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Effect of Concentration of Nutrient Solution on Vegetative Growth and Fruit Yield of Hydroponically Grown Tomato Plants

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Tomato (*Lycopersicon esculentum* Mill. cv. Ogatazuiko) plants were grown in low concentration (a quarter of the control levels) or control (full strength Yamasaki's tomato solution until 7 weeks, and then 1.5 fold strength). The EC of the low nutrient solution was adjusted daily to avoid deficiency of nutrient supply. There was significant reduction in leaf dry weight, stem dry weight, crop growth rate (CGR) and leaf area index (LAI) of plants grown in low nutrient solution after 6 weeks. These differences were present for the next 9 weeks. There were no significant differences in root dry weight, total number of fruits and early fruit yield, but the total fruit yield from plants grown in low nutrient solution was 32% less than that from the control plants. The relative amount of assimilate in the fruit and the net assimilation rate (NAR) of plants grown in low nutrient solution was significantly greater than the control plants from week 6 to week 12, however, it was less than the control plants at week 15. The concentration of nutrient solution had no effect on the P, Ca and Mg content in leaves, but the N and K content in leaves was significantly lower in plants grown in low nutrient solution than in control plants at week 15. The experiment showed that it is possible to control excessive vegetative growth without the loss of fruit yield by the use of a low concentration of nutrient solution (EC 0.7–0.9 dS/m) with the frequent supplementing of N and K after topping.

INTRODUCTION

It is known that hydroponics tend to provide conditions which promote rapid growth.[1,2] An increase of yield due to the decreased interval between planting and harvesting can be expected in leaf vegetables grown hydroponically. However, in the case of tomato, which is a fruit vegetable and requires a more specific balance between vegetative growth and reproductive growth, the rapid growth tends to lead to excessive vegetative growth. Under such conditions, the light transmission rate to the inner crop canopy is reduced and as a consequence fruit production and quality may be poor.[1,3,4]

For these reasons, growers have been trying to restrict the plant growth vigor of tomato by controlling the supply of water and nutrients in the soil. However, controlling the vigor of vegetative growth in hydroponics is very difficult, because of the continuous supply of water and nutrition.[1,5] Also, the potential of hydroponics as a means of controlling the vigor of vegetative growth has not yet been fully exploited and deserves further investigation.

A major factor in controlling the vigor of tomato plants grown hydroponically is

the concentration of the nutrient solution. When the concentration of nutrient solution is lower or higher than the standard solution, vegetative growth of tomato is restricted.[6,7] In Europe, growers adopted nutrient film technique (NFT) which restricted vigorous vegetative growth using a high concentration of nutrient solution.[5] In deep solution systems, however, the high concentration of the nutrient solution hinders root growth and may lead to severe damage to the plant.[6] Furthermore, management using high concentration of nutrient solutions brings about an increase in the cost of fertilizer and may also cause pollution of underground water after drainage.

In this experiment, the effect of low nutrient solution (a quarter of the control levels) in controlling excessive vegetative and fruit growth in tomato was investigated. The management of the nutrient solution which can restrict vegetative growth without reducing fruit yield is discussed.

MATERIALS AND METHODS

Seeds of the tomato cultivar 'Ogatazuiko' were sown in vermiculite on January 17, 1987 in a green house at the Agricultural and Forestry Research Center, University of Tsukuba. When the first true leaf appeared, seedlings were transferred to several 70 liter hydroponic containers ($82 \times 52 \times 18$ cm) for raising seedlings using one half strength Yamasaki's tomato solution. The composition of macro nutrient in Yamasaki's tomato solution was as follows: N 7 meq, P 2 meq, K 4 meq, Ca 4 meq and Mg 2 meq/liter. At the 5 true leaf stage, the seedlings were planted into 12 containers (70 liter volume) with 4 uniform plants each.

Two concentrations of the nutrient solution, a control (full strength Yamasaki's tomato solution) and low concentration (1/4 strength) were used from March 6 when the first flower buds appeared. The electrical conductivities (EC) of the nutrient solutions were maintained at 0.7 and 1.4 dS/m for the low concentration and control respectively until first truss began to develop (April 30). The EC of the tap water used for dilution was 0.3 dS/m. Then, the concentration of each nutrient solution was conventionally increased by 1.5 fold (low, 0.9 dS/m; control, 2.0 dS/m) after this stage. The pH of nutrient solution was maintained at 6.0–7.0 by adding H_2SO_4. The nutrient solution in each container was aerated using an air compressor. The electrical conductivity (EC) of the low nutrient solution was adjusted daily to avoid deficiency of nutrient supply. In the case of the control regimes, supplementary chemical applications were made to return the nutrient level to its original level after the nutrient solution had decreased 20% from the initial level.

The stem of each plant was detopped when there were the 2 leaves above the 6th truss, on May 12. Four plants were sampled every 3 weeks from March 27 to June 19 for measurements of leaf area and dry weight of each organ (leaf, stem, root, fruit). Leaf area was measured with an automatic area meter (Hayashi Denkoh Co., Ltd., Tokyo, Japan) and dry weights were determined after drying in a ventilated oven for 7 days at 70°C. Subsamples of dried leaves were ground and the N content was determined by the Kjeldahl method.[8] K, Ca and Mg content was measured by atomic absorption spectrophotometry (Spectrometer Model 170-10, Hitachi, Ltd., Tokyo, Japan). P content was determined by the vanadomolybdophosphoric yellow method.[9] Growth analysis was performed using the formulation by Hunt.[10] The experiment was terminated on June 19 when the fruits of the fifth truss had ripened.

Fluctuation of mineral element concentration in nutrient solution

The changes in the nutrient element concentrations in the nutrient solution are shown in Fig. 1. NO_3-N, K, Ca and Mg concentration in the control nutrient solution were always higher than those in the low concentration of nutrient solution. The NO_3-N concentration in the control nutrient solution was maintained above 5 meq except at the 14th week, but that in the low nutrient solution began to decrease from the 6th week, and then dropped below 0.2 meq even though the concentration of the nutrient solution was increased to 1.5 fold from the 7th week. Though K and Ca in the control nutrient solution sharply increased after increasing the nutrient solution concentration to 1.5 fold, they decreased rapidly at the 10th week and then became relatively stable. Mg in the control increased slowly after changing the concentration. The changes in K, Ca and Mg concentrations in the low nutrient solution were very small during the experimental period.

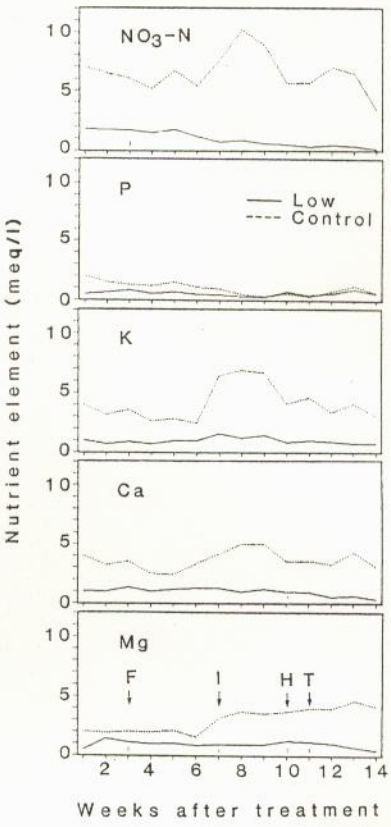

Fig. 1 Fluctuation of NO_3-N, P, K, Ca and Mg concentration in nutrient solution during the culture period.

F, beginning of flowering; I, concentration of nutrient solution was increased to 1.5 fold standard; H, beginning of harvest; T, detopping.

Vegetative growth

Leaf and stem growth in low nutrient solution was largely restricted and thin stems and small leaves were observed. Low nutrient solution significantly affected to the shoot vegetative growth, but not to the root growth (Fig. 2). From week 6 to week 15, dry weight of leaf and stem of low nutrient solution were 20–30% lower than in the controls, despite the fact that at week 3 there was no significant difference between both treatments.

Fruit growth and yield

Until week 12 fruit development (based on dry weight) was not affected by the concentration of nutrient solution. However, at the end of experimental period, fruit dry weight in low nutrient solution was significantly lower than that in the control plants (Fig. 2). Fruit number and fruit yield are shown in Table 1. There

Table 1 Effect of concentrations in the nutrient solution on the fruit number and yield in hydroponically grown tomato plants (Mean ± SD).[a]

Concentration of nutrient solution	Number of fruits				Fruit yield (kg. fresh wt./plant)		
	Small	Medium	Large[b]	Total	1–2 truss	3–5 truss	Total
Low	21.2	6.0	4.3	31.5	1.9	1.1	3.0
	(154)	(48)	(61)	(96)	(100)	(44)	(68)
Control	13.3	12.5	7.0	32.8	1.9	2.5	4.4
	(100)[c]	(100)	(100)	(100)	(100)	(100)	(100)
LSD $P=0.05$	2.7	1.8	n.s.	n.s.	n.s.	0.5	0.3

[a] Each value is the mean of 4 plants at 15 weeks after treatment.

[b] Small, below 100 g; Medium, between 100 and 200 g; Large, above 200 g (fresh weight).

[c] ( ), Relative value of number of fruit and fruit yield (control = 100).

was no significant difference in the total number of fruits and the number of large-sized fruits per plant. But, the number of medium-sized fruits of low nutrient solution was 52% less than the control plants, and the number of small size fruits was significantly greater. No significant difference in fruit yield of the first and second truss was noticed between the two regimes, however, the total fruit yield and fruit above the third truss in low nutrient solution was 32 and 64% lower than those in control plants.

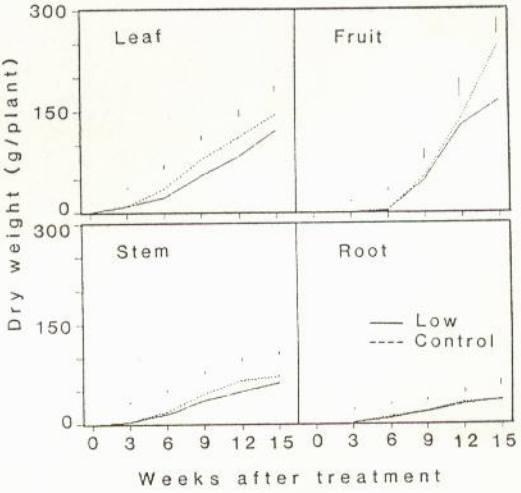

Fig. 2 Changes in tissue dry weight with time of tomato plants grown in 2 different concentration of nutrient solutions.

The vertical bars represent LSD values at $P=0.05$.

Growth analysis and partitioning of assimilate

From week 6 to week 15 (Table 2), crop growth rate (CGR) and leaf area index (LAI) of plants grown in low nutrient solution were significantly lower than those in control plants, but net assimilation rate (NAR) in low nutrient solution was higher than that in control plants except at the end of the experimental period. At the end of experimental period, CGR of plant grown in low nutrient solution had decreased with significant reduction of NAR.

By week 12 (Table 3), the relative amount of assimilate in the leaves and stems of plant grown in low nutrient solution was significantly less than that in control plants, whereas the relative amount of assimilate in the roots was significantly greater until week 15. The relative amount of assimilate in the fruit of plants grown in low nutrient solution was significantly greater than that in control plants from week 6 to week 12. However, it was significantly less than that in control plant at week 15.

Table 2 Effect of concentration of the nutrient solution on CGR, LAI and NAR in hydroponically grown tomato plants (Mean±SD).

Concentration of nutrient solution	WAT[a]	CGR[b] ($g/m^2/day$)	LAI[b] (m^2/m^2)	NAR ($g/m^2/day$)
Low	6– 9	5.10±0.13	2.64±0.05	1.93±0.06
	9–12	6.24±0.06	4.00±0.07	1.56±0.01
	12–15	5.36±0.31	4.94±0.04	1.08±0.04
Control	6– 9	6.54±0.06	3.82±0.08	1.71±0.01
	9–12	7.56±0.28	5.40±0.18	1.40±0.02
	12–15	7.84±0.20	6.45±0.02	1.22±0.03

[a] WAT, weeks after treatment.
[b] CGR, crop growth rate; LAI, leaf area index; NAR, net assimilation rate.

Table 3 Effect of concentration in the nutrient solution on dry matter partitioning in hydroponically grown tomato plants (Mean±SD).[a]

Concentration of nutrient solution	WAT[b]	Dry matter partitioning (%)			
		Fruit	Leaf	Stem	Root
Low	6	5.3±0.7	48.7±1.0	28.2±0.2	17.8±0.6
	9	29.7±0.5	36.8±1.0	21.6±0.6	11.9±0.6
	12	44.4±1.6	28.7±0.6	16.9±0.7	10.0±0.2
	15	43.0±0.2	30.4±0.4	14.8±0.2	9.5±0.4
Control	6	4.1±0.3	53.8±1.3	27.6±0.8	14.5±0.5
	9	26.2±0.7	40.4±1.0	23.8±0.5	9.6±0.6
	12	38.2±0.7	33.8±0.6	18.9±0.5	9.1±0.5
	15	49.6±0.7	28.9±0.6	14.6±0.5	6.9±0.2

[a] Each value is the mean of 4 plants. [b] WAT, weeks after treatment.

Table 4 Effect of concentration in the nutrient solution on N, P, K, Ca and Mg contents in leaves of tomato plants (Mean±SD).[a]

Concentration of nutrient solution	WAT[b]	N	P	K (% dry weight)	Ca	Mg
Low	9	2.56±0.10	0.43±0.03	3.63±0.39	2.66±0.32	0.86±0.14
	12	2.32±0.31	0.46±0.02	3.56±0.34	4.19±0.51	1.21±0.11
	15	1.62±0.15	0.63±0.08	1.72±0.14	3.93±0.24	1.12±0.09
Control	9	2.82±0.25	0.41±0.03	4.14±0.31	2.38±0.19	0.69±0.06
	12	2.62±0.11	0.47±0.03	4.48±0.14	4.23±0.19	1.09±0.04
	15	2.26±0.16	0.61±0.09	3.63±0.50	4.42±0.16	1.43±0.20

[a] Each value is the mean of 4 plants. [b] WAT, weeks after treatment.

Mineral element concentration in leaves

Table 4 shows the nutrient element concentrations in leaves in both treatments. The concentration of nutrient solution had no significant effect on the leaf P, Ca and Mg concentrations, while the N in leaves of plants grown in low nutrient solution was

17% lower than the control plants at the end of experiment. The concentration of K in leaves of plant grown in low nutrient solution began to decrease from the 12th week and was 53% lower as compared to the control regime at the 15th week.

DISCUSSION

In low nutrient solution (Fig. 1), the deficiency of NO_3-N was observed from week 6 to week 15, despite daily adjustments of the EC of the nutrient solution. This result is in agreement with the report of Takano,[11] which he suggested was because of ionic inbalance and depletion caused by rapid uptake of NO_3-N from the nutrient solution, even though the EC of the nutrient solution was constant. However, such ionic inbalance was not noticed in control plants. This means that the supply of each mineral element in control conditions was sufficient.

There are some reports that vegetative growth of tomato plants grown in low nutrient solutions was restricted.[5,6,12] In our experiment, a similar effect was observed from the flowering period of the third truss. Specifically, it was estimated that restriction of vegetative growth in low nutrient solution was influenced mainly by the low N concentration of nutrient solution, because the decrease in vegetative growth was correlated with N depletion of the solution. This result suggests that a low N concentration of nutrient solution is an important factor for controlling of vegetative growth of tomato plants grown in hydroponics.

Between weeks 6 and 12, the LAI in control plant was higher than that of low nutrient condition grown plants but, the NAR was lower (Table 2). In general, the photosynthesis rate is mainly influenced by light intensity, water and nutrition supply. However, from high production of dry matter in control plants (Fig. 2), it is unlikely that the low NAR in control plants could have been caused by the supply water and nutrition deficiency. Although direct measurements of light intensity were not made, the high LAI in control plants lead to poor light conditions of the inner canopy of tomato plants. Therefore, we could assume that low NAR in control plants could have caused a reduction in the light transmission rate to the inner canopy due to intershading of leaves. On the other hand, at the end of the experiment the NAR in low nutrient plants was greatly decreased and was lower than the control plants. Yoshida and Coronel[13] and Dejong[14] reported that there are close relationships between photosynthesis rate and the N content in leaves of rice and peach, respectively. As shown in Table 4, the N content in leaves of plants grown in low nutrient solution was significantly low. It was therefore explained that the low NAR in low nutrient condition grown plants at the end of the experiment was related to the N deficiency of the leaf.

According to Adams and Winsor,[15] K content in leaves and K uptake are affected by the N concentration rather than K concentration in peat. And Besford and Maw[16] indicated when the supply of K to tomato plant is restricted, the ion is preferentially utilized by the fruit at the expense of fully expended leaves, which rapidly lose K. In our experiments, although the K content of leaves in plants grown in low concentration of nutrient solution was 51% lower than that in the control plants at the end of experiment, the depletion of K in the nutrient solution was not observed. This might be due to the restriction of K uptake from roots and the intensive remobilization of K from leaves to fruits.

The fruit yield of tomato is related to the production of photo-assimilates and their partitioning to the fruits. In general, severe restriction of vegetative growth

reduces the fruit growth, because the total photo-assimilate was decreased. In our previous experiment, a similar result was observed, fruit yield was decreased with reduction of the leaf dry weight of tomato plants.[17] However, there were no significant differences in fruit yield when the leaf dry weight was only 20% restricted. In this experiment, a similar result was observed at week 12, when the leaf dry weight of low nutrient condition grown plants was 24% lower as compared to that in control plants, but there was no significant difference in fruit growth (Fig. 2). This result is explained by the higher photo-assimilate partitioning to the fruits (Table 3) and means that it is possible to control excessive vegetative growth without the loss of fruit yield in hydroponically grown tomato plants. Though many factors are related to the photo-assimilate partitioning to the fruit, it was reported that the K content in leaves is closely correlated to the photo-assimilate partitioning in sugarcane[18] and tomato plant.[19] According to data from experiments at the Glasshouse Crops Res. Inst., Littlehampton,[20] the critical K content for fruit growth of dried tomato leaves for normal fruit growth is 2.5%. In our experiment, at week 15, the K content in leaves in low nutrient plant was 1.76% and this value was significantly lower than the critical K content for fruit growth. It is therefore supposed that the low total fruit yield in plants grown in low concentration of nutrient solution could have been principally caused by the decrease of photo-assimilate partitioning rate by the K deficiency of leaves.

In conclusion, the low concentration of nutrient solution obtained the desired result for controlling excessive vegetative growth and early fruit yield of tomato plant in hydroponics; but not the total fruit yield, because of the N and K deficiency of leaves at the end of the experiment. Therefore, we suggest the strategy of controlling vegetative growth without loss of fruit yield of tomato as follows: use of low concentration of nutrient solution (EC 0.7–0.9 dS/m) supply from planting until topping and then, the supplementing of N and K frequently enough to prevent deficiency of these in leaves. It was obvious that the effect of low nutrient solution on controlling of excessive vegetative growth of tomato plant was mainly related to the N level of the nutrient solution. Therefore, an investigation of the controlling of plant vigor by low N of nutrient solution is needed.

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＜和文抄録＞

培養液濃度が水耕トマトの栄養生長ならびに果実収量に及ぼす影響

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トマト「大型瑞光」を標準濃度（EC 1.4→2.0 dS/m）とその 1/4 濃度（EC 0.7→0.9 dS/m）の培養液（山崎トマト処方培養液；定植後7週からはそれぞれ1.5倍とした）で栽培した．低濃度区は養分供給の不足を防ぐため毎日 EC を調整した．処理後6週から実験終了時まで，低濃度区は葉と茎の乾物重，CGR ならびに LAI の減少が認められた．根の乾物重，総果数および初期収量において，培養液濃度間の差はなかったが，総果実収量は低濃度区が標準濃度区にくらべ32%も低下した．処理後6週から12週の間で，NAR ならびに果実の乾物分配率は低濃度区で高かったが，処理後15週では標準濃度区より低かった．培養液濃度は葉中 P, Ca ならびに Mg 濃度には影響を与えなかったが，生育末期の葉中 N, K 濃度は低濃度区が標準濃度区より著しく減少した．トマトの水耕栽培においては，摘心後 N ならびに K の十分な追肥を行えば，低濃度（EC 0.7-0.9 dS/m）培養液によって果実収量を減少させずに水耕トマトの栄養生長をコントロールできることを示した．