CRITICAL NUTRIENT UPTAKE ABILITY OF TOMATO PLANTS (*SOLANUM LYCOPERSICUM* L.) GROWN USING THE NUTRIENT FILM TECHNIQUE (NFT) BY DESCENDING NUTRIENT CONCENTRATION METHOD

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ABSTRACT

The critical nutrient uptake ability of each element in tomato plants (*Solanum lycopersicum* L. cv. Reika) grown using the Nutrient Film Technique (NFT) was investigated by descending nutrient concentration method using three seedling sizes. All the cultures started from different concentrations of nutrient solution and supplemented only with rainwater. The changes in NO_3-N concentration of nutrient solution decreased right after the start of the experimental period in all the different seedling stages. The bigger plants absorbed the nutrient elements very fast and reached the final concentration faster than younger plants, but uptake by all plant stages reached almost the same final concentration. The changing patterns of the concentration of other elements were similar to those of nitrate. The uptake rates of each element were measured to determine the points for the critical uptake rate to become zero. A zero value means that the plants can no longer absorb the nutrient from the solution. The critical nutrient concentrations for tomato obtained in our experiment were, 0.01-0.04 me/L for NO_3-N, 0.02-0.09 me/L for PO_4-P, 0.03-0.10 me/L for K, 0.02-0.20 me/L for Ca, and 0.01-0.09 me/L for Mg. These concentrations were lower than those of the ascending method in our previous study. The differences in the values of the critical nutrient concentration of each element are discussed.

Key words: uptake concentration, hydroponics, critical concentration

INTRODUCTION

In a closed type soilless culture system, nutrient management has been based on the maintenance of relatively high ion nutrient concentrations. Considerable attention has been given to the change in absorption of water and nutrient uptake at different growth stages of crops (Van Goor et al., 1988). Likewise, several studies were performed on the suitable nutrient concentration for the growing plant (Gomez-Lepe et al., 1974; Moustafa and Morgan, 1983; Larouche et al., 1989), however there are still differences in the recommended concentrations.

The minimum critical nutrient concentrations measured by Maruo et al. (2001 and 2004) and in our previous paper (Gonzales et al., 2010) were much lower than the concentrations commonly used in nutrient solution. In principle, the critical nutrient concentration of each element should not be different. There are two methods which can be used to measure the critical nutrient concentration in each element. One is the ascending method which we used in the previous study. In this method all treatments started with rainwater and different strengths of nutrient solution were supplemented according to the consumed solution. The absorption concentrations were measured under the concentration ascending condition. The other method is the descending method in which the culture starts from higher concentrations and supplemented only with rainwater. The critical nutrient concentration of each element can be measured according to the given nutrient conditions under the concentration descending method and can be estimated using the average concentration of the nutrient solution which gave zero values in the absorption concentration.

Therefore, this study adopted the descending method to grasp more precisely the critical concentration for tomato plants. Results for the ascending and the descending methods were compared, and the differences in the values of the critical nutrient concentration of each element are discussed. In this study, three different seedling stages of tomato plants were used to further clarify the critical nutrient concentrations of each element more accurately.

MATERIALS AND METHODS

Preparation of Tomato plants

Tomato (*Solanum lycopersicum* L. cv. Reika; Sakata Seed Co. Japan) was used as the test plant in this experiment. Seeds were sown in cell trays filled with fine granulated rockwool on October 23, 2007. After emergence, the seedlings were irrigated once a day with a 1/4 strength nutrient solution (Enshi-formula). On November 28, 2008, when the seedlings had two true leaves, they were potted to 9.5 cm plastic pots filled with 300 mL fine granulated rockwool and grown with 1/2 strength nutrient solution until transplanting. Seedlings were transplanted to the NFT system when they reached at the stage of 4 true-leaves (December 8-14, 2008), 8 true-leaves (December 23-31 2008), and 11 true-leaves (January 3-14, 2008). Plants were spaced 15 cm apart and the flow rate was 2 L/h per plant. The air temperature in the plastic greenhouse was kept at above 12^{o}C by a heating system and ventilation windows were opened when temperatures reached 25^{o}C.

Experimental design

In both methods, i.e. ascending and descending nutrient concentration method, the system was principally the same but the volume of nutrient solution in the system was different. The total volume of the solution was reduced. A NFT system with, 180 cm long channels and a 1% slope were used. Total volume of the nutrient solution in the tank and culture bed was 6.5 L. Nutrient solution for each channel was controlled independently. Six beds were used, each bed contained 12 plants for a total of 72 plants. The details of the system used were described fully in our previous paper (Gonzales et al., 2010).

Seventy two seedlings in each stage (4 true- leaves, 8 true-leaves, and 11 true- leaves) were prepared. Roots and substrates in the pots were washed with sufficient rainwater until the EC value of the drained solution was similar with rainwater. We started six concentrations of nutrient solution according to the treatments (1, 1/2, 1/4, 1/6, 1/8, and 1/10 strength) and were supplemented with only rainwater which was kept in the header tank. The nutrient composition of the treatments and the method of the measurement of the solution were described in the previous paper.

RESULTS AND DISCUSSION

The changes in the nitrate concentration in the nutrient solution at different growth stages of tomato seedlings are shown in Figure 1. The highest concentration of the nutrient solution started from 16 me/L. The vertical axis of the graphs must be drawn full scale to 16 me/L, but the difference in the decreasing pattern can not be shown clearly because the concentration of each treatment decreased quickly. Therefore, the vertical axis was changed to 1 me/L in full scale. As a result, the data of the highest strength (1 U) treatment could not be plotted because it is out of range in the graph. The concentration of nutrient solution decreased rapidly right after the start of the experiment. Once the nutrient solution reached a certain concentration, the speed slowed down and continuously decreased until finally reaching a plateau, except for the treatments of smaller size plants. Although the duration needed to reach the plateau differed depending on the size of the plants, the final concentration was almost the same value.
For small plants, the nitrate concentrations decreased slower than the bigger plants (Fig. 1-a). Therefore, we can grasp the dynamic change more clearly. In treatment 1/10-1/6 strength, nitrate

concentrations decreased faster until the 1st day and the speed slowed down until the 3rd day. On the 3rd day it slowed down again and then continuously decreased until the end of the experiment. The decreasing pattern was similar to the other treatments but the slopes are not completely parallel. This means that there was a difference in the uptake rate of NO_3-N depending on the strength of NO_3-N solution. A continuous decrease suggested that the final concentration of nitrate did not reach the critical minimum uptake of this plant size within the experimental period.

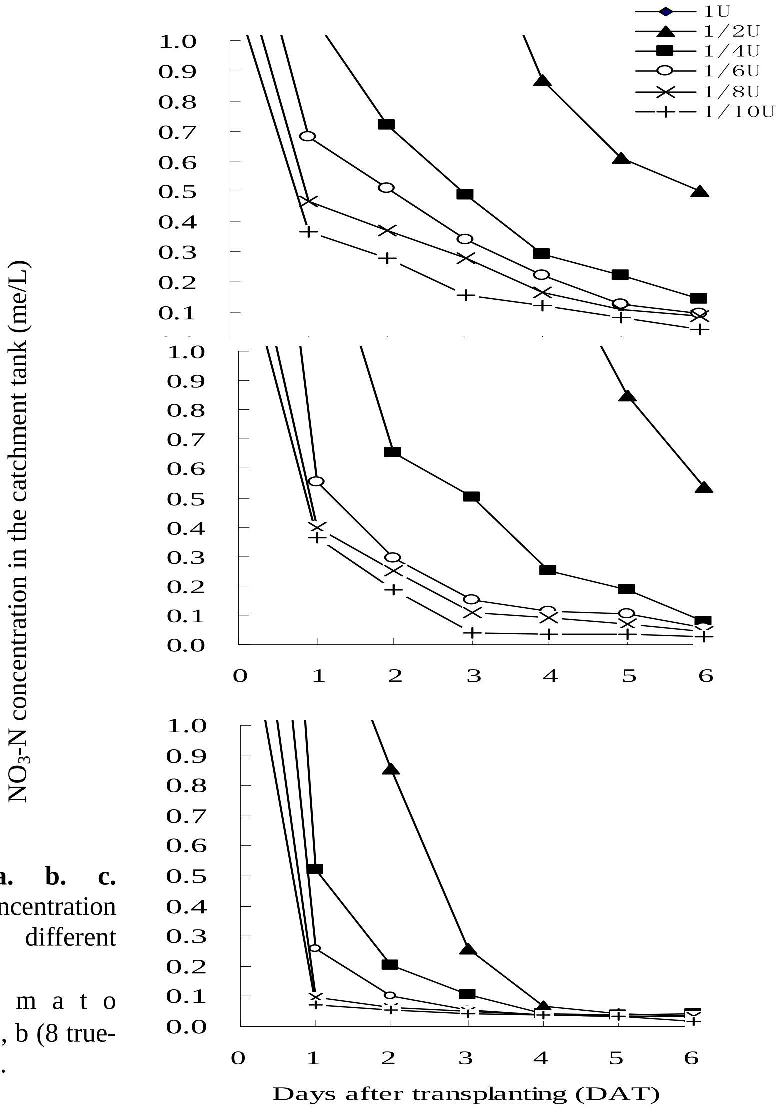

Fig. 1. a. b. c. Changes in NO_3-N concentration of the nutrient solution at different growth stages of tomato plants. a (4 true- leaves), b (8 true- leaves), c (11 true- leaves).

The plants with the biggest size absorb NO_3-N faster than those of other sizes (Fig. 1-c). In treatment 1/10-1/4 strength, the plant quickly reached close to the plateau of the graph on the 1st day or 2nd day. Even at 1/2 strength, the concentration leveled off on the 5th day. In figure 1-b, the response of nitrate concentration in the plant was in the middle of the two plant sizes. As shown in the figure, the concentration at the flat points can be used to estimate the critical uptake concentration of tomato plants. The final concentration of the other elements on the 6th day, including the nitrate, is shown in Table 1.

Table 1. a. b. c. Final concentration of selected mineral elements remaining in the nutrient solution

six days after treatment using tomato plants at different growth stages. a (4 true-leaves), b (8 true-leaves), and c (11 true-leaves).

a. 4 true-leaves stage

	Nutrient concentration left in the catchment tank (me/L)[y]				
Treatment (U)[z]	**NO_3-N**	**PO_4-P**	**K**	**Ca**	**Mg**
1 U	2.88	0.63	2.15	1.85	0.29
1/2 U	0.58	0.47	2.07	0.57	0.24
1/4 U	0.18	0.15	0.94	0.31	0.15
1/6 U	0.13	0.09	0.58	0.21	0.06
1/8 U	0.11	0.07	0.34	0.18	0.05
1/10 U	0.05	0.04	0.11	0.08	0.05

b. 8 true-leaves stage

	Nutrient concentration left in the catchment tank (me/L)[y]				
Treatment (U)[z]	**NO_3-N**	**PO_4-P**	**K**	**Ca**	**Mg**
1 U	2.10	0.48	1.72	1.25	0.68
1/2 U	0.77	0.16	1.02	0.69	0.32
1/4 U	0.23	0.12	0.27	0.48	0.13
1/6 U	0.05	0.06	0.06	0.07	0.03
1/8 U	0.04	0.03	0.05	0.05	0.03
1/10 U	0.01	0.02	0.03	0.04	0.02

c. 11 true-leaves stage

	Nutrient concentration left in the catchment tank (me/L)[y]				
Treatment (U)[z]	**NO_3-N**	**PO_4-P**	**K**	**Ca**	**Mg**
1 U	2.04	0.54	0.42	1.16	0.47
1/2 U	0.13	0.17	0.15	0.25	0.21
1/4 U	0.03	0.09	0.10	0.20	0.09
1/6 U	0.01	0.07	0.05	0.05	0.03
1/8 U	0.01	0.04	0.03	0.02	0.02
1/10 U	0.01	0.03	0.02	0.03	0.01

[z]U (strength)

[y]nutrient concentration left in the catchment tank was computed: concentration of element in the tank (me/L) * total volume in the system / no. of plant

The changing patterns of the concentration of the other elements were similar to those of nitrate. Bigger plants absorbed the nutrient elements faster than the younger plants, the values of the final concentration became smaller than those of the other sized plants within the limited experimental period. Therefore, we can estimate the critical absorption concentration of each element using the values of bigger sized plants grown in lower nutrient concentration.

The uptake rates of each element from 4 to 6 days after treatment are shown in Table 2. In each plant stage, treatments started with higher concentrations (1/2 or 1 strength), the uptake rate was higher compared to lower concentration treatments in which the values were already very low or nearly zero. The number of value zero increased according to the plant size. As there were differences in uptake rates and /or uptake concentrations by different plant sizes, the time needed for the uptake of each element was also different.

Therefore, the critical concentration of each nutrient can be estimated using the average concentration of the nutrient solution which gave zero values in the uptake rate. From these results, we can estimate the critical uptake concentration of each element using the values obtained from the bigger sized plants grown in the treatment using lower nutrient concentration as a starting point.

Table 2 a. b. c. Uptake rate of each element from 4th to 6th days after treatment. a (4 true-leaves), b (8 true-leaves) and c (11 true-leaves).

a. 4 true-leaves stage

	Uptake rate (me/plant/day)[y]				
Treatment (U)[z]	**NO_3-N**	**PO_4-P**	**K**	**Ca**	**Mg**
1 U	0.11	0.14	0.12	0.09	0.07
1/2 U	0.09	0.10	0.09	0.07	0.06
1/4 U	0.04	0.03	0.07	0.03	0.02
1/6 U	0.02	0.02	0.05	0.03	0.01
1/8 U	0.02	0.02	0.05	0.03	0.02
1/10 U	0.02	0.02	0.05	0.02	0.02

b. 8 true-leaves stage

	Uptake rate (me/plant/day)[y]				
Treatment (U)[z]	**NO_3-N**	**PO_4-P**	**K**	**Ca**	**Mg**
1 U	0.09	0.11	0.06	0.09	0.07
1/2 U	0.08	0.05	0.03	0.06	0.04
1/4 U	0.05	0.02	0.02	0.04	0.01
1/6 U	0.02	0.02	0.00	0.00	0.00
1/8 U	0.00	0.00	0.00	0.00	0.00
1/10 U	0.00	0.00	0.00	0.00	0.00

c. 11 true-leaves stage

	Uptake rate (me/plant/day)[y]				
Treatment (U)[z]	**NO_3-N**	**PO_4-P**	**K**	**Ca**	**Mg**
1 U	0.07	0.04	0.05	0.05	0.06
1/2 U	0.01	0.02	0.01	0.03	0.02
1/4 U	0.00	0.00	0.00	0.00	0.00
1/6 U	0.00	0.00	0.00	0.00	0.00
1/8 U	0.00	0.00	0.00	0.00	0.00
1/10 U	0.00	0.00	0.00	0.00	0.00

[z]U (strength)

[y]Uptake rate was computed: amount of nutrient in the tank (me) [4th-6th day] / 12plants / 2 days.

The zero value means that the plants can no longer uptake the nutrient and the concentrations of the nutrient solution do not decrease further. Therefore, the critical concentration of each nutrient can be estimated using the average concentration of the nutrient solution which gave zero values in the uptake rate. From these results, we can estimate the critical uptake concentration of each element using the values obtained from the bigger sized plants grown in the treatment using lower nutrient concentration as a starting point.

The critical nutrient uptake concentrations of each element are compared between the results of the previous ascending method (Gonzalez et al 2010) and those of the present descending method (Table 3). In both methods, all the values are extremely low concentrations in comparison to common cultural sense. However, the values of PO_4-P, Ca and Mg in the present study were much lower than those of the previous result, while the values of NO_3-N and K are nearly the same in both methods.

From these data, there might be two groups of ions. For the first group (i.e. PO_4-P, Ca and Mg), the nutrient uptake is easily influenced by the surrounding solution concentration under steady feeding condition. For the second group (i.e. NO_3-N and K), the nutrient uptake is hardly affected by the surrounding solution concentration. It was suggested that the amount of nutrient solution per plant was influenced more strongly in the ascending method because it was about three times higher in the previous study. Therefore, the different values between the two methods can be minimized, if the amount of the solution per plant could be reduced properly. As sufficient amount of the solution was used in the commercial culture, a substantial critical uptake concentration of each ion for practical culture is considered to be near to those of the ascending method. However the value in the descending method is thought to be near to the real uptake ability of plants in view of plant physiology.

	Critical concentration (me/L)				
	NO_3-N	**PO4-P**	**K**	**Ca**	**Mg**
Ascending concentration[z]	0.01 - 0.02	0.2	0.05 - 0.10	0.4 - 0.50	0.10
Descending concentration	0.01 - 0.04	0.02 - 0.09	0.02 - 0.10	0.02 - 0.20	0.01 - 0.09

[z] Data from Gonzales et al. (2010).

Table 3. Comparison of the mineral element in the nutrient solution using ascending and descending nutrient concentration method.

CONCLUSION

The results from a previous study and the present results agree with the observation of Maruo and co-workers (2001, 2004) which demonstrated that the critical nutrient concentrations were much lower than those used in the commercial nutrient solution. The values of the critical nutrient concentration in the present study were lower than those found in Maruo's report for each element. The difference is due to an improved system used in this experiment which was able to obtain more accurate measurements for volume and the mineral element in the solution. The critical nutrient concentration in this study seems to be more precise and nearer to the real values. These findings suggest that cultivation using low nutrient concentration could be attained if each nutrient is properly supplied. Growers can not only save the use of fertilizer but by doing so, environmental impact can also be lowered.

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