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Research Report

Influence of Fertilizer Concentrations on the Performance of Seedling Grafts of Tomato Grown in Coir Based Root Media

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Abstract. The influence of various concentrations of the standard fertilizer on the performance of seedling grafts tomato was investigated using coconut coir containing root media. Two different formulations of coir dust (CO) with perlite (PL) and vermiculite (VM) (5:5 and 7:3 mixtures of CO + VM and CO + PL, v/v) were used as growing media. Five variations (0, 0.1, 1, 2, 4x conc.) of a standard fertilizer (SF) containing (mg·L^{-1}) 190 N, 54.5 P_2O_5, 149 K_2O, 542 CaO, 24.3 MgO, 19.5 S, and micronutrients in pre-plant fertilizers were used for seedling growth before grafting. The root stock (cultivar J3B Strong) and scion (cultivar Sunmyung) were grown in 50 cell (volume 33 cc) and 105 cell (volume 18 cc) trays, respectively. Both were fertilized once a week with the N concentrations of 50, 120, and 200 mg·L^{-1} (using 14-00-14 and 20-10-20 commercial analysis fertilizers alternately) in stages 2, 3, and 4, respectively. At 31 days after sowing, seedling plants of both the root stock and scion were excised above the soil line, trimmed, and used for seedling grafting. The cut grafted plants were planted into the 50-cell pack trays (cell volume 33 cc) and incubated for 7 days inside a plastic tunnel under a shade cloth for callusing and adventitious root formation. After an additional 7 days of gradual acclimatization with lower humidity, the rooted grafted plants began to receive fertilizer treatments once a week. When examined 31 days after sowing, the highest weights of the root stock seedlings were obtained with the 2x SF solution in CO + PL mix (4.1 g/seedling) and 1x SF solution in CO + VM mix (5.0 g/seedling). The electrical conductance (EC) of the soil extracts for the two treatments were 3.85 and 1.94 dS·m^{-1}, respectively. Fresh weights of the grafted plants (Sunmyung/J3B Strong) grown in CO + VM and CO + PL mixes were not significantly different from each other when measured 13 days after grafting. Elevated plug-phase fertilizer levels in CO + PL mix resulted in an increase of fresh weights from the grafted plants in 13 days. However, substrate EC (5.19 dS·m^{-1}) at 4x SF solution in CO+PL mix was much higher than that recommended for plug seedling production. Grafted plants were tolerant to high salinity. Fresh weights of grafted plants were higher when grown with 200 mg·L^{-1}N in CO + PL mix or 100 mg·L^{-1}N CO + VM mix than other treatments. The substrate ECs of the two treatments were 3.85 and 1.94 dS·m^{-1}, respectively. Grafted plants grew well when exposed to elevated substrate salt concentrations. Results of this experiment suggest that the production of high quality tomato seedling grafts is possible with salt concentrations much higher than that recommended for plug seedling production. The optimum fertilizer concentration, however, must be determined separately for a given root medium mixture containing coconut coir.

***Additional key words*:** cut grafting, grafted plug seedling, pre-plant fertilization

Introduction

The current concern for the growers in grafted seedling production of vegetables is the increased grafting efficiency. Since most of the grafting procedures of seedlings for vegetable crops are conducted by hand in Korea, the increase of efficacy in grafting would decrease the production cost (Lee, 1994, 2000). In order to increase the efficiency in the grafting process, growers cut the basal part of hypocotyl of the root stock before grafting to remove the root system. After grafting, the seedlings are planted into a rooting medium to induce the formation of the grafted union and the development of new adventitious roots from the basal part of root stock simultaneously (Ko et al., 2008; Lee, 2000). This requires that the root medium should have good in aeration and sterile. In addition, the physical and chemical properties of the growing media greatly affect the rooting procedure as well as the growth of the plug seedling after grafting.

Most of the greenhouse industries use soilless medium with proper soil physico·chemical properties for production of grafted seedlings. Growers generally alter the blending ratios of 2 to 3 kinds of constituent materials to adjust the physical properties of the root medium. However, in case of chemical properties, most of root medium constituents have low or unbalanced nutrient contents and fertilizers are incorporated during root medium formulations to adjust soil chemical properties of root medium. This is so called pre-planting fertilization (Argo, 1998; Choi et al., 2000; Nelson, 2003).

Pre-planting fertilizers influence the early growth of plug seedlings. The research results in levels of pre-planting fertilization and root medium for plug seedling growth can be found in various references (Handreck, 1996; Koranski, 1990; Nelson et al., 1996; Styer and Koranski, 1997). Yet, most of the previous research is related to plug seedling growth of floral crops, and it is difficult to find research results of the appropriate pre-planting fertilization levels in seedling production of fruit vegetables. Based on a survey in 2007, around 502 millions of seedling grafts for fruit vegetables are produced annually in Korea (Ko et al., 2008).

The major component of root media has been changed from peat moss to coir dust in the Korea because coir dust may not affect water holding capacity as compared to peat moss, but the price is low. However nutrient concentrations of coir dust are different from those of peat moss (Nelson, 2003). This difference implies that the recommendations of pre-planting fertilizers for seedling growth of general floral crops would not be suitable for the development of new adventitious roots and growth of seedling grafts. Yet limited research results are available for the pre-planting fertilization in production of seedling grafts.

We formulated root media by blending coir dust with perlite or vermiculite, then varied the levels of pre-planting fertilization. The objective of this research was to investigate the influence of pre-planting fertilizer levels in root media containing coir dust on the seedling growth of tomatoes before grafting, the formation of grafted union and the greenhouse acclimation.

Materials and Methods

Root Medium Formulations and Pre-planting Fertilization Levels

The coir dust processed in India (Symandy Co., India) and vermiculite or perlite imported from China and processed in Korea (Shinsung Minerals Co., Jincheon, Korea) were purchased. Then, two root media were formulated: coir : vermiculite (5:5, v/v) and coir : perlite (7:3, v/v). The reason of the differences in blending ratio of root medium components was to adjust physical properties of root media. The total porosity, container capacity, and air-filled porosity of coir : vermiculite (5:5) medium were 85.5, 78.9, and 6.60 %, respectively and those of coir : perlite (7:3) were 86.7, 80.7, and 9.59 %, respectively. During the blending process of root medium, 2.28 $g \cdot L^{-1}$ of dolomitic lime [$CaMg(Co_3)_2$], 0.63 $g \cdot L^{-1}$ of calcium carbonate ($CaCo_3$), and 0.9 $mL \cdot L^{-1}$ of the soil wetting agent Aquagro^{L} (Aquatrols Corp. of America, USA) were incorporated..

For the 1.0x treatment (standard fertilizer) in pre-planting fertilization, the fertilizers such as 0.303 g of 18-18-18, 0.015 g of $MgSO_4 \cdot 7H_2O$, 31 mg of $Na_2B_4O_7$, 3.1 mg of Fe-EDTA, 1.5 mg of Mn-EDTA, 0.9 mg of Zn-EDTA, 0.6 mg of KNO_3, 0.15 mg of $Na_2MoO_4 \cdot 2H_2O$, 3.1 mg of H_3PO_4, 0.202 g of KNO_3, and 2.28 g of $Ca(NO_3)_2 \cdot 4H_2O$ (Omex Agrifulids Co., Ltd. UK) were dissolved in water and sprayed on to 1L of root media. For 0.5x, 2.0x, and 4.0x fertilizations, half, two times, and four times as much of 1x treatment, respectively, were applied to the root media.

Plant Growth before Grafting

The 50-cell plug trays for root stock and 105-cell plug trays for scion were filled with root media containing the various levels of pre-planting fertilizers. Then, the seeds of root stock 'J3B Strong' and scion 'Sunmyung' (Nong Woo Seed Co., Ltd., Suweon, Korea) were sown. The trays were put in a germination room maintained at 27 to 28℃ in temperature and higher than 95% in relative humidity. When the cotyledons emerged, the trays were moved to a glasshouse. The average day and night temperatures during the seedling growth period were 30℃ and 20℃, respectively, with the highest temperature at 33℃ and the lowest temperature at 16℃.

The seedlings were fed with liquid fertilizers and the concentration of fertilizer solutions were controlled at 50 $mg \cdot L^{-1}$ N in plug stage 2, 120 $mg \cdot L^{-1}$ N in plug stage 3, and 200 $mg \cdot L^{-1}$ N in plug stage 4 from complete fertilizers of 14-00-14 and 20-10-20 (Planta Co., Ltd. CA, USA). The seedlings were fertilized once a week and two fertilizers were applied alternatively during the entire growing period. The fertilization and irrigation was monitored and the amount of water that drained through the drain hole was controlled to 30% of the plug tray's capacity (Ku and Hershey, 1991). At 31 days after sowing, the seedlings were measured and the root media were extracted for the analysis of chemical properties.

Plant Growth during the Formation of Graft Union after Grafting

The root medium formulations and pre-planting fertilizer levels were identical to those in the experiment for seedling growth before grafting. Each root medium containing pre-planting

fertilizers were filled into 50 cell plug trays with the appropriate packing densities and the grafted seedlings were planted on to the root media. The grafting methods and post-grafting care in controlling light intensity and humidity followed the methods described by Kang (2008).

The rate of light transmittance elevated gradually from 5 days to 7 days after grafting and the seedlings were cultivated under full sun light beginning 8 days after grafting. During these days, the humidity inside of the acclimation room also decreased to a normal state. All seedlings were fed with 200 $mg \cdot L^{-1}$ of 20-10-20 fertilizer at 8 days after grafting. The seedlings were investigated in growth and root media were extracted to analyze the chemical properties 13 days after grafting.

Growth of Grafted Seedlings during the Greenhouse Acclimation

All root media in this experiment contained equal amount of pre-planting fertilizers with 1x treatment and were filled into 50 cell plug trays. The grafted seedlings were planted to the plug trays and treated with same procedure mentioned in plant growth during the formation of graft union after grafting. The seedlings had been fertilized 8 days after grafting with four variations in fertilizer concentrations such as 0, 50, 100, and 200 $mg \cdot L^{-1}$ N from 14-0-14 and 20-10-20 ($N\text{-}P_2O_5\text{-}K_2O$) fertilizers. The seedlings were fed with fertilizers once a week and the both fertilizers were applied alternatively in post planting fertilization. In the fertilization and irrigation process, the amount of water that drained through the drain hole was controlled to 30% of the plug tray's capacity (Ku and Hershey, 1991). The seedling growth examination as well as soil analysis of root media was conducted 31 days after grafting.

Investigation of Seedling Growth and Analysis of Root Media

The seedlings were measured at 31 days after sowing to acquire the growth of before grafting, measured again at 13 and 31 days after grafting for those in the formation of the grafted union and in greenhouse acclimation, respectively. The methods in the investigation of seedling growth followed the methods described by Kang (2008).

The soil samples were also collected on the same days of growth measurement. The pH and EC of the root media were measured by the saturated paste method (Warncke, 1986). The concentrations of NH_4^+-N (Chaney and Marback, 1962), NO_3^--N (Cataldo et al., 1975), $P_2O_5^{-3}$ (Murphy and Riley, 1962) in the extracted solution were analyzed by colorimetric methods. The parts of the extracted solution were also used for analysis of K, Ca, Mg. The instruments used for nutrient analysis were a UV/Vis spectrophotometer (CE-5001, Cesil, England), an atomic absorption spectrophotometer (AA-680, Shimadzu, Japan), a pH meter (Fisher-20, USA) and an EC meter (Orion-50, USA).

Statistical Analysis

Data for growth measurements and soil analysis were subjected to a randomized complete block analysis of variances and the means were tested by an LSD test. Those were also subjected to polynomial regression analysis. The equations with the highest F values and incremental F values among linear and quadratic responses were used as best fit using the CoStat program (Version 6.3, CoHort Software, Monterey, CA).

Results

Measurements of seedling growth 31 days after sowing the tomato root stock, 'J3B Strong', are shown in Table 1. In raising the seedling in the CO + PL medium, plant heights and hypocotyls lengths did not show significant differences among pre-planting fertilization treatments. Seedling growth in the plant width, stem diameter, number of leaves, and fresh weight were the highest in the 2.0x treatment, but there were no statistical differences among the three treatments of the 1.0x, 2.0x, and 4.0x. In the case of seedling growth in CO + VM , the fresh weight of 1.0x treatment was the heaviest followed by those of 2.0x and 4.0x treatments.

When comparing the fresh weight productions between the two root media, the fresh weights in all of the pre-planting treatments of CO + PL medium were in the ranges of 1.35 to 4.07g while those in the CO + VM were in the 2.26-5.02g and raising seedlings in the medium containing the vermiculite (VM) performed better than that containing perlite (PL). The differences between the two media based upon plant width, number of leaves, and fresh weights were significant.

The chemical properties of root media determined 31 days of sowing are shown in Table 2. The electrical conductivities in all treatments of CO + PL and CO + VM were in the ranges of 2.21 to 2.89 $dS \cdot m^{-1}$ and 2.01 to 2.51 $dS \cdot m^{-1}$, respectively, and the difference between two root media was significant. The potassium concentrations in the CO + PL medium were in the ranges of 237 to 341 $mg \cdot L^{-1}$ and those in the CO + VM medium were in 44.7 to 79.3 $mg \cdot L^{-1}$ range. The differences were statistically significant ($p \leq 0.001$). However, the concentrations of sodium in the CO + PL medium were much lower than those of the CO + VM medium ($p \leq 0.001$). The elevation of blending ratio in coir dust and vermiculite in the formulation of root medium increased the potassium and sodium concentrations, respectively, in soil solutions of root media.

Table 1. Growth characteristics of tomato root stock 'J3B Strong' 31 days after sowing in 50 plug tray as influenced by various pre-planting fertilizer levels and root media.

Root media[z]	PPFL[y]	Plant height (cm)	Plant width (cm)	Hypocotyl length (cm)	Stem diameter (mm)	Number of leaves	Fresh weight (g/plant)
CO + PL	0.0	7.5 a[x]	8.9 c	3.40 a	2.53 b	3.0 c	1.35 c
	0.5	10.0 a	11.8 b	3.53 a	2.78 b	3.6 b	2.49 b
	1.0	10.9 a	14.8 a	3.67 a	3.47 a	4.1 a	3.85 a
	2.0	10.3 a	15.0 a	3.67 a	3.50 a	4.1 a	4.07 a
	4.0	8.8 a	13.6 ab	3.56 a	3.42 a	3.9 ab	3.94 a
Regression		NS	Q***	NS	Q***	Q***	Q***
CO + VM	0.0	7.6 c	9.7 c	3.44 a	2.85 a	3.7 b	2.26 d
	0.5	7.3 c	10.2 bc	3.68 a	4.01 a	3.7 b	2.87 c
	1.0	10.3 ab	13.0 a	3.46 a	3.46 a	4.0 ab	5.02 a
	2.0	11.2 a	11.2 b	3.44 a	3.36 a	4.4 a	4.46 b
	4.0	9.4 b	13.3 a	3.70 a	3.09 a	4.3 a	4.13 b
Regression		Q***	Q***	NS	NS	Q***	L***
F-test Root media		NS	*	NS	NS	*	*

[z]CO + PL: coir dust + perlite (7:3, v/v), CO + VM: coir dust + vermiculite (5:5).
[y]PPFL: pre-planting fertilizer level; The 1.0x treatments contained (1 L of root media) 0.303 g of 18-18-18, 0.015 g of $MgSO_4 \cdot 7H_2O$, 31 mg of $Na_2B_4O_7$, 3.1 mg of Fe-EDTA, 1.5 mg of Mn-EDTA, 0.9 mg of Zn-EDTA, 0.6 mg of KNO_3, 0.15 mg of $Na_2MoO_4 \cdot 2H_2O$, 3.1 mg of H_3PO_4, 0.202 g of KNO_3, and 2.28 g of $Ca(NO_3)_2 \cdot 4H_2O$. For 0.5x, 2.0x, and 4.0x fertilizations, half, two times, and four times as much of 1x treatment, respectively, were applied to the root media.
[x]Mean separation within columns for each root media by DMRT at $P \leq 0.05$.
[NS,Q,L]Nonsignificant, linear, quadratic, significance in trends of regression or in F-test: ***$P \leq 0.001$, *$P \leq 0.05$.

Table 2. The characteristics in soil chemical properties of various root media 31 days after sowing tomato root stock 'J3B Strong' in 50 plug tray as influenced by pre-planting fertilizer levels.

Root media[z]	PPFL[y]	EC ($dS \cdot m^{-1}$)	pH	NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg	Na
				($mg \cdot L^{-1}$)						
CO + PL	0.0	2.21 e[x]	6.2 c	81 e	16.0 b	104 c	320.8 b	4.5 d	8.3 d	262 c
	0.5	2.40 d	6.7 b	142 d	23.2 a	194 a	241.7 d	6.9 c	10.0 c	226 c
	1.0	2.57 c	6.7 b	181 c	22.4 a	159 b	237.6 d	7.5 bc	14.2 b	205 b
	2.0	2.76 b	7.1 a	288 b	17.2 b	164 ab	273.2 c	8.6 b	14.2 b	260 a
	4.0	2.89 a	7.2 a	466 a	16.4 b	120 c	341.0 a	12.5 a	26.6 a	440 a
Regression		Q***	L***	Q***	NS	Q*	Q***	L***	Q***	Q***
CO + VM	0.0	2.01 e	6.81 d	61 d	10.4 c	75 b	79.3 a	5.7 e	7.9 e	476 a
	0.5	2.14 d	6.89 c	163 c	10.4 c	146 a	44.7 e	7.1 d	9.1 d	349 d
	1.0	2.22 c	7.09 b	177 b	17.7 a	153 a	51.9 d	12.4 c	11.7 c	340 d
	2.0	2.34 b	7.21 a	240 a	13.0 b	129 a	53.5 c	12.7 b	12.2 b	385 c
	4.0	2.51 a	7.16 a	249 a	10.4 c	130 a	56.3 b	18.7 a	13.4 a	401 b
Regression		Q***	Q***	L***	NS	NS	Q*	Q***	L***	Q*
F-test Root media		***	*	NS	**	NS	***	*	*	***

[z]CO + PL: coir dust + perlite (7:3, v/v), CO + VM: coir dust + vermiculite (5:5).
[y]PPFL: pre-planting fertilizer level; The 1.0x treatments contained (1 L of root media) 0.303 g of 18-18-18, 0.015 g of $MgSO_4 \cdot 7H_2O$, 31 mg of $Na_2B_4O_7$, 3.1 mg of Fe-EDTA, 1.5 mg of Mn-EDTA, 0.9 mg of Zn-EDTA, 0.6 mg of KNO_3, 0.15 mg of $Na_2MoO_4 \cdot 2H_2O$, 3.1 mg of H_3PO_4, 0.202 g of KNO_3, and 2.28 g of $Ca(NO_3)_2 \cdot 4H_2O$. For 0.5x, 2.0x, and 4.0x fertilizations, half, two times, and four times as much of 1x treatment, respectively, were applied to the root media.
[x]Mean separation within columns for each root media by DMRT at $P \leq 0.05$.
[NS,Q,L]Nonsignificant, linear, quadratic, significance in trends of regression or in F-test: ***$P \leq 0.001$, *$P \leq 0.01$.

Table 3. Growth characteristics of tomato scion 'Sunmyung' 31 days after sowing in 105 plug tray as influenced by various pre-planting fertilizer levels and root media.

Root media[z]	PPFL[y]	Plant height (cm)	Plant width (cm)	Hypocotyl length (cm)	Stem diameter (cm)	Number of leaves	Fresh weight (g/plant)
CO + PL	0.0	4.1 c[x]	5.7 d	3.08 c	2.14 c	3.0 c	0.68 d
	0.5	5.2 b	8.6 c	3.38 ab	2.61 b	3.5 b	1.44 c
	1.0	6.0 a	9.6 b	3.39 ab	3.01 a	3.9 a	2.24 b
	2.0	6.2 a	10.7 a	3.56 a	3.15 a	3.8 ab	2.78 a
	4.0	6.3 a	10.5 a	3.29 bc	3.01 a	3.9 a	2.44 ab
Regression		L***	L***	Q***	Q***	L***	Q***
CO + VM	0.0	6.4 b	7.3 d	3.57 ab	2.45 d	3.3 b	1.49 c
	0.5	6.2 b	5.5 e	2.77 c	2.41 d	3.1 b	1.50 c
	1.0	6.8 b	8.3 c	3.84 a	2.95 c	3.9 a	2.31 b
	2.0	7.9 a	10.0 b	3.36 b	3.11 b	3.6 ab	2.32 b
	4.0	6.7 b	14.3 a	3.49 b	3.54 a	3.6 ab	3.19 a
Regression		Q*	L***	NS	L***	NS	L***
F-test Root media		***	NS	NS	NS	NS	NS

[z]CO + PL: coir dust + perlite (7:3, v/v), CO + VM: coir dust + vermiculite (5:5).
[y]PPFL: pre-planting fertilizer level; The 1.0x treatments contained (1 L of root media) 0.303 g of 18-18-18, 0.015 g of $MgSO_4 \cdot 7H_2O$, 31 mg of $Na_2B_4O_7$, 3.1 mg of Fe-EDTA, 1.5 mg of Mn-EDTA, 0.9 mg of Zn-EDTA, 0.6 mg of KNO_3, 0.15 mg of $Na_2MoO_4 \cdot 2H_2O$, 3.1 mg of H_3PO_4, 0.202 g of KNO_3, and 2.28 g of $Ca(NO_3)_2 \cdot 4H_2O$. For 0.5x, 2.0x, and 4.0x fertilizations, half, two times, and four times as much of 1x treatment, respectively, were applied to the root media.
[x]Mean separation within columns for each root media by DMRT at $P \leq 0.05$.
[NS,Q,L]Nonsignificant, linear, quadratic, significance in trends of regression or in F-test: ***$P \leq 0.001$, *$P \leq 0.05$.

As shown in Table 3, the fresh weight 31 days after sowing of scion 'Sunmyung' increased until the pre-planting fertilization levels elevated to 2.0x, then but decreased in 4.0x treatment of pre-planting when the seedlings were grown in the CO + PL medium. The seedling growths in fresh weight productions, plant widths and stem diameters increased lineally as the pre-planting fertilizer levels were elevated 4.0x in the CO + VM medium. Even though hypocotyls lengths and number of leaves were different among treatments of pre-planting fertilizer levels, trends were not observed in the CO + VM medium.

The results of soil analysis 31 days after sowing of scion 'Sunmyung' were shown in Table 4. The ECs in all treatments of the CO + PL medium were included in 1.47-3.12 $dS \cdot m^{-1}$ which were much higher than 1.06-1.97 $dS \cdot m^{-1}$ measured in the CO + VM medium. The differences in EC of two root media were significant at $p \leq 0.001$ in an F-test. The elevation of pre-planting fertilizer levels in the CO + PL medium resulted in the linear increase in concentrations of NO_3^--N, K, Ca, Ma and Na and the quadratic decrease of PO_4-P concentration. The elevation of pre-planting fertilizer levels in the CO + VM medium resulted in a linear increase of EC, pH and Na concentrations and a quadratic increase in the concentrations of K, Ca, Mg. But the elevation of pre-planting fertilizer levels decreased the PO_4-P concentrations in the soil solution of the CO + VM medium. Except the NO_3-N, significant differences were observed between CO + PL and CO + VM media in EC, pH and the concentrations of NH_4-N, PO_4-P, K, Ca, Mg, Na.

The growth of grafted seedlings ('Sunmyung'/'J3B Strong') as influenced by pre-planting fertilizer levels in two root media were investigated 13 days after grafting and are shown in Table 5. The treatments of pre-planting fertilizer levels, in which the plant height was the highest, were 2.0x and 4.0x for the CO + PL medium and 4.0x for the CO + VM medium. The plant widths, stem diameters, and fresh weights also showed similar tendencies.

The chemical properties of root media analyzed 13 days after grafting are shown in Table 6. The ECs were in the range of 3.31-5.19 $dS \cdot m^{-1}$ for the CO + PL and 3.96-5.13 $dS \cdot m^{-1}$ for the CO + VM media. In each medium, the elevation of the pre-planting fertilization levels resulted in an increased of EC, but the difference between the two root media were not significant.

The growth characteristics of grafted seedlings, 'Sunmyung'/'J3B Strong', 31 days after grafting are shown in Table 7. In this experiment, after grafting, seedlings were planted into two kinds of root media in which pre-planting fertilizer levels

Table 4. The characteristics in soil chemical properties of various root media 31 days after sowing of tomato scion 'Sunmyung' in 105 plug tray as influenced by pre-planting fertilizer levels.

Root media[z]	PPFL[y]	EC ($dS \cdot m^{-1}$)	pH	NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg	Na
							($mg \cdot L^{-1}$)			
CO + PL	0.0	1.47 e[x]	6.8 d	7 c	16.2 ab	141 a	9 d	0.8 e	2.03 d	215 d
	0.5	1.87 c	7.0 c	44 b	11.5 c	112 a	127 c	0.9 d	2.71 c	333 c
	1.0	1.85 d	7.3 b	51 b	13.3 c	66 b	218 b	1.7 c	4.54 b	377 b
	2.0	3.12 b	7.4 a	54 b	17.4 a	66 b	225 ab	2.1 b	5.65 a	391 b
	4.0	3.21 a	7.3 ab	183 a	14.2 ab	78 b	234 a	2.6 a	5.79 a	464 a
Regression		L***	Q***	L***	NS	Q***	L***	L***	L***	L***
CO + VM	0.0	1.06 e	7.2 c	34 e	19.7 a	317 a	34 b	16.4 b	6.53 b	262 b
	0.5	1.11 d	7.4 b	44 d	21.9 a	300 b	34 b	12.8 c	5.79 c	226 b
	1.0	1.34 c	7.3 b	74 c	17.9 a	242 c	29 d	8.5 e	5.19 d	205 c
	2.0	1.50 b	7.4 b	92 b	19.2 a	246 c	30 c	12.0 d	6.12 c	260 c
	4.0	1.97 a	7.5 a	340 a	20.1 a	197 d	41 a	24.9 a	8.07 a	440 a
Regression		L***	Q***	L***	NS	Q***	Q***	Q***	Q***	L***
F-test Root media		***	*	NS	**	***	***	***	***	***

[z]CO + PL: coir dust + perlite (7:3, v/v), CO + VM: coir dust + vermiculite (5:5).
[y]PPFL: pre-planting fertilizer level; The 1.0x treatments contained (1 L of root media) 0.303 g of 18-18-18, 0.015 g of $MgSO_4 \cdot 7H_2O$, 31 mg of $Na_2B_4O_7$, 3.1 mg of Fe-EDTA, 1.5 mg of Mn-EDTA, 0.9 mg of Zn-EDTA, 0.6 mg of KNO_3, 0.15 mg of $Na_2MoO_4 \cdot 2H_2O$, 3.1 mg of H_3PO_4, 0.202 g of KNO_3, and 2.28 g of $Ca(NO_3)_2 \cdot 4H_2O$. For 0.5x, 2.0x, and 4.0x fertilizations, half, two times, and four times as much of 1x treatment, respectively, were applied to the root media.
[x]Mean separation within columns for each root media by DMRT at $P \leq 0.05$.
[NS,Q,L]Nonsignificant, linear, quadratic, significance in trends of regression or in F-test: ***$P \leq 0.001$, *$P \leq 0.01$.

Table 5. Growth characteristics of tomatos ('Sunmyung'/ 'J3B Strong') 13 days after cut grafting in 50 plug tray as influenced by various pre-planting fertilizer levels.

Root media[z]	PPFL[y]	Plant height (cm)	Plant width (cm)	Hypocotyl length (cm)	Stem diameter (cm)	Number of leaves	Fresh weight (g/plant)
CO + PL	0.0	13.4 c[x]	6.3 c	3.02 a	2.54 d	4.7 c	0.99 d
	0.5	14.9 b	10.3 a	3.05 a	2.92 c	5.1 ab	1.92 c
	1.0	15.3 b	9.3 b	3.23 a	3.20 b	5.3 ab	2.28 b
	2.0	16.6 a	10.2 a	3.20 a	3.41 a	5.0 bc	2.65 a
	4.0	16.9 a	10.3 a	3.06 a	3.48 a	5.4 a	2.81 a
Regression		Q***	L***	NS	Q***	L**	Q***
CO + VM	0.0	10.2 d	7.2 d	2.79 b	3.00 c	5.2 a	1.32 d
	0.5	10.5 d	8.4 c	2.68 b	3.00 c	5.4 a	1.64 c
	1.0	14.3 c	11.0 b	2.92 ab	3.35 b	5.5 a	2.63 b
	2.0	15.7 b	12.5 a	3.08 a	3.36 b	5.6 a	2.88 a
	4.0	17.1 a	12.4 a	3.07 a	3.63 a	5.7 a	2.74 ab
Regression		L***	L***	Q**	L***	NS	Q***
F-test Root media		***	*	***	*	***	NS

[z]CO + PL: coir dust + perlite (7:3, v/v); CO + VM: coir dust + vermiculite (5:5).
[y]PPFL: pre-planting fertilizer level; The 1.0x treatments contained (1 L of root media) 0.303 g of 18-18-18, 0.015 g of $MgSO_4 \cdot 7H_2O$, 31 mg of $Na_2B_4O_7$, 3.1 mg of Fe-EDTA, 1.5 mg of Mn-EDTA, 0.9 mg of Zn-EDTA, 0.6 mg of KNO_3, 0.15 mg of $Na_2MoO_4 \cdot 2H_2O$, 3.1 mg of H_3PO_4, 0.202 g of KNO_3, and 2.28 g of $Ca(NO_3)_2 \cdot 4H_2O$. For 0.5x, 2.0x, and 4.0x fertilizations, half, two times, and four times as much of 1x treatment, respectively, were applied to the root media.
[x]Mean separation within columns for each root media by DMRT at $P \leq 0.05$.
[NS,Q,L]Nonsignificant, linear, quadratic, significance in trends of regression or in F-test: ***$P \leq 0.001$, *$P \leq 0.01$.

Table 6. The characteristics in soil chemical properties of various root media 13 days after cut grafting of tomato ('Sunmyung'/ 'J3B Strong') in 50 plug tray as influenced by pre-planting fertilizer levels.

Root media[z]	PPFL[y]	EC ($dS \cdot m^{-1}$)	pH	NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg	Na
							($mg \cdot L^{-1}$)			
CO + PL	0.0	3.31 e[x]	6.5 d	25 b	16.8 a	275 a	350 b	9.9 a	3.7 b	358 d
	0.5	3.56 d	6.5 d	28 b	11.1 b	257 a	345 b	10.2 a	3.2 c	459 b
	1.0	4.20 c	6.6 c	30 b	8.8 bc	151 b	409 a	9.9 a	3.6 b	524 a
	2.0	4.22 b	6.9 b	31 ab	7.8 bc	131 b	283 c	6.9 b	1.9 d	393 c
	4.0	5.19 a	7.0 a	39 a	7.2 c	157 b	269 c	10.0 a	4.8 a	389 c
Regression		L***	L***	L***	Q***	Q***	L**	NS	Q**	NS
CO + VM	0.0	3.96 d	6.9 b	30 c	10.4 b	163 a	50 d	10.0 b	3.6 d	437 b
	0.5	3.95 e	6.7 c	31 c	11.3 b	116 b	60 b	12.1 a	6.7 b	388 c
	1.0	4.22 c	7.0 b	35 b	12.1 ab	115 b	64 a	12.2 a	8.0 a	260 e
	2.0	4.48 b	7.0 b	38 b	14.3 a	131 ab	65 a	9.8 b	5.1 c	333 d
	4.0	5.13 a	7.2 a	66 a	11.7 b	138 ab	53 c	7.9 c	3.4 d	515 a
Regression		Q***	L**	L***	Q**	NS	Q***	Q***	Q*	Q***
Root media		NS	***	***	NS	**	***	NS	**	**

[z]CO + PL: coir dust + perlite (7:3, v/v), CO + VM: coir dust + vermiculite (5:5).
[y]PPFL: pre-planting fertilizer level; The 1.0x treatments contained (1 L of root media) 0.303 g of 18-18-18, 0.015 g of $MgSO_4 \cdot 7H^2O$, 31 mg of $Na_2B_4O_7$, 3.1 mg of Fe-EDTA, 1.5 mg of Mn-EDTA, 0.9 mg of Zn-EDTA, 0.6 mg of KNO_3, 0.15 mg of $Na_2MoO_4 \cdot 2H^2O$, 3.1 mg of H_3PO_4, 0.202 g of KNO_3, and 2.28 g of $Ca(NO_3)_2 \cdot 4H_2O$. For 0.5x, 2.0x, and 4.0x fertilizations, half, two times, and four times as much of 1x treatment, respectively, were applied to the root media.
[x]Mean separation within columns for each root media by DMRT at $P \leq 0.05$.
[NS,Q,L]Nonsignificant, linear, quadratic, significance in trends of regression or in F-test: ***$P \leq 0.001$, *$P \leq 0.01$.

Table 7. Growth characteristics of tomato 31 days after cut grafting ('Sunmyung'/ 'J3B Strong') in 50 plug tray as influenced by post-planting fertilizer levels. The grafted seedlings were moved to a greenhouse after the formation of a successful union and were fertigated with various fertilizer concentrations during greenhouse acclimation.

Root media[z]	FC[y] ($mg \cdot L^{-1}$)	Plant height (cm)	Plant width (cm)	Hypocotyl length (cm)	Stem diameter (cm)	Number of leaves	Fresh weight (g/plant)
CO + PL	0	13.4 c[x]	15.1 ab	4.10 b	3.19 b	6.1 b	3.68 b
	50	15.4 a	13.9 b	4.13 b	3.33 b	6.2 b	4.21 ab
	100	13.8 bc	15.7 a	5.25 a	3.58 a	6.2 a	4.48 a
	200	14.8 ab	15.8 a	5.51 a	3.58 a	6.2 a	4.38 a
CO + VM	0	20.7 c	17.4 b	4.58 ab	3.24 d	6.2 a	6.06 b
	50	21.5 b	20.6 a	3.75 b	3.41 c	6.1 a	7.12 a
	100	23.3 a	17.4 b	4.21 ab	3.80 a	6.2 a	7.13 a
	200	19.5 d	16.2 b	4.66 a	3.58 b	6.2 a	5.28 c
F-test Root media		***	***	*	NS	NS	***

[z]CO + PL: coir dust + perlite (7:3, v/v), CO + VM: coir dust + vermiculite (5:5); All root media contained an equal amount of pre-planting fertilizers with 1.0X treatment.
[y]FC: fertilizer concentration; The seedlings had been fertilized once a week since 8 days after grafting based on N concentrations from 14-0-14 and 20-10-20 ($N\text{-}P_2O_5\text{-}K_2O$) fertilizers. The both fertilizers were applied alternatively.
[x]Mean separation within columns for each root media by DMRT at $P \leq 0.05$.
[NS,Q,L]Nonsignificant, linear, quadratic, significance in trends of regression or in F-test: ***$P \leq 0.001$, *$P \leq 0.05$.

were fixed to 1.0x and post planting fertilizer concentrations of 20-10-20 and 14-0-14 were varied to 0, 50, 100, and 200 $mg \cdot L^{-1}$ based on nitrogen concentrations. The grafted plug seedlings planted in the CO + PL medium showed superior growth, with thicker stem diameters and heavier fresh weights as the concentrations of the post-planting fertilization were elevated. On the other hand, in the case of the CO + VM medium, the fresh weight increased until the concentration

Table 8. The characteristics in soil chemical properties of various root media 31 days after cut grafting of tomato ('Sunmyung'/ 'J3B Strong') in 50 plug trays as influenced by post-planting fertilizer levels. The grafted seedlings were moved to a greenhouse after the formation of successful unions and were fertigated with various fertilizer concentration during greenhouse acclimation.

Root media[z]	FC[y] ($mg \cdot L^{-1}$)	EC ($dS \cdot m^{-1}$)	pH	NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg	Na
							($mg \cdot L^{-1}$)			
CO + PL	0	1.78 d[x]	7.6 a	72 b	41.0 c	176 c	142 c	36.0 a	10.1 a	408 a
	50	3.26 c	7.6 a	76 b	41.0 c	256 b	242 b	31.1 b	7.8 b	313 b
	100	3.85 b	7.6 a	315 a	53.3 b	269 b	276 a	25.9 c	7.2 b	277 bc
	200	4.25 a	7.5 b	332 a	81.1 a	397 a	275 a	22.7 c	5.7 c	252 c
CO + VM	0	1.13 d	7.6 c	17 c	23.6 c	123 c	17 c	14.5 a	3.3 a	347 a
	50	1.43 c	7.8 b	17 c	30.2 b	153 bc	17 c	12.1 b	2.5 b	244 b
	100	1.94 b	7.8 b	31 b	32.1 b	161 b	25 b	9.3 c	2.4 b	223 c
	200	2.25 a	8.0 a	45 a	108.0 a	212 a	50 a	7.4 d	2.6 b	210 c
F-test Root media		***	***	***	NS	***	***	***	***	*

[z]CO + PL: coir dust + perlite (7:3, v/v), CO + VM: coir dust + vermiculite (5:5); All root media contained an equal amount of pre-planting fertilizers with 1.0X treatment.
[y]FC: fertilizer concentration; The seedlings had been fertilized once a week since 8 days after grafting based on N concentrations from 14-0-14 and 20-10-20 ($N\text{-}P_2O_5\text{-}K_2O$) fertilizers. The both fertilizers were applied alternatively.
[x]Mean separation within columns for each root media by DMRT at $P \leq 0.05$.
[NS,Q,L]Nonsignificant, linear, quadratic, significance in trends of regression or in F-test: $^{***}P \leq 0.001$, $^{*}P \leq 0.05$.

of post-planting fertilization was elevated to 100 $mg \cdot L^{-1}$ but decreased when the concentration reached 200 $mg \cdot L^{-1}$. Comparing the fresh weights of the seedlings grown in the two different root media, those grown in the CO + VM medium were significantly heavier than those grown in the CO+PL medium ($p \leq 0.001$).

The electrical conductivities of root media 31 days after grafting increased as post-planting fertilizer concentrations were elevated (Table 8). The ECs of the CO + PL and the CO + VM media fertilized with 200 $mg \cdot L^{-1}$ in post-planting fertilization were measured at 4.25 and 2.25 $dS \cdot m^{-1}$, respectively, 31 days after grafting and the differences between two media were significant at $p \leq 0.001$.

Moreover, the elevation of post-planting fertilizer concentrations in each of the two root media resulted in the increase of NH_4-N, NO_3-N, PO_4-P, and K concentrations as well as the decrease of Ca and Mg concentrations in the soil solution of the root media 31 days after grafting. The pH, EC, and nutrient concentrations analyzed in this experiment except NH_4-N showed significant differences between the two root media based on an F-test.

Discussion

The root media for plug seedling growth generally contain pre-planting fertilizers for early stage growth after germination (Argo, 1998; Nelson, 2003). The level of pre-planting fertilization for plug seedling growths are controlled to the range of 0.5 to 1.0 $dS \cdot m^{-1}$ of electrical conductivity (Koranski, 1990; Nelson et al., 1996; Styer and Koranski, 1997) when it is measured by the saturated extraction method (Warncke, 1986). In the individual nutrient concentrations of root media, Styer and Koranski (1997) claim that 40-60 for NO_3-N, 5-8 for P, 50-100 for K, 60-120 for Ca, and 30-60 $mg \cdot L^{-1}$ for Mg are the appropriate ranges. Koranski (1990) also reported the appropriate EC levels and individual nutrient concentrations in plug stage 1 (roots emerge from seed coats) and in stage 2 (root penetrates the soil and the stem and seed leaves emerge). Based on his claim, EC values should lie between 0.75-1.2 $dS \cdot m^{-1}$ and the appropriate nutrient concentrations should be in the ranges of 40-75 for N, 10-15 for P, 30-50 for K, 50-75 for Ca, and 25-35 $mg \cdot L^{-1}$ for Mg. For stage 3 (true leaves grow and develop) and 4 (seedlings are ready for shipping, transplanting, or holding), the appropriate EC levels in root media are 1.0 to 1.5 $dS \cdot m^{-1}$ and individual nutrient concentrations are 60-100 for NO_3-N, 10-15 for P, 50-80 for K, and 80-120 $mg \cdot L^{-1}$ for Ca.

In considering the influences of pre-planting fertilizer levels on seedling growth before grafting in our research, tomato root stock 'J3B Strong' in the CO + VM medium produced heavier fresh weights as the level of pre-planting fertilization was elevated from 0x to 1.0x and those in the CO + PL medium produced heavier fresh weights as the level was elevated from 0x to 2.0x fertilization. Similar results were obtained in the case of the tomato scion 'Sunmyung'. Through these results, it can be concluded that normal seedling growth is possible with soil nutrient concentrations that are much higher than those proposed in previous research (Koranski, 1990; Nelson et al., 1996; Styer and Koranski, 1997).

During the formation of graft unions after grafting, seedling growths were the highest in the treatments of 1.0x for CO + PL and 2.0x for CO + VM 13 days after grafting and the ECs of the treatments were 4.14 and 5.84 $dS \cdot m^{-1}$, respectively (Table 6). Hanan (1998), Nelson (2003), Syter and Koranski (1997), and Koranski (1990) previously reported that the root media for plug seedling growth should have EC lower than 1.0 $dS \cdot m^{-1}$ for normal crops and 1.2 $dS \cdot m^{-1}$ for crops that have strong salt tolerance when determined by the saturation extraction method (Warncke, 1986). However, these results were based on the plug seedling growth of floral crops. Almost all of the plug seedlings produced in Korea are fruit vegetables such as tomatoes, hot peppers, egg-plants, and oriental melons. The crop duration in the production of grafted plug seedlings are 7 to 8 weeks which are longer than the 5 to 6 weeks in seedling production of floral crops in America (Koranski, 1990; Syter and Koranski, 1997). In addition, growers generally prefer root media in which the fertility can be maintained for the longest time possible. Considering the fertility maintenance and kinds of crops, elevation of pre-planting fertilization levels up to 3.0 $dS \cdot m^{-1}$ in terms of electrical conductivity would not be a any problem in the seedling production of fruit vegetables.

The ECs of the CO + PL medium with the higher incorporation ratio of CO were higher than those of the CO+VM medium. The reason for this can be found in the research results conducted by Colla et al., (2007), Nelson (2003), and Nicholas (2007). They reported that the coir dust contains large amounts of K, Na, and Cl and these elements continue to affect the EC of root media even after formulation. The root media containing the vermiculite had higher Na and lower phosphorus concentrations compared to those containing the perlite. This is due to the fact that vermiculites contain high amounts of Mg and Na (Choi et al., 2000) and therefore the CO + VM medium had the higher Na concentrations than the CO + PL medium. When the pH or the concentrations of Ca, Mg, or Na in root media increased, the concentrations of phosphorus in the soil solution of root media decreased. This was why the phosphorus became unavailable by combining phosphorus with Ca, Mg, or Na as explained by Hanan (1998).

In summary, the seedling growths of tomato root stock and scion before grafting were good even at much higher salt concentrations than those proposed for the plug cultivation of floral crops. The root media with much higher electrical conductivity than those recommended for seedling growth of floral crops performed well for seedling growth of tomatoes during the formation of grafted unions between stock plant and scion and those in greenhouse acclimation. These results proved that the proposed soil salt concentrations from previous researches are not suitable for the production of grafted plug seedlings of tomato and new standards should be applied depending on the root medium.

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