J. Japan. Soc. Hort. Sci. 77 (2): 143–149. 2008.
Available online at www.jstage.jst.go.jp/browse/jjshs1
JSHS © 2008

Effect of Fertigation Management and the Composition of Nutrient Solution on the Yield and Quality of High Soluble Solid Content Tomatoes

Shahnaz Sarkar[1], Yoshikazu Kiriiwa[2], Masanobu Endo[2], Tomoya Kobayashi[2] and Akira Nukaya[2]*

[1]*The United Graduate School of Agricultural Science, Gifu University, Yanagido, Gifu 501–1193, Japan*
[2]*Faculty of Agriculture, Shizuoka University, Ohya, Suruga-ku, Shizuoka 422–8529, Japan*

The present experiment was conducted to clarify the effects of different fertigation systems (drip or sub fertigation) in combination with 2 formulae of nutrient solution (modified Enshi formulation or Shizudai tomato formulation) at EC 4 dS·m^{-1} on the response of "High soluble solid content tomato" grown in soilless culture systems from September, 2005 to February, 2006. The growth, total yield and size of fruit decreased in the sub fertigation system regardless of the nutrient solution formulation. On the other hand, the soluble solid content was higher in the sub fertigation system. Sub fertigation inhibited water uptake compared to drip fertigation. EC of the medium solution was higher in the sub than drip fertigation system, and higher with the Shizudai than the Enshi formulation. The highest and lowest EC values were 29.6 and 16.1 dS·m^{-1} in Sub × Shizudai and Drip × Enshi treatment, respectively. The matric potential of medium in the sub fertigation system was higher than that in the drip fertigation system. The proline concentration of leaves taken on November 17 and December 2 was higher in the sub than the drip fertigation system regardless of the nutrient solution formulation. Judging from the above results, growth and yield suppression in the sub fertigation system seems to be mainly caused by salinity stress, not by water stress.

Key Words: drip fertigation, proline, salinity stress, sub fertigation, water stress.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the most popular horticultural crops in the world. Recent studies on consumer habits regarding fresh vegetables have shown that taste and aroma are the most important factors in the selection of fresh produce (Dorais et al., 2000). Currently, there is an ever-increasing demand for high soluble solid content. The quality of tomato fruit is controlled by the interaction of genetic, environmental and cultural factors. Ho (1999) reported that improvement of fruit quality is an urgent issue for greenhouse growers who want to meet the ever-increasing demand of consumers in a highly competitive fresh fruit market. Water and salinity stresses have been applied to improve tomato fruit quality (Zushi et al., 2005). Salinity stress in the root zone is known to improve tomato fruit quality by increasing the Brix value (Adams, 1991; Adams and Ho, 1989; Cuartero and Fernandez-Munoz, 1999; Ehret and Ho, 1986). Differences of salinity sources in the nutrient solution also greatly influence tomato plant growth, and the development and quality of fruits. EC management is an important strategic tool (Auerswald et al., 1999; Li et al., 1999; Van Ieperen, 1996) for the production of good quality, with high sugar content, tomato fruits. In commercial farms in Japan, it is common to produce high quality tomatoes, the so-called high sugar content tomatoes or fruit tomatoes by the application of high EC nutrient solution, including NaCl, to induce stress or by restricting the amount of fertigation or the volume of substrate to apply water stress in soilless culture. Therefore, in the present study, two nutrient solution formulae as a source of salinity, namely the modified Enshi formulation, which consists of major nutrients, and the Shizudai formulation, which includes NaCl, $CaCl_2$, KCl, and $MgCl_2$ in addition to a basic nutrient solution, were used.

Meanwhile, the methods of fertigation also influenced the plant growth and fruit quality of tomatoes (Dorais et al., 2001; Incrocci et al., 2006; Santamaria et al., 2003). In drip fertigation system, it is common practice

Received; June 18, 2007. Accepted; October 10, 2007.
* Corresponding author (E-mail: abanuka@agr.shizuoka.ac.jp).

to give an excess amount of nutrient solution at a leaching fraction of 0.2 to 0.3, in order to keep the EC of the nutrient solution constant to avoid salt accumulation in the medium by flushing out salts not taken by crops (Incrocci et al., 2006; Santamaria et al., 2003). Compared with drip fertigation, sub fertigation apt to leads to salt accumulation in the growth medium, especially in the upper medium part of the pot (Molitor, 1990; Treder et al., 1999), since upward water movement by capillary force and evapo-transpiration-driven mass flow allows soluble salts to accumulate.

Variations such as the fertigation system and source of salinity may affect the growth and yield of tomatoes; however, there have been few reports on the influence of combinations of fertigation system and the source of salinity on the growth, yield and quality of tomatoes. Therefore, the present study was conducted to clarify the effect of fertigation management (drip fertigation and sub fertigation) and the composition of nutrient solution (Enshi formulation and Shizudai formulation) on the response of tomatoes grown in substrate culture using non-woven fabric pots filled with a small quantity of coir substrate.

In the present study, the intensity of salinity and water stress caused by treatments in the root environment was expressed as the EC of medium solution and matric potential of medium, respectively; however, it is difficult to compare the intensity between salinity and/or water stress. Recently, proline content in leaves has been considered a reliable indicator of the environmental stress imposed on plants (Claussen et al., 2004). Thus, the extent of stress intensity among treatments were also compared based on the proline content in leaves.

Materials and Methods

Tomato seeds 'House Momotaro' were sown in non-woven fabric pots (12 cm diameter, approximately 800 mL volume), which prevented root penetration from the pots. These pots were filled with fine coir dust, on September 14, 2005 after germinating at 25°C for 2 days and raised until the 6 true leaves stage. The pots were then placed in troughs (20 cm wide, 4 m long with 3 cm side walls), and covered by gray plastic film, with a spacing of 50 cm between pots and 80 cm between troughs. The treatments stated below were initiated on October 19, 2005, immediately after setting the pots on the trough. The experiment was conducted at Shizuoka University in a heated glasshouse in which inside minimum (heating) and ventilation air temperatures were 18°C and 23°C, respectively. Plants were grown vertically with a single stem and detopped at the 2nd upper leaf above the 4th truss on November 22, 2005. Flowers during anthesis were vibrated manually every day to ensure pollination. The number of fruits was adjusted to have 4 fruits per cluster at the appropriate time. Harvesting of the 1st cluster of fruits commenced on December 15 and terminated at the 3rd cluster on February 14, 2006.

Treatments consisted of a combination of 2 fertigation systems (sub fertigation and drip fertigation) and 2 kinds of nutrient solution (modified Enshi formulation, abbreviated to Enshi, and Shizudai tomato formulation, abbreviated to Shizudai, as shown in Table 1). Treatments were abbreviated to Drip × Enshi, Drip × Shizudai, Sub × Enshi, Sub × Shizudai as shown in Table 2. Both nutrient solutions were adjusted to an electrical conductivity (EC) of 4 $dS \cdot m^{-1}$ and pH of 6.0 to 6.7 when prepared. In the drip fertigation system with

Table 1. Composition of nutrient solutions.

Nutrient solution	EC ($dS \cdot m^{-1}$)	NO_3-N	P	S	Cl	K	Ca	Mg	Na
		($me \cdot L^{-1}$)							
Modified Enshi formulation (Enshi)	4	24	6	10	0	12	14	10	0
Shizudai tomato formulation (Shizudai)	4	12	3	9	16	10	10	9	9

Table 2. Effects of a combination of nutrient solution and fertigation system on the growth of tomatoes at the end of the experiment.

Treatment			Stem length (cm)	Stem diameter[z]		Fresh weight (g/plant)		
Fertigation system	Nutrient solution	Abbreviation		1st cluster	3rd cluster	Stem	Leaf	Stem + Leaf
Drip	Enshi	Drip × Enshi	132	16.1	11.2	157	381	538
Drip	Shizudai	Drip × Shizudai	136	15.1	10.2	174	438	612
Sub	Enshi	Sub × Enshi	134	16.5	11.6	123	217	339
Sub	Shizudai	Sub × Shizudai	125	15.9	9.9	119	157	276
Nutrient solution[y]			NS	*	**	NS	NS	NS
Fertigation system[y]			NS	NS	NS	***	***	***
Interaction			NS	NS	NS	NS	NS	NS

[z] Measured at the 1st leaf just below each cluster at flowering time.
[y] *, **, and *** means significantly different at 5%, 1%, and 0.1% level, by t-test, respectively and NS means not significant.

free drainage, the nutrient solution was distributed from a single reservoir tank for each treatment and was administrated through one emitter per pot, each having a flow rate of 25 mL per min. The leaching fraction (i.e. the ratio between drainage and fertigation volume) was around 0 to 0.05 and 0.1 to 0.2 in the first and second halves of the growing season, respectively. The drained solution was collected at the bottom end of each trough to measure the volume and to monitor the EC and pH every day. In the sub fertigation system, nutrient solution was distributed from a PVC tube (13 cm diameter, 4 m long) with 17 holes, 20 cm apart, which was laid along the trough wall with a flow rate of around 1 L/min/plant and collected in a 90 L recirculating tank.

The fertigation schedule was controlled by an operation timer and the nutrient solution was applied 21 times a day (mostly every 30 minutes) from 6:00 to 17:00, October 19 through November 8, and 20 times a day from 6:00 to 16:30, November 9 through February 14, 2006 in both systems. The duration of fertigation (30 to 180 seconds per time) was determined by daily manual operation according to weather conditions in order to apply the nutrient solution just before the leaves start showing wilting symptoms on the upper part of tomato plants. The amount of residual volume, the EC and pH of reservoir tanks in the drip fertigation system and those of recirculating tanks in the sub fertigation system were measured every day. The amount of water consumption was calculated every day by deducting the drained solution from the amount of applied nutrient solution. The nutrient solution in the tanks of both systems was refilled with full-strength original solution, as shown in Table 1, to compensate for crop water consumption every day. The nutrient solution in sub fertigation was renewed twice during the experiment on November 7 and December 8 and the EC finally reached 8.6 and 7.7 $dS \cdot m^{-1}$ in Enshi and Shizudai, respectively, at the end of the experiment (data not shown). A complete randomized block experimental design was adopted with 2 blocks for 4 treatments in Table 2. Each treatment consisted of 16 plants (8 plants per trough); thus, 64 plants were used for the whole experiment.

During the experiment, the diameter of the main stem just below the fruit clusters during each flowering time was measured. Stem length and the fresh weight of leaves and stems were measured at the end of the experiment. In addition to the weight and number of fruits harvested in due course in the ripening stage, the incidence of non-marketable fruit was also recorded. Soluble solid content of fruit juice of each cluster, squeezed by hand with cheesecloth, was determined with a hand refractometer (Model FR-100, Atago Co. Ltd., Japan). Major elements, Na and Cl contents, of fruit harvested in the 3rd cluster were measured by the method of Nukaya et al. (1977), after drying the fruit pulp at 80°C for 2 days in a ventilated oven.

In order to measure the stress level of plants, the proline concentration of the leaf lamina adjacent to the 1st cluster on November 2, the 1st and 2nd clusters on November 17, and the 1st to 3rd clusters on December 2 was measured as described by Bates et al. (1973). The matric potential of coir substrate in pots was measured by tensiometer (Model AG-T-200, Ishiguro Nozai Co. Ltd., Japan), which was buried 3 cm from the stem basis, at an interval of 5 minutes from December 9 to January 16, and the data were collected by a datalogger (Model 21x, Campbell Scientific, Inc., USA). Medium solutions were extracted using a porous cup buried in the pot and sucked up with a syringe during the night on December 27, December 28, January 12, and January 24, to measure the EC and major elemental contents.

All data were subjected to ANOVA and Scheffe's Multiple Range Test, as and when necessary.

Results

There was no significant interaction in stem length, stem diameter, fresh weight of stem and fresh weight of leaves among the treatments (Table 2). Stem length was not affected by treatments both before pinching and at the end of the experiment (data not shown). Stem diameter was significantly greater in Enshi than Shizudai formulation, regardless of the fertigation system. On the other hand, the fresh weight of stem and leaves was greater in the drip fertigation system than the sub fertigation system, regardless of the nutrient solution formulation. The flowering date of each cluster was not affected by the treatment (data not shown).

Fruit fresh weight was greatest in the Drip × Enshi and Drip × Shizudai (67 g for both systems), followed by Sub × Enshi (55 g), and then Sub × Shizudai (44 g), as shown in Table 3. Most of the fruits were classified as M size, between 40 and 80 g/fruit. The number of M size fruit was 7.9, 8.4, 6.8, and 7.1 fruit/plant in Drip × Enshi, Drip × Shizudai, Sub × Enshi and Sub × Shizudai, respectively; however, the number of S size fruits (less than 40 g) increased in the sub fertigation system and that of L size fruit (more than 80 g) increased in the drip fertigation system. As a result, total yield was significantly higher in the drip fertigation system (810 and 795 g/plant in Drip × Enshi and Drip × Shizudai, respectively) than in the sub fertigation system (592 and 489 g/plant in Sub × Enshi and Sub × Shizudai, respectively). Also, the number of fruits harvested per plant decreased in the sub fertigation system regardless of the nutrient solution formulation, because of a slightly higher occurrence of blossom end-rotted fruit. On the other hand, soluble solid content was higher in the sub fertigation system (11.0%) than in the drip fertigation system (10.0%). Also, it was affected by the nutrient solution formulation and was higher in Shizudai (10.7%) than in Enshi (10.3%). The highest value (11.2%) was observed in the Sub × Shizudai treatment, as shown in Table 3.

The root system was distributed throughout the pot

in the drip fertigation system, but existed only in the lower part of the pot in the sub fertigation system. The root volume and thickness were less in the sub fertigation system.

Water consumption per plant was almost the same among treatments from the first month to the middle of November; however, it then became lower in the sub fertigation system than in the drip fertigation system, and was especially lower in the Sub × Shizudai. The difference became apparent on November 20, and it then also decreased in the Sub × Enshi on December 5. Sub fertigation inhibited water consumption compared to the drip fertigation (Fig. 1).

Changes in the matric potential of the medium measured on a fine day in December 26 are shown in Figure 2, with a typical pattern of fluctuation. The matric potential in the sub fertigation system fluctuated between −0.5 and 0 kPa during the day time and was higher than that in the drip fertigation system between −2.0 and −0.8 kPa. From December 20 to January 16, the matric potential fluctuated between −2.0 (very occasionally −3.0) and −0.7 kPa in the drip fertigation system, although in the sub fertigation system it fluctuated between −1.5 and 0 kPa (data not shown).

The EC of the medium solution was higher in the sub than drip fertigation system, and higher in the Shizudai than in the Enshi formulation. The highest and lowest EC values were 29.6 and 16.1 $dS \cdot m^{-1}$ in Sub × Shizudai and Drip × Enshi treatment, respectively. The NO_3-N concentration was also higher in the sub fertigation system, and lower in the Shizudai formulation than in the Enshi formulation. The Na concentration was highest in Sub × Shizudai, followed by Drip × Shizudai, and lowest in both Drip × Enshi and Sub × Enshi treatments. K and Mg were higher with the sub than drip fertigation system. P and Ca were higher in the Enshi than Shizudai formulation, but were not affected by the fertigation system (Table 4).

Na and Cl in fruits tended to be higher in the Shizudai formulation than the Enshi formulation regardless of the fertigation system. NO_3-N and Mg were significantly higher in the sub fertigation system. P and K were not affected by the treatment.

The proline concentration of the leaves taken just below the first flower cluster on November 2 was not different among treatments; however, that on November 17 and December 2 was higher in the sub than drip fertigation system regardless of the nutrient solution

Table 3. Effect of a combination of nutrient solution and fertigation system on the yield of tomatoes at the end of the experiment.

Treatment	Total yield (g/plant)	Marketable yield (g/plant)	Number of fruit (number/plant)	Fruit fresh weight (g/plant)	Soluble solid content (%)
Drip × Enshi	810	802	11.8	67 a[z]	9.8
Drip × Shizudai	795	767	11.4	67 a	10.2
Sub × Enshi	592	561	9.9	55 b	10.8
Sub × Shizudai	489	482	11.2	44 c	11.2
Nutrient solution[y]	NS	NS	NS	—	**
Fertigation system[y]	***	***	*	—	***
Interaction	NS	NS	NS	**	NS

[z] Mean separation within columns by Scheffe's multiple range test, at 5% level.
[y] Same as Table 2.

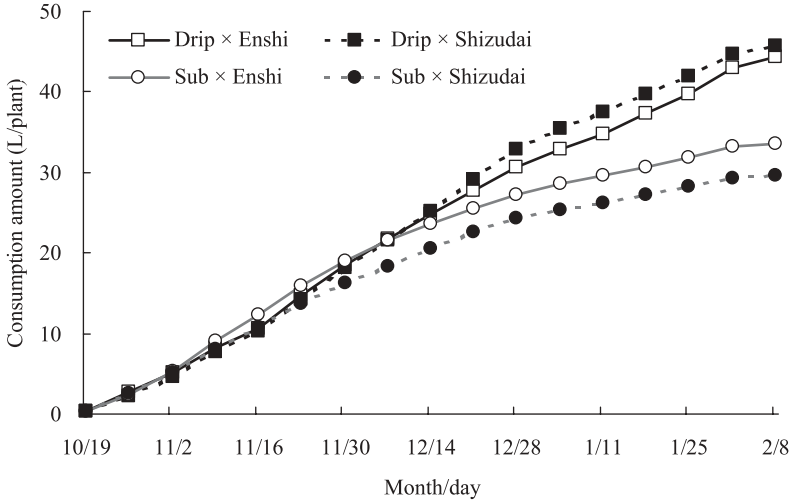

Fig. 1. Cumulative consumption of nutrient solution.

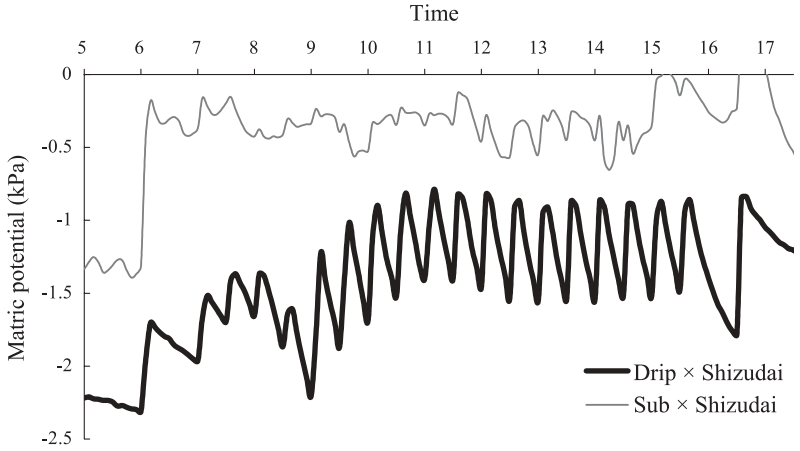

Fig. 2. Changes in matric potential of medium (December 26, fine day).

Table 4. Effect of a combination of nutrient solution and fertigation system on EC and the concentration of elemental contents in medium solution.

Treatment	EC ($dS \cdot m^{-1}$)	NO_3-N	P	K	Ca	Mg	Na
		($me \cdot L^{-1}$)					
Drip × Enshi	16.1[x]	173	7	57	37	86	5 c[z]
Drip × Shizudai	21.9	63	1	52	20	83	95 b
Sub × Enshi	22.5	218	11	71	32	129	6 c
Sub × Shizudai	29.6	90	3	68	26	145	145 a
Nutrient solution[y]	*	*	*	NS	*	NS	—
Fertigation system[y]	*	*	NS	*	NS	*	—
Interaction	NS	NS	NS	NS	NS	NS	***

[z] Same as Table 3.
[y] Same as Table 2.
[x] Average value of samples taken at December 27 and 28, January 12 and 24 (n = 3).

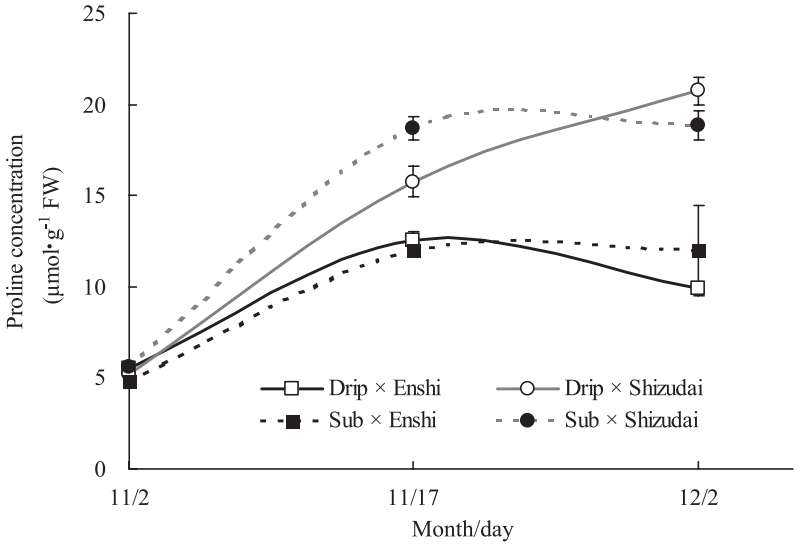

Fig. 3. Changes in the proline concentration of leaves attached below the 1st cluster.

formulation, as shown in Figure 3. The proline concentration, taken just below the first to third flowering cluster on November 2 was also higher in the sub than the drip fertigation system; that in the sub fertigation system increased with increasing cluster number, but that in the drip fertigation system was almost stable among sampling dates (data not shown).

So, the fertigation system significantly differed in leaf

proline content. No significant difference was found in the proline content of leaves supplying a different formulation of nutrient solution. But both (Drip and Sub) fertigation systems showed a high significant difference in the leaf proline content in tomato plants.

Discussion

It is widely believed that tomatoes grown under saline and/or water stress conditions bear higher quality fruits (Cuartero et al., 1999); however, quality varied with the cultural practice and also the composition of nutrient solution i.e. source of salinity.

With respect to cultural practices, Santamaria et al. (2003) observed that the yield of cherry tomato was lower with sub irrigation than with traditional free-drainage drip irrigation, but the quality was higher in sub irrigation. In contrast, Incrocci et al. (2006) reported no significant influence of irrigation methods on fruit yield and quality, when round tomatoes were cultivated by conventional drip irrigation or by sub irrigation in a closed system.

On the other hand, with respect to the source of salinity, major nutrients or NaCl may influence the yield and quality of tomatoes in a different manner, especially at higher (more than 10 $dS \cdot m^{-1}$) EC in soilless culture. Adams (1991) concluded that yield reduction with increasing salinity at 12 $dS \cdot m^{-1}$ by major nutrients, due to poorer vegetative growth resulting from deficiencies of Mg, B and Fe, was greater than that of NaCl, as reported previously for NFT (Adams and Ho, 1989; Ehret and Ho, 1986), and that this response is general, irrespective of the osmoticum used (Ho and Adams, 1989).

The present experiment revealed that the growth, yield and water consumption per plant were generally greater in the drip than the sub fertigation system, but the quality expressed as soluble solid content of fruit was higher in the sub than in the drip fertigation system, as reported by Santamaria et al. (2003). This increased soluble solid content in the sub fertigation system might be related to decreased fruit size, as shown in Table 3. Yield reduction in the sub fertigation system was caused by a reduction in fruit weight, but not in the number of fruits, as pointed out by Li et al. (2001) and Willumsen et al. (1996); however, growth and yield were not affected by the source of salinity, in contrast to the result of Adams (1991) and Ehret and Ho (1986). Increased soluble solid content with the Shizudai formulation was caused by not only the reduced size of the fruit, but also higher salinity stress expressed as EC and higher Na concentration in the root environment, as shown in Table 4. The results of sensory testing experiments reported by Dorais et al. (2000) and Peterson et al. (1998) showed that fruit from high EC-treated plants with NaCl enhanced the sensory evaluation of the sweetness of tomato fruit and improved the overall flavor intensity of tomato fruit. In the present experiment, the effect of a combination of fertigation management and the composition of nutrient solution on the sensory evaluation of fruit taste and quality was not investigated. Further investigation should be conducted to clarify this point.

Salinity stress expressed as EC of the medium solution (Table 4) was higher in the Shizudai than Enshi formulation, and to a much greater extent in the sub than drip fertigation system in the present experiment. Na concentration in medium solution was extremely higher in the Shizudai formulation. Incrocci et al. (2006) stated that, in sub irrigation treatment, salts, especially Na, tended to be concentrated in the upper layer and the reverse phenomenon was observed in drip irrigation treatment. On the other hand, the matric potential of the coir substrate in pots was determined by tensiometer to express water stress, as shown in Figure 2. The matric potential was always higher in the sub than in the drip fertigation system during the experiment. This means that water stress in the medium was always higher in the drip fertigation system. Judging from the above results of EC and the matric potential of medium, growth and yield suppression in the sub fertigation system seems to be mainly caused by salinity stress, but not by water stress.

However, it is difficult to compare the intensity of salinity and water stress, because the unit of such stress is different. Recently, an increase of proline has been shown in various plant parts when exposed to various

Table 5. Effect of a combination of fertigation methods and composition of nutrient solution on elemental contents in fruit (% of dry matter basis).

Treatment	NO_3-N	P	K	Ca	Mg	Na	Cl
Drip × Enshi	0.39	0.31	2.60	0.03	0.13	0.1 c[z]	0.12
Drip × Shizudai	0.41	0.27	2.42	0.01	0.14	0.2 b	0.80
Sub × Enshi	0.48	0.26	2.49	0.02	0.18	0.2 c	0.19
Sub × Shizudai	0.46	0.36	2.57	0.02	0.17	0.4 a	0.81
Nutrient solution[y]	NS	NS	NS	*	NS	—	***
Fertigation system[y]	**	NS	NS	NS	*	—	NS
Interaction	NS	NS	NS	NS	NS	*	NS

[z] Same as Table 3.
[y] Same as Table 2.

stresses (Hare et al., 1999). For instance, proline concentration was 10- and 18-fold in shoots and roots when plants were subjected to a nutrient solution containing 100 mM NaCl (Storey and Wyn Jones, 1975); therefore, proline should be a reliable indicator of the environmental stress imposed on plants, as reported by Claussen et al. (2004). In our experiment, the proline content of leaves was always higher in the sub than in the drip fertigation system, as shown in Figure 3. This result is highly correlated between the high EC of medium solution, and growth and yield suppression in the sub fertigation system induced by salinity stress. Zushi et al. (2005) concluded that, based on the proline and other amino acid contents of tomato fruit, changes in the physical responses were different between water stress and salinity stress, and salinity stress was more efficient than water stress to produce high quality tomato fruit; however, they determined the proline content of fruit only and did not discuss the stress intensity. Therefore, further investigation is also necessary to clarify the relationships among yield reduction, strength of salinity and water stress, and proline content.

Acknowledgement

We would like to thank Dr. M. Fazalur Rahman Mallick for his critical review of the manuscript and for correcting the English.

Literature Cited

Adams, P. 1991. Effects of increasing the salinity of the nutrient solution with major nutrients or sodium chloride on the yield, quality and composition of tomatoes grown in rockwool. J. Hort. Sci. 66: 201–207.

Adams, P. and L. C. Ho. 1989. Effects of constant and fluctuating salinity on the yield, quality and calcium status of tomatoes. J. Hort. Sci. 64: 725–732.

Auerswald, H., D. Schwarz, C. Kornelson, A. Krumbein and B. Bruckner. 1999. Sensory analysis, sugar and acid content of tomato at different EC values of the nutrient solution. Sci. Hort. 82: 227–242.

Bates, L. S., R. P. Waldren and I. D. Teare. 1973. Rapid determination of free proline for water-stress studies. Plant Soil 39: 205–207.

Cuartero, J. and R. Fernandez-Munoz. 1999. Tomato and salinity. Sci. Hort. 78: 83–125.

Claussen, W. 2004. Proline as a measure of stress in tomato plants. Plant Sci. 168: 241–248.

Dorais, M., A. P. Papadopoulos, G. Tucrotte, X. Hao, D. L. Ehret and A. Gosselin. 2000. Control of tomato fruit quality and flovour by EC and water management. Greenhouse Proc. Crops Res. Cent. Annu. Rep. 18–21.

Dorais, M., A. P. Papadopoulos and A. Gosselin. 2001. Influence of electric conductivity management on greenhouse tomato yield and fruit quality. Agronomie 21: 367–383.

Ehret, D. and L. C. Ho. 1986. The effects of salinity on dry matter partitioning and fruit growth in tomatoes grown in nutrient film culture. J. Hort. Sci. 61: 361–367.

Hare, P. K., W. Cress and J. van Staden. 1999. Proline synthesis and degradation: a model system for elucidating stress-related signal transduction. J. Exp. Bot. 50: 413–434.

Ho, L. C. and P. Adams. 1989. Effects of diurnal changes in the salinity of the nutrient solution on the accumulation of calcium in tomato fruit. Ann. Bot. 64: 373–382.

Ho, L. C. 1999. The physiological basis for improving tomato fruit quality. Acta Hort. 478: 33–40.

Incrocci, L., A. Malorgio, A. Della Bartola and A. Pardossi. 2006. The influence of drip irrigation or subirrigation on tomato grown in closed-loop substrate culture with saline water. Sci. Hort. 107: 365–372.

Li, J. H., M. Sagi, J. Gale, M. Volokita and A. Novoplansky. 1999. Response of tomato plants to saline water as affected by carbon dioxide supplementation. I. Growth, yield and fruit quality. J. Hort. Sci. Biotech. 74: 487–493.

Li, Y. L., C. Stanghellini and H. Challa. 2001. Effect of electrical conductivity and transpiration on production of greenhouse tomato (*Lycopersicon esculentum* L.). Sci. Hort. 88: 11–29.

Molitor, H. D. 1990. The European perspective with emphasis on subirrigation and recirculation of water and nutrients. Acta Hort. 272: 165–173.

Nukaya, A., M. Masui and A. Ishida. 1977. Salt tolerance of green soybeans. J. Japan. Soc. Hort. Sci. 46: 18–25.

Peterson, K. K., J. Willumsen and K. Kaack. 1998. Composition and taste of tomato as affected by increased salinity and different salinity sources. J. Hort. Sci. Biotech. 73: 205–215.

Storey, R. and R. G. Wyn Jones. 1975. Betaine and chlorine levels in plants and their relationships to NaCl stress. Plant Sci. 7: 161–168.

Santamaria, P., G. Campanile, A. Parente and A. Elia. 2003. Sub irrigation vs. drip-irrigation: effects on yield and quality of soilless grown cherry tomato. J. Hort. Sci. Biotech. 78: 290–296.

Treder, J., B. Matysuak and J. Nowak. 1999. The effects of ptting media and concentration of nutrient solution on growth and nutrient content of three Ficus species cultivated on ebb-and-flow benches. Acta Hort. 481: 433–439.

Van Ieperen, W. 1996. Effects of different day and night salinity levels on vegetative growth, yield and quality of tomato. J. Hort. Sci. 71: 99–111.

Willumsen, J., K. K. Petersen and K. Kaack. 1996. Yield and blossom-end rot of tomato affected by salinity and cation activity ratios in the root zone. J. Hort. Sci. 71: 81–98.

Zushi, K., N. Matsuzoe, S. Yoshida and J. Chikushi. 2005. Comparison of chemical composition contents of tomato fruit grown under water and salinity stresses. J. SHITA 17: 128–136 (In Japanese with English abstract).