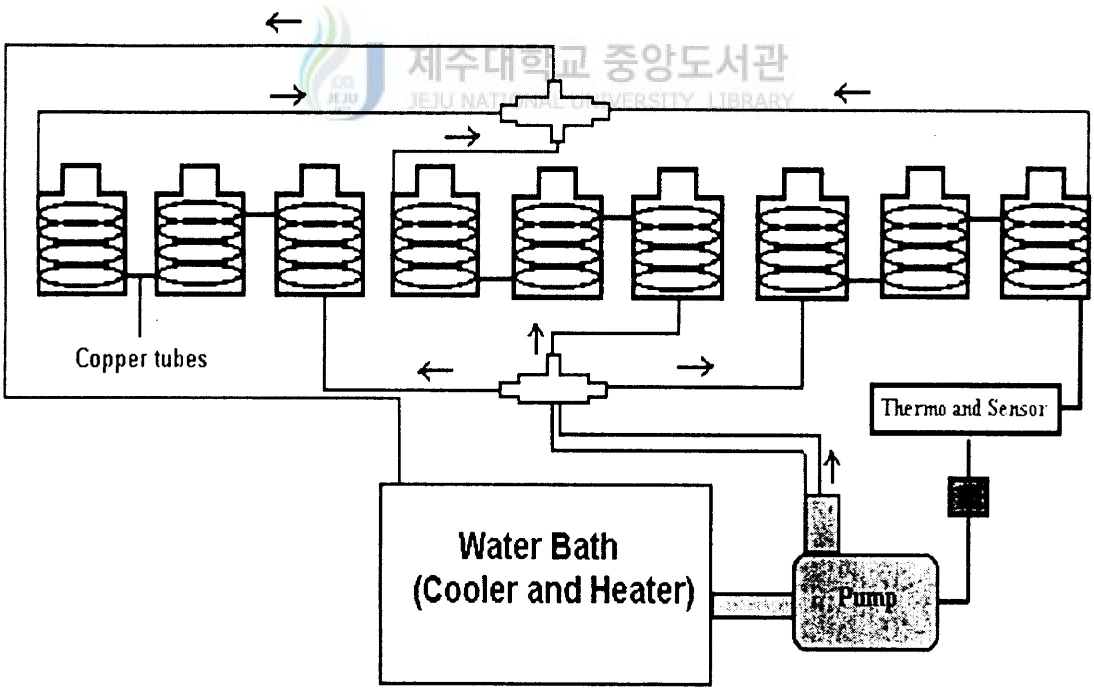


Figure 4. Temperature control part (Thermometer and sensor were connected with digital timer and pump to supply water continuously around copper tubes to control intended temperatures)

2.4 Electric controlling part

All parts of this system are under the control of so called **Electric controlling part**. Materials were digital timer, electric power, electric timers, IC timers, thermo, sensors and electric cables. This is to use digital timer for controlling of time interval of supplying and draining solution part, temperature part, oxygen supply part. Based on the testing result of nutrient supplying in preliminary experiment, we set up 15 minutes time interval for day time and 25 minutes for night time, and also time of supplying was 2 minutes.

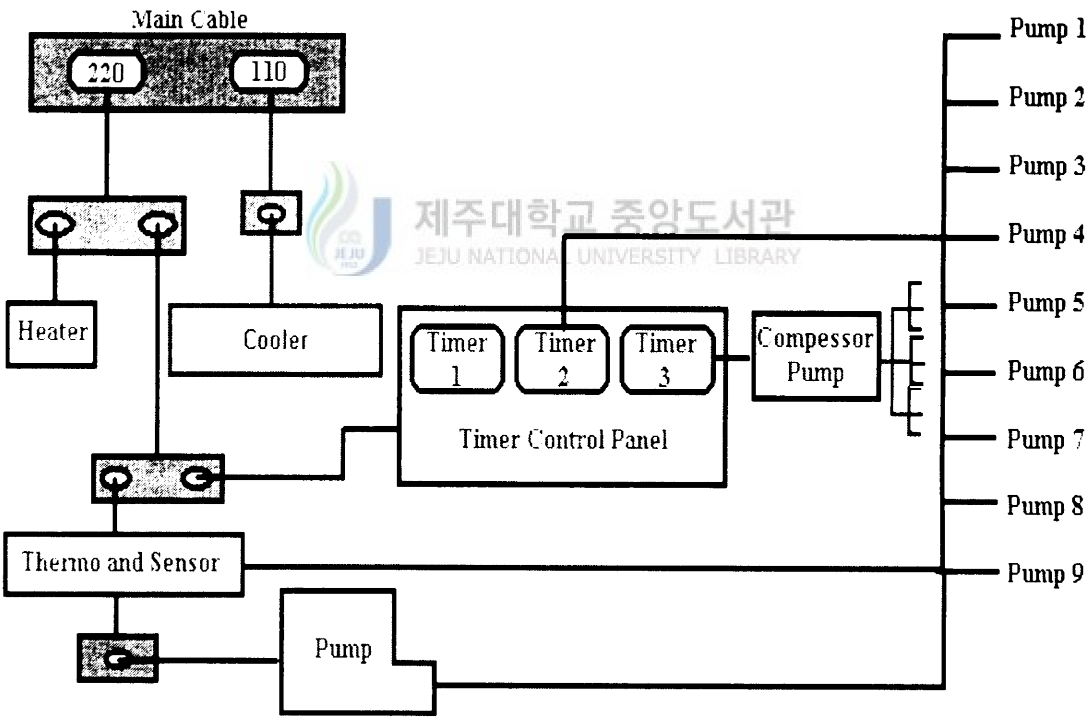


Figure 5. Electric controlling part (Timer 1: control of time interval, Timer 2: control of nutrient supplying time, Timer 3: oxygen supplying time)

3. Nutrient solution preparation

The composition and concentration of the nutrient stock solution was prepared based on the analytical data of Jeju citrus orchard soil. The stock solution was diluted into three nutrient concentration levels (low, medium and high) for supplying.

Table 1. Composition of element and chemicals of stock solution, 10 times of high level of initial supply solution.

Element	Concentration (mg/L)	Chemical	Amount (mg/L)
NO_3-N	3880	KNO_3	2280
P	670	$5[Ca(NO_3)2.2H_2O]\ NH_4NO_3$	4720
K	880	$Mg\ SO_4.7\ H_2O$	2460
Ca	800	$NH_4\ H_2PO_4$	776
Mg	240	Fe-EDTA	125
S	960	H_3BO_3	15
Fe	17	$Mn\ SO_4.\ 5\ H_2O$	10
B	2.6	$Zn\ SO_4\ 7\ H_2O$	11
Mn	2.2	$Cu\ SO_4\ 5\ H_2O$	0.25
Zn	0.25	$N_2Mo\ O_4\ 2\ H_2O$	0.1
Cu	0.05		
Mo	0.04		
Na	0.038		

Table 2. Three nutrient concentrations (ppm) of initial supply solution diluted from fertilizer composition at table 1.

Element concentration	Low (ppm)	Medium (ppm)	High (ppm)
NO_3-N	97	194	388
P	16	33	67
K	22	44	88
Ca	20	40	80
Mg	6	12	24
S	24	48	96
Fe	0.4	0.8	1.7
B	0.06	0.13	0.26
Mn	0.05	0.11	0.22
Zn	0.006	0.012	0.025
Cu	0.001	0.002	0.005
Mo	0.001	0.002	0.004
Na	0.0009	0.0019	0.0038

4. Method of measurement and analysis

4.1 Measurement of soil and air temperatures

Soil and air temperature was recorded by data-logger (Thermor recorder, TR-71FS, Korea) continuously which had two sensors near the research location. One sensor was in soil (20 cm deep) and the other in air condition (1 m above the ground).

4.2 Measurement of chlorophyll content

Twenty leaves in each citrus tree have been selected for monthly measurement of chlorophyll content (10 for young leaves and 10 for old leaves). The measurement were conducted by SPAD meter (SPAD-502, Minolta, Japan) at the beginning of every month.

4.3 Measurement of growth rate

Steel wires were wound around the branches 10 cm from the top of citrus tree to make a base mark for next measurement in April. The branch length was measured by a ruler to investigate growth rate of citrus trees in July and October.

4.4 Measurement of fresh weight increase

The weight of citrus trees bottles were measured to know the initial weight at the beginning of this research. And then citrus tree bottle were taken out every month to measure amount of fresh weight increase, and the measurement was conducted by mass balance.

4.5 Measurement of water uptake

Amount of water uptake was measured by weighing the weight decease between initial and remain nutrient solution whenever nutrient solution was replaced. Total uptake amount was calculated as sum of all measurement periods, then divided by total cultivation days to know daily amount of water uptake.

4.6 Nutrient solution sampling procedures

Nutrient solution sample was prepared with three nutrient concentration levels and being diluted as fresh solution in each supply period. Volume of initial and remain nutrient solution sample from high, medium and low levels were weighted and taken for analyzing **before** and **after** supplying period. The supplying time interval was 4-5 days in warm season and 6-7 days in cool season (this is based on testing results).

4.7 Analysis of nutrient solution samples

Nutrient solution (N.S) samples were divided into two groups of samples, N.S taken before supplying to citrus tree called initial sample and remain N.S called remained sample. Both of samples were collected for analyzing to know nutrient absorption of citrus.

Both initial and remain solution samples were filtered by using quantitative filter paper (Advantec-Toyo number 6). Dilution (9 times) was made only for analysis of anion element, but analysis of cation elements was done without dilution. Measurement of pH and EC were conducted by pH meter (Orion-52OA) and EC meter (TOA, CM-14P). Anions were determined by using ion chromatography(DX 500, Dionex, USA) and ammonium ion was analyzed by auto analyzer(AA ¢ , Bran+Lubbe GmbH, France). Cations were determined by using inductively coupled plasma atomic emission spectrometer (JY panorama, Jobin Yvon, France).

5. Calculation method of nutrient absorption

Amount of nutrient absorption of citrus were calculated by using the following formulation:

$$\frac{(W.I.S \times C.I) - (W.R.S \times C.R)}{1000} = A.N\ (mg)$$

Formulation notation:

W.I.S is Weight of initial solution (g)

C.I is Concentration of initial solution sample (ppm)

W.R.S is Weight of remain solution (g)

C.R is Concentration of remained solution sample (ppm)

A.N is Amount of nutrient uptake as mg.

6. Calculation method of nutrient requirements per one kg fresh weight increases

Nutrient amount required to produce one kg fresh weight increase of citrus tree was calculated based on the following formulation:

$$\frac{T.N.U}{T.F.W.I \times 0.001} = A.N\ (mg/kg\ of\ fresh\ weight\ increase)$$

Formulation notation:

T.N.U is total nutrient uptake amount (mg)

T.F.W.I is total fresh weight increased (g)

A.N is amount of nutrient uptake as mg per kg of fresh weight increases

7. Data process

All data for nutrient uptake amount, growth rate, fresh weight increased, water uptake and chlorophyll content were processed by excel program (window 2000).

III. RESULTS AND DISCUSSION

1. The spray hydroponic culture system

This spray hydroponic culture system for determination of nutrient absorption of citrus functioned successfully so that we could determine amount of several nutrient elements absorbed by citrus trees. It has been thought that there are many difficulties to determine nutrient and water uptake by citrus, a kind of perennial tree, in soil condition because it was almost impossible to analyze chemically the whole plant or to analyze the different amount of nutrients in soil before and after nutrient absorption experiment. Since this system was air tight, the real water uptake could be measured directly by measuring the decreased amount of the initial supplying solution. In addition, the amount of nutrient uptake by citrus trees could be easily determined by analyzing the different amount of nutrients contained in the initial nutrient solution and the remained nutrient solution. The spray type hydroponic system, without using any media such as rock wool, sands, and barks, has advantages that could measure the volume of the nutrient solution in the system without loss and consequently accurate amount of nutrient and water uptake by citrus trees could be determined.

This system was very easy to use, and did not require much time for building. Different from the soil pot experiment, it was not necessary to sacrifice citrus trees during the experiment as shown in the report of Hirobe and Ogaki, 1968. Thus, this system is considered convenient for the purpose of nutrient determination research not only for citrus but also for other perennial crops.

2. **Factors on citrus growth and development**

2.1 Soil and air temperatures

Data-logging of soil and air temperatures in citrus field showed the soil temperature was very constant during day time and night time in a month (range of soil temperature in April: 14-16, June: 17-18, August: 21-23, September: 20-22)

The average soil temperatures was not changed much depending on the seasons as shown in Fig. 6. But monthly average temperature of air was lower than that of soil from February to May but became higher from June to September, showing around 20^0 C temperature difference between the seasons. The highest temperature of soil and air was recorded in July and August.

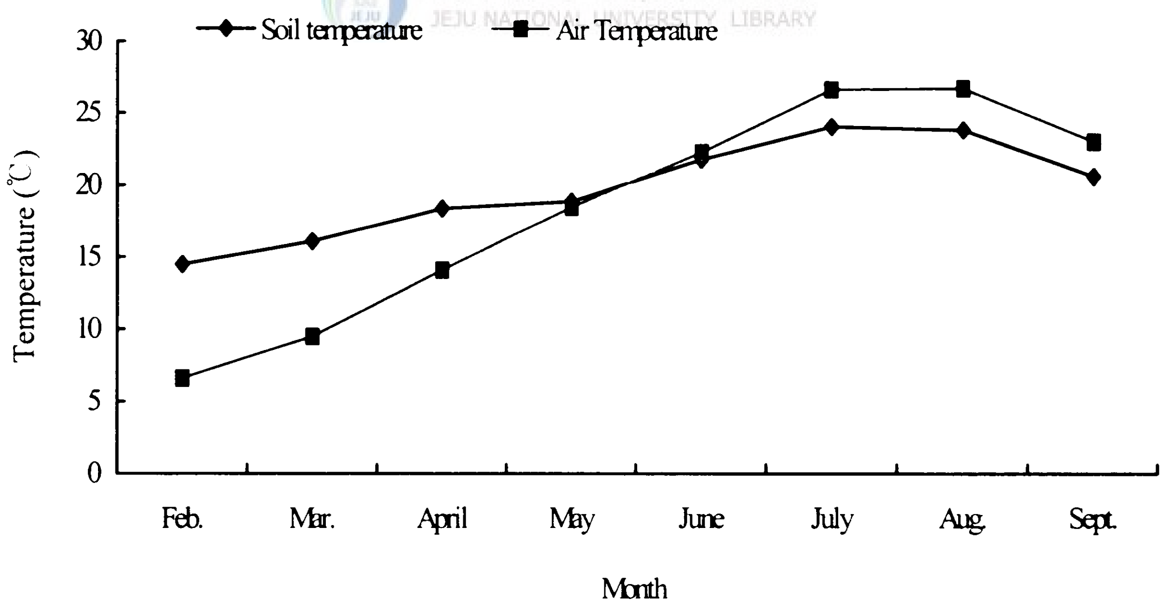
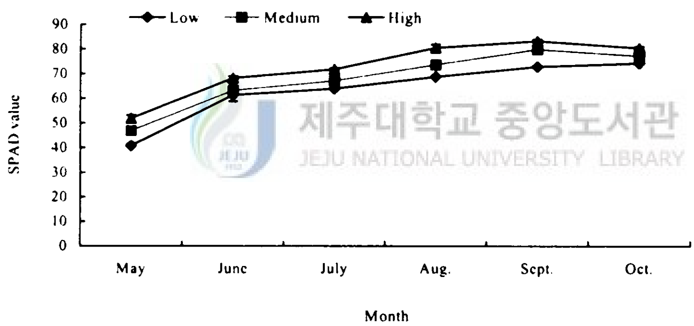


Figure 6. The change of monthly average soil and air temperatures in citrus orchard at Cheju National University during the research implementation.

2.2 Chlorophyll content

The general ranges of chlorophyll content of Jeju citrus by SPAD values were reported 70-80 (Han, 1997). But chlorophyll content can be different depending on the growth stages of leaves, chlorophyll content of old leaves were observed higher than that of young leaves at the beginning of the year (April, May, and June) while SPAD values of young leaves were increased rapidly and became higher than those of old leave in July. The leave of citrus grown in the higher level concentration solution contained more chlorophyll than in the medium and lower concentration solutions, regardless of new and old leaves. The content of chlorophyll was increased from spring to summer continuously.



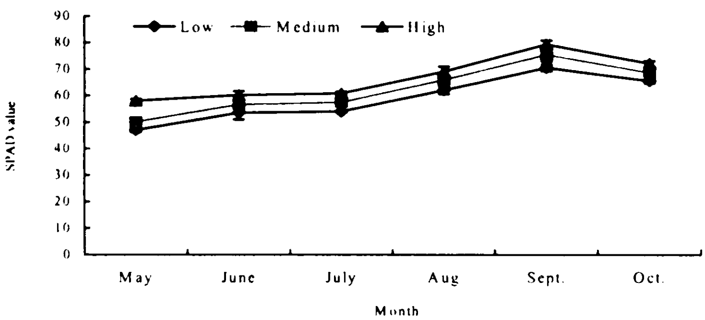


Figure 7. Chlorophyll content of citrus leaves at the three nutrient concentration levels (above : young leaf, below : old leaf).

2.3 Growth rate

To ensure that the citrus tree grows and develops normally in hydroponics as it does in soil condition, growth rate (G.R) of citrus tree was measured in three growth periods (April, July and October). The obtained result showed growth rate of citrus tree by hydroponics was similar to the growth rate in soil conditions (Hirobe and Ogaki, 1968). GR was also different by each treatment of culture solution concentrations. The increased length of GR from April to October was 33 cm in the higher treatment, 28 cm in the medium, and 24 cm in the lower treatment. There were two main growth stages through the year; the first one was at the beginning of June and the next one at the middle of August. The similar investigation of GR was reported (Han, 1997).

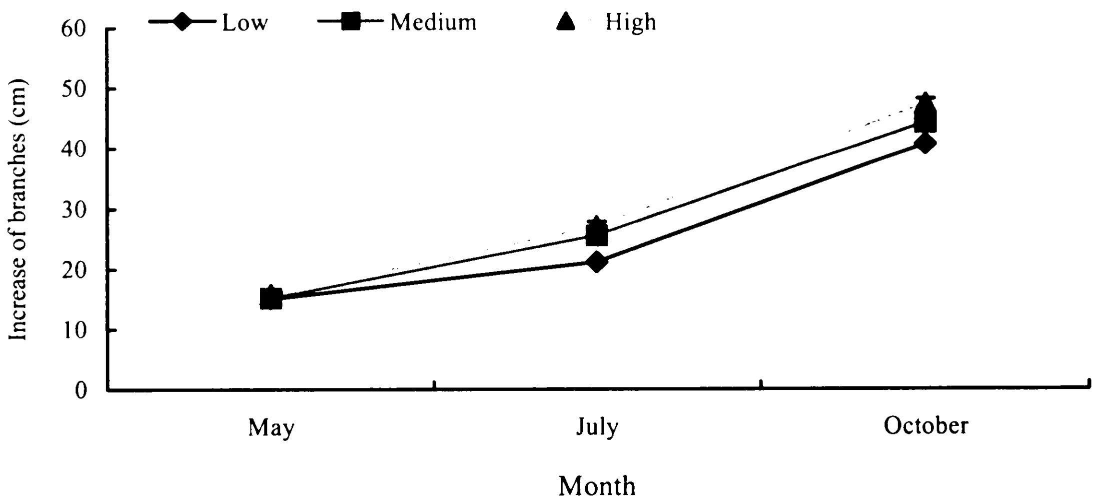


Figure 8. Growth of citrus branches of at the three nutrient concentration levels.

2.4 Increases of fresh weight

Fresh weight increases of citrus tree is shown monthly in Figure 9. The higher concentration of nutrient solution, the heavier fresh weights was through the experimental period. Two steps of fresh weight increase were found, the first one (220 g) was May to July and the other one (400 g) from August to October. The former increase period was resulted from spring-shoots, and the latter from summer-shoot and spring-shoots branches. The similar investigation of fresh weight increase (300-350 g) of citrus trees grown in soil condition was reported by Hirobe and Ogaki (1968).

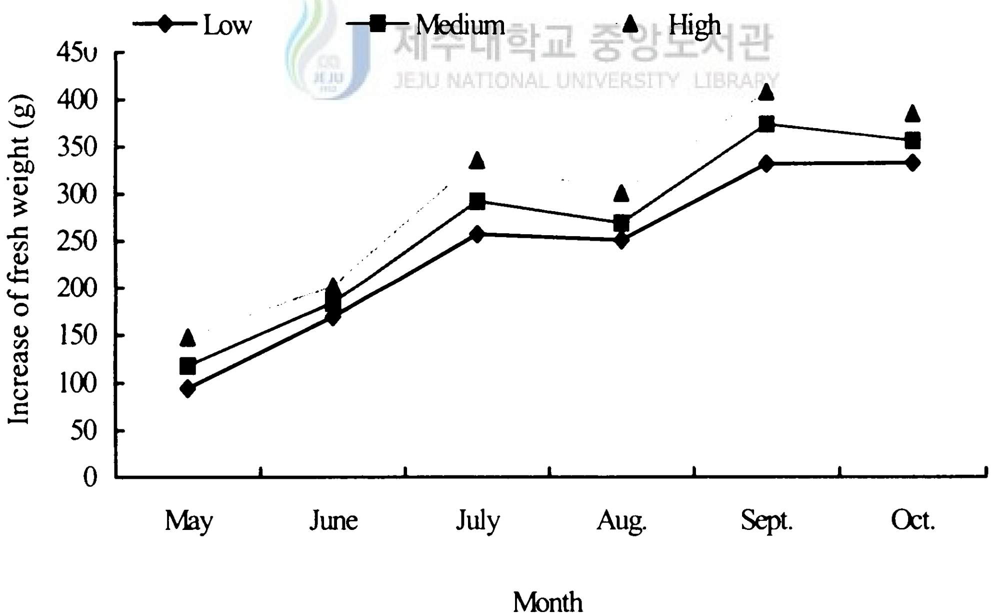


Figure 9. Monthly fresh weight increase of citrus as characterized by vegetative and reproductive growth.

2.5 Water uptake

The amount of water uptake by citrus trees were increased as season advanced because of higher temperature and increased fresh weight of trees (Figure 10). The amount of water uptake in May and June was much lower than that in other month due to low temperature. In July and August, higher water amount was required because this period had highest temperature of the year and growth rate. The highest water uptake by citrus tree was found in fruiting season, September. There was a strong indication that the water uptake in higher nutrient concentration treatment was lower than in the medium and lower treatment, due to its higher osmolarity. The same result was reported by Romero and Cuartero (2001).

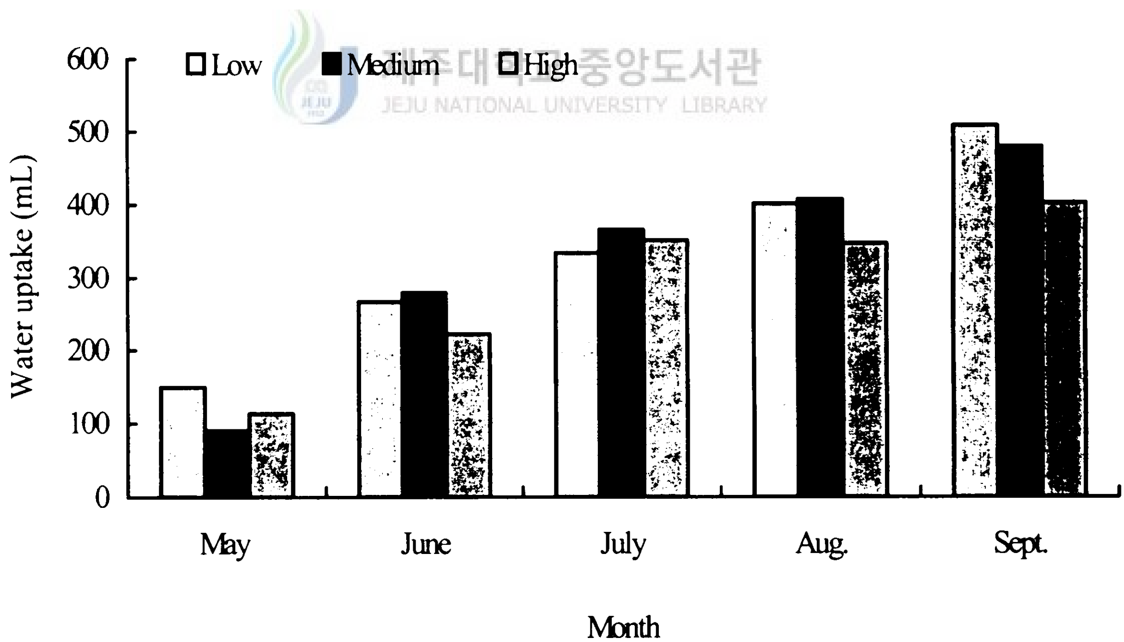


Figure 10. Water uptake per tree per day at the three nutrient concentration levels

3. Nutrient element absorption by citrus

3.1 NO_3-N uptake

The concentration of nutrient solution were affected very much the absorption of NO_3-N by citrus trees. In the higher level concentration, much more absorption of NO_3-N occurred (Figure 11). Obtained result showed two periods of highest NO_3-N requirement by citrus tree in a year, July and September. The uptake amount per tree per month was 4680 mg in high treatment and 2017 mg in low treatment. In July citrus absorbed greatly not only NO_3-N but also other elements due to rapid growth and in September also greater amount of nutrients were required for fruiting. In May, June and August citrus required NO_3-N much lower than other months of the year.

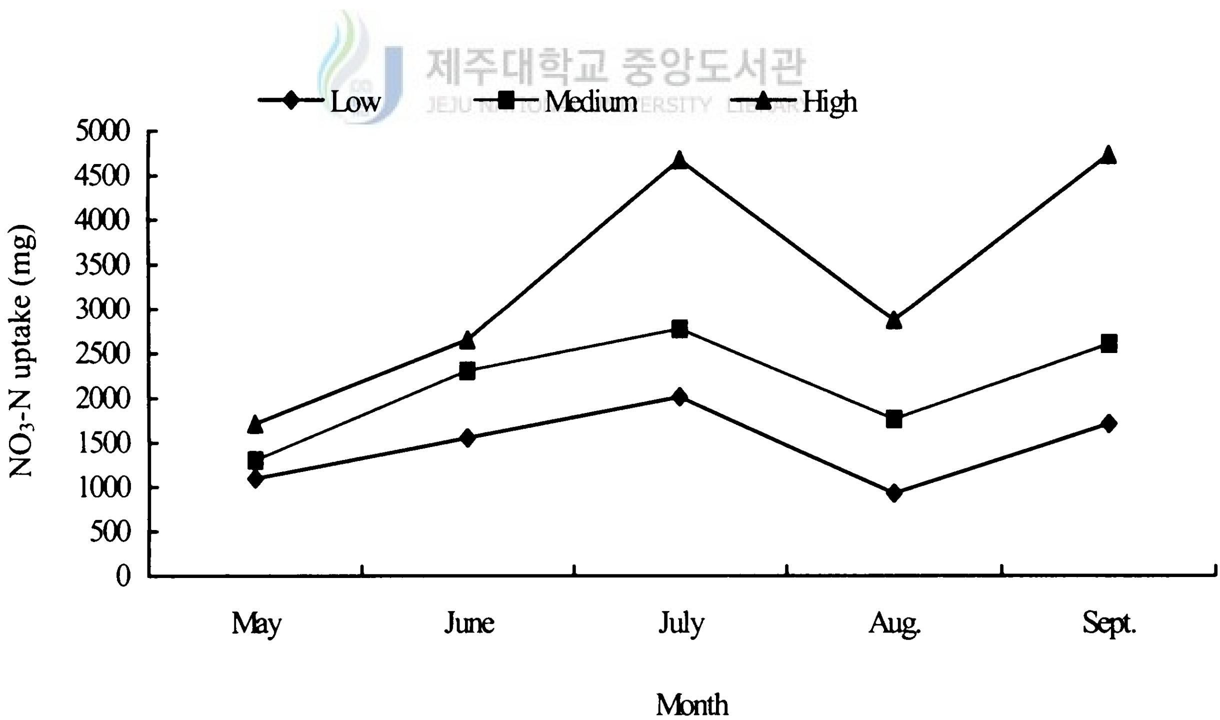


Figure 11. Monthly NO_3-N uptake per tree at the three nutrient concentration levels.

3.2 K uptake

Monthly potassium absorption of citrus was changed by the nutrient concentration levels and the seasons (Figure 12). The result showed that citrus tree did not require much K in spring so that amount of K uptake was really low in May (300 mg in high treatment, 200 mg in medium, and 170 mg in low. In July, the highest uptake was observed, 1000 mg per tree per month in the high treatment, 700 mg in the medium, and 581 mg in the low. Citrus tree required higher uptake amount for fruiting in September than in May and June. It can be suggested that the citrus tree did not require much amount of K in fruiting period than in growing season.

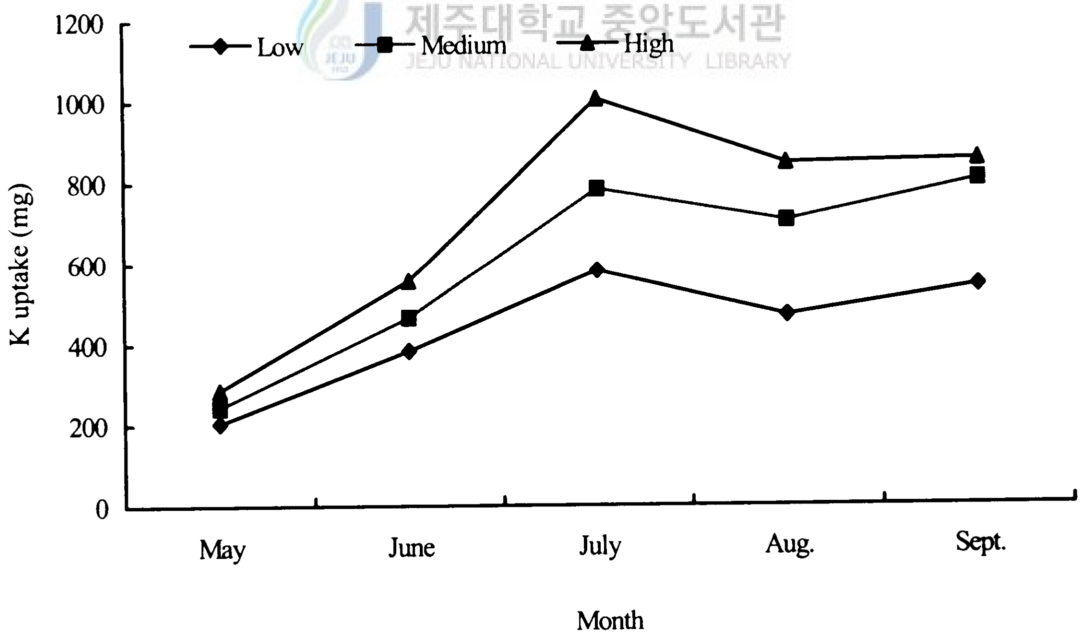


Figure 12. Monthly potassium uptake by citrus tree at the three nutrient concentration levels.

3.3 Ca uptake

The uptake amount of Ca by citrus was affected by the nutrient concentration of supplying solution and the seasons through the year (Figure 13). Calcium uptake was increased until July and decreased in August at the three concentration levels, 300 mg per tree per month at the high concentration of culture solution, 250 mg at the medium and 200 mg at the low in May. At beginning of the year (May, June) citrus tree did not require much amount of calcium, about 300 mg was needed per tree per month in high treatment and 200 mg for low treatment. The highest Calcium uptake by citrus was shown in July, being 775 mg per tree per month at the high concentration, 634 mg at the medium and 600 mg at the low. At the high and medium concentrations, the calcium uptake was greater in September than in August.

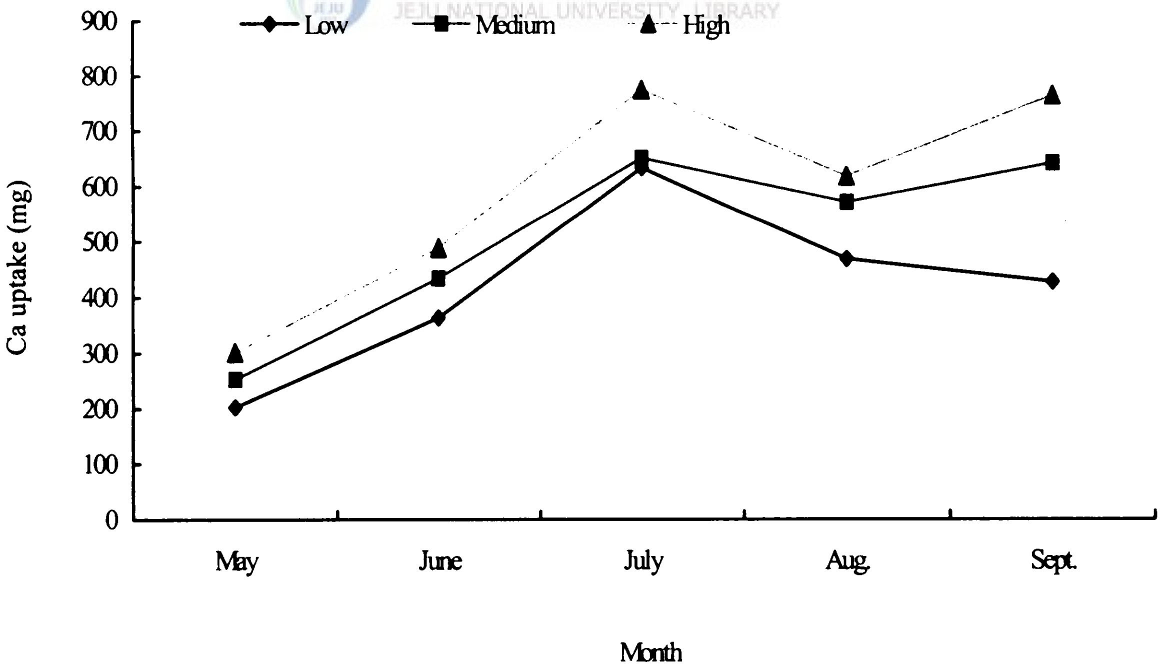


Figure 13. Monthly calcium uptake per tree at the three nutrient concentration levels.

3.4 P uptake

Although phosphorus was reported as one of major elements for citrus growth (Chapman and Rayner, 1951), the uptake of phosphorus per tree per month gave comparatively lower values than those of NO_3-N, K, and Ca (Figure 14). At the medium and low concentrations, the seasonal change of phosphorous uptake was smaller. The higher uptake of phosphorous in July and September seemed to be same as other elements. Hirobe and Ogaki (1968) reported similar investigation in soil conditions, showing higher uptake in active growing season and fruiting season

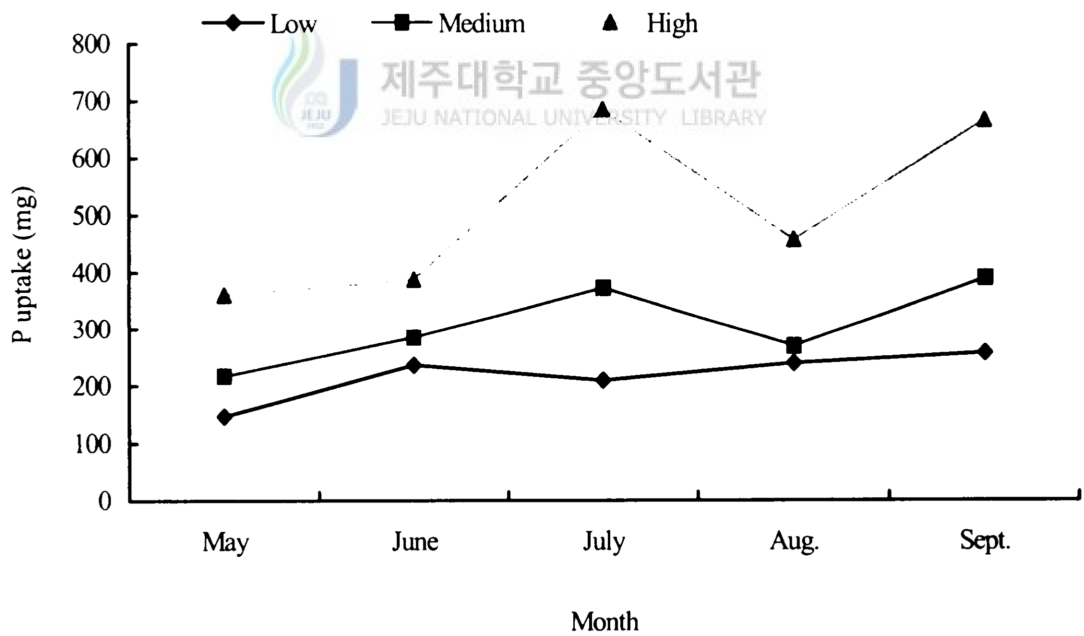


Figure 14. Monthly phosphorus uptake per tree at the three nutrient concentration levels.

3.5 NH_4-N uptake

Uptake amount of NH_4-N was determined separately from NO_3-N uptake. The seasonal change of NH_4-N uptake was not as big as NO_3-N, K and Ca (Figure 15). The absorption amount of NH_4-N by citrus was much lower comparing with that of NO_3-N because NH_4-N concentration in the initial supplying solution was lower than NO_3-N. The amount of NH_4-N uptake at the high concentration was 516 mg per tree per month in September but NH_4-N uptake at the low was 203 mg.

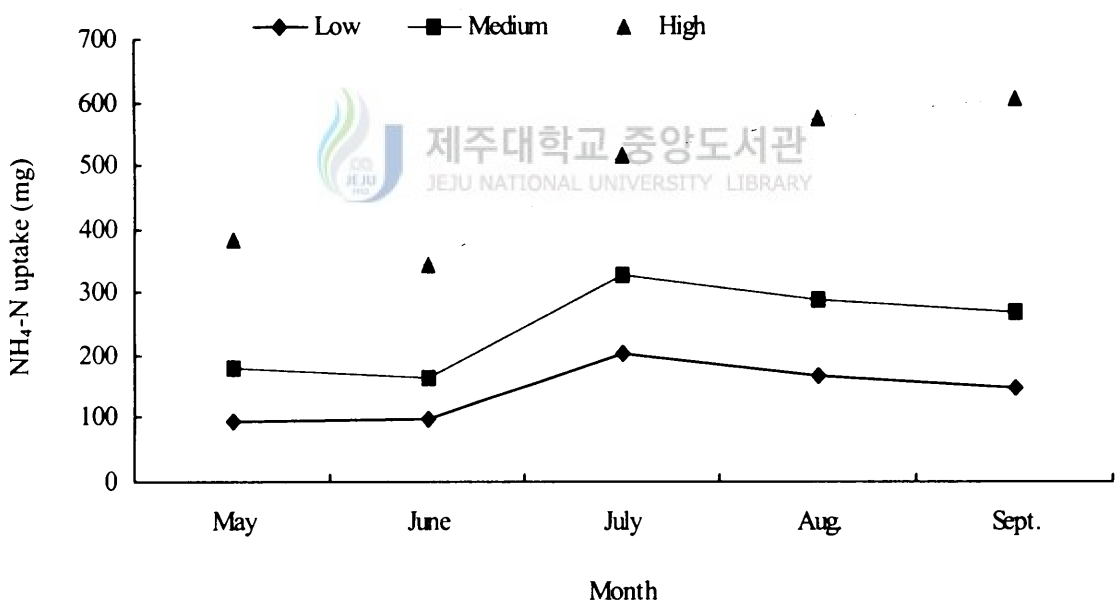


Figure 15. Monthly NH_4-N uptake per tree at the three nutrient concentration levels.

3.6 S uptake

Sulfur uptake by citrus had the similar tendency as other elements mentioned above (Figure 16). The seasonal change of sulfur uptake per tree per month was not drastic except for 1004 mg at the high concentration in July. Sulfur uptake in September for fruiting was a bit lower than in July but quite higher than in May.

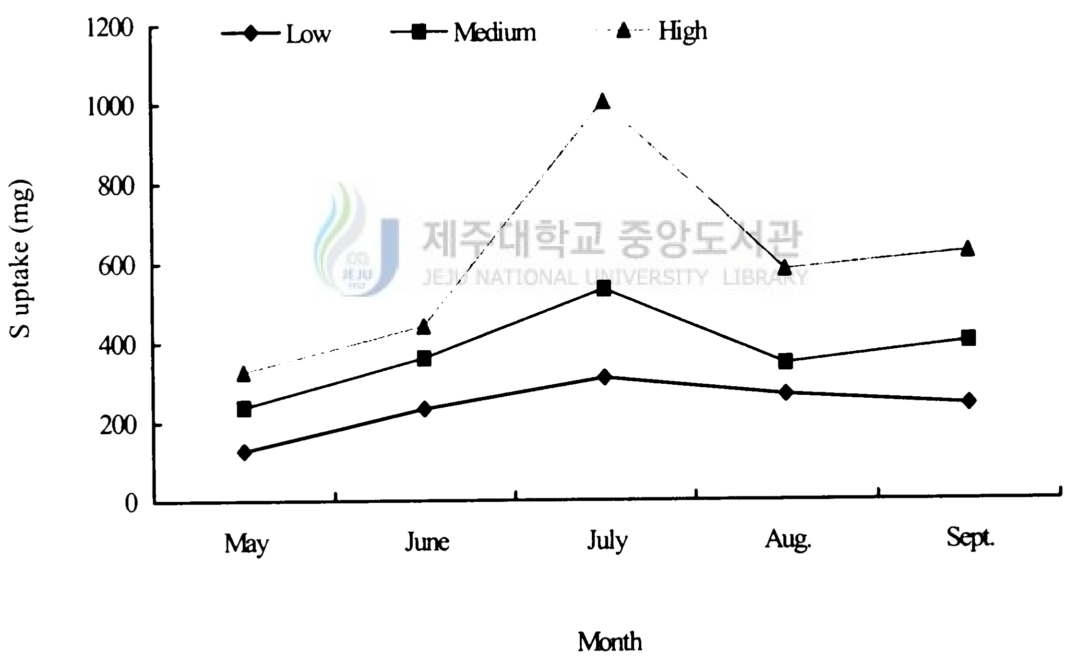


Figure 16. Monthly sulfur uptake per tree at the three nutrient concentration levels.

3.7 Mg uptake

Magnesium absorption by citrus tree was rapidly increasing after May, being depending on the different concentration levels of nutrient solution and the seasons through the year (Figure 17). The highest uptake was still found in July, with 186 mg per tree per month at the high concentration level, and 152 mg at the low concentration. Fruiting season, in September, also required high amount of magnesium but a bit lower than in July.

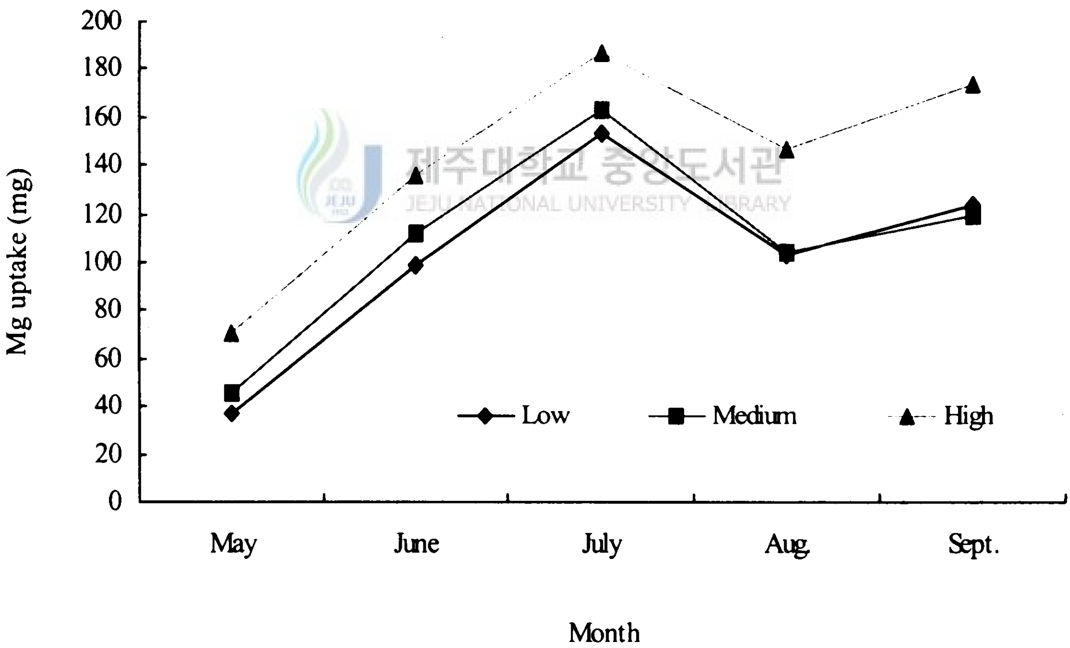


Figure 17. Monthly magnesium uptake per tree at the three nutrient concentration levels.

3.8 Fe uptake

Since iron is one of the micronutrient elements for the plants, citrus tree really required a small amount of Fe for its growth and development (Figure 18). The highest absorption amount of Fe per tree per month was occurred in July. However, the uptake amount was only 13 mg at the high concentration level, 7 mg at the medium, and 3.4 mg at the low. In September citrus required about smaller of Fe than in July, 11 mg at the high concentration level, 4 mg at the medium, and 3 mg at the low.

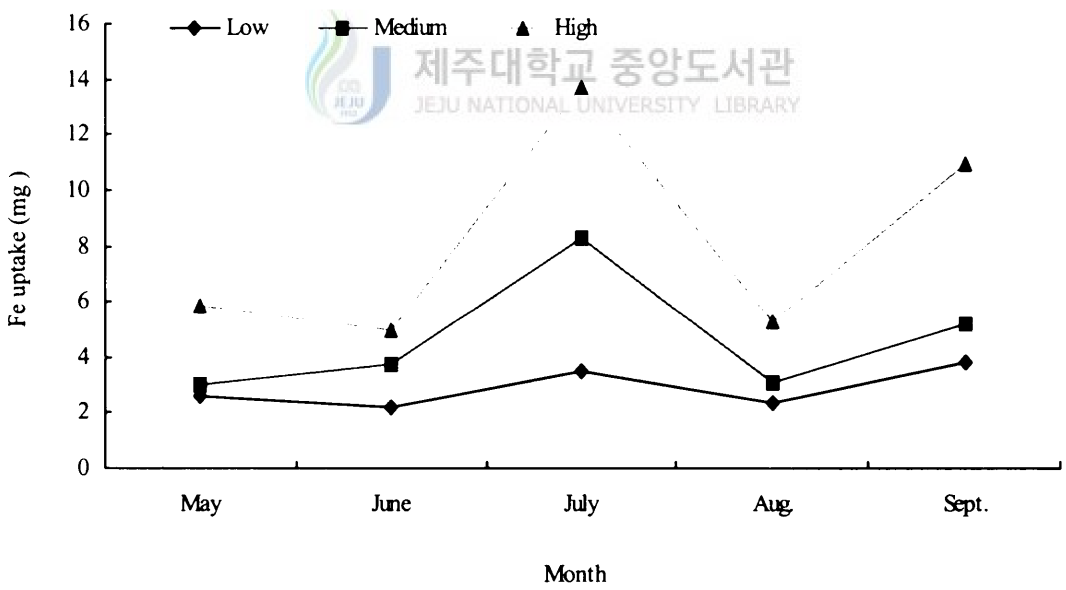


Figure 18. Monthly iron uptake per tree at the three nutrient concentration levels

3.9 Total accumulated amount of nutrient absorption of citrus

Table 3. Total accumulated amount of nutrient absorption of citrus for 6 month

Element	NO_3-N	K	Ca	NH_4-N	P	Mg	S	F
Low	7320	2182	2101	712	1091	516	1182	14.5
Medium	10778	3007	2558	1231	1536	543	1882	23.3
High	16670	3553	2954	2425	2559	715	2982	40.7

4. Nutrient requirement for one kg fresh weight increase

Based on the result obtained from the nutrient absorption amount of citrus and the fresh weight increase, the amount of nutrient requirement to produce one kg fresh weight of citrus was calculated (Table 3). This is to know the correlation between the amount of nutrient requirement and the fresh weight increase of citrus trees.

Table 4. Amounts of nutrient requirement for citrus tree to produce one kg of fresh weight (mg)

Treatments	NO_3-N	NH_4-N	P	K	Ca	Mg	S	Fe
Low	5094	495.4	759	1518	1462	359.0	823.2	10.1
Medium	6756	771.9	963	1884	1603	340.6	1180	14.6
High	9359	1361	1436	1994	1658	401.5	1674	22.8

In the table 3 showed that more amount of nutrient was needed to produce one kg of fresh weight at the high concentration level than the medium and the low. This fact is observed from all the elements examined. From the result, it can be suggested that supplying too high concentration culture solution should be avoid to save nutrition or fertilizers.

IV. CONCLUSION

Since it was difficult to determine nutrient absorption and water uptake by the perennial plants such as citrus tree under soil conditions, actual nutrient amount needed by the crops have not been well documented. There are many factors affecting the nutrition and water uptake by trees, such as: temperature, age of the tree, growth stage, soil fertility, etc. Considering those kind of complex difficulties, the authors designed an air tight spray hydroponic system to measure the nutrition and water uptake by citrus trees, and confirmed that the system functioned successfully.

Temperature and seasonal changes through the year significantly affected citrus growth and development. A rapid increase of citrus fresh weight occurred in twice periods, from May to June and from August to October. The increase in former period resulted from spring-shoot, and the latter from summer-shoot and spring-shoots. The monthly uptake amount of water by citrus trees were increased from May to September because of raised temperature and increased fresh weight of trees. Contrary to the tendency of nutrient uptake, more water uptake was observed at the low concentration of nutrient solution than at the high concentration.

The uptake amounts of nutrient elements were significantly different depending on the concentration of nutrient solution. The higher concentration, the greater uptake amount by citrus tree. NO_3-N, K and Ca were found major nutrient elements with their higher uptake comparing to other elements, absorption range being 200 to 4500 mg per tree per month. But NH_4-N, S, Mg, and P were found the secondary major nutrients, absorption range being 14 mg per tree per month to 1000mg. Iron proved a micronutrient element with uptake amount ranging from 2 mg to 16 mg per tree per month. The results showed the highest uptake of most elements occurred in July due to rapid growth season and in September for fruiting.

Amount of nutrient requirement to produce one kg fresh weight of citrus tree were varied depending on the concentration of nutrient solution. More amount of nutrient was needed to produce one kg of fresh weight at the high concentration level than the medium and the low. This fact was observed from all the elements examined. From the result, it can be suggested that supplying too high concentration culture solution should be avoided to save the nutrition or fertilizers. But the optimum amount of each element for natural growth of citrus tree should be figured out by further investigation. Thus, in order to avoid from being waste of fertilizer, the low and medium nutrient concentration is recommended for citrus grower.

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