Hort. Environ. Biotechnol. 56(1):17-21. 2015.
DOI 10.1007/s13580-015-0040-2

ISSN (print) : 2211-3452
ISSN (online) : 2211-3460

Research Report

Performance of Seedling Grafts of Tomato as Influenced by Root Substrate Formulations, Fertigation Leaching Fractions, and N Concentrations in Fertilizer Solution

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Received April 1, 2014 / Revised October 25, 2014 / Accepted November 18, 2014

Abstract. Influence of root substrate formulations, leaching fractions (LF) of fertigation during seedling growth before grafting and fertilizer N concentrations after grafting on growth of tomato grafted seedlings and changes in root substrate chemical properties were investigated. Sphagnum peatmoss + perlite (7:3, v/v, PP) and coir + perlite (7:3, CP) containing pre-plant fertilizers were used as substrates. LF (volume leached/applied) was set as 0, 0.25, 0.50, 0.75 and 0.9 during seedling cultivation. Seedlings of rootstock (J3B Strong) and scion (Sunmyung) were grown in 50- and 105-cell trays, respectively. Plants were fed with 50, 100, or 200 $mg\cdot L^{-1}$ N using 14-0-14 and 20-10-20 commercial fertilizers alternatingly for seedling stages 2, 3, and 4, respectively. Grafted tomato seedlings planted in 50-cell trays containing PP or CP were callused and rooted inside a humid greenhouse plastic tunnel for 7 days. When grafted tomato seedlings were rooted after acclimation under lower humidity condition, N fertilizers with 4 different concentrations (0, 50, 100, 200 $mg\cdot L^{-1}$) were applied. During 31 days of culture, highest fresh weight of rootstocks was obtained with 0.75x LF in CP, while PP showing no influence on seedling growth by LF. Electrical conductance (EC) of CP with 0.75x LF was 2.88 $dS\cdot m^{-1}$. Growth of scion seedlings was largest with 0.25x LF in PP, and EC of this treatment was 0.855 $dS\cdot m^{-1}$. For 13 days post-grafting, plant growth was better as LF increased for both substrates. When seedlings were grown with 0.90x LF, EC for PP and CP was 0.833 and 2.923 $dS\cdot m^{-1}$, respectively. Fresh weight of grafted plants grown for 31 days after grafting was the highest with 50 $mg\cdot L^{-1}$ N for PP and 0 $mg\cdot L^{-1}$ N for CP. Substrate EC in these treatments were 0.66 and 1.42 $dS\cdot m^{-1}$, respectively. This study suggests that LF and fertilizer N concentration must be optimized according to substrate formulations for growing high-quality grafted seedlings.

***Additional key words*:** cut grafting, plug seedling, growing media

Introduction

Tomato seedlings are generally grafted and acclimatized before being transplanted to greenhouse soil in Korea. Because growers want to produce many grafted seedlings in a given time, they prefer the method of cut grafting. For the cut-grafting method described by Choi et al. (2012), the root systems of rootstocks, as well as scions, are removed before grafting and the graft union and new adventitious roots are induced in controlled environments providing steady conditions, such as temperature, light intensity and humidity.

In Korea, coir dust (by-product of coconut fiber processing), instead of Sphagnum peat moss, is the major component of root media used in production of grafted tomato seedlings (Choi et al., 2011). However, coir dust has serious problems relating to high salt concentrations of K, Na, and Cl when the dust is not allowed to age enough and washing with plain water or calcium nitrate solution is required (Nelson, 2003; Shin et al., 2012). The salt concentrations in root media formulated with coir would be excessive for root development and the resulting growth of grafted seedlings, especially for cut grafting. An additional problem is that Korean growers producing grafted seedlings prefer root media that contain excess pre-plant nutrient charge fertilizers because they want the fertility of the media to be sustained for a long time.

The drain-water-mediated leaching of dissolved substances from the bottom of growing containers has received attention because it wastes water and fertilizer, and may also contaminate groundwater (Ku and Hershey, 1991). On the other hand, leaching has beneficial aspects because it removes excess salts and prevents salinity buildup in the root zone. Previous work has mostly been related to media containing peat moss, and the results did not carefully consider the effects from different kinds of root media.

The objective of this research was to determine the influence of various substrate formulations and leaching fractions on growth of grafted tomato seedlings.

Materials and Methods

Root Substrate Formulations

The rootstock plant 'J3B' and scion 'Sunmyung' were chosen for this experiment. The seeds of both cultivars were purchased from the Nongwoo Seed, Suwon, in Korea. The root medium components were Canadian Sphagnum peat moss, horticultural grade perlite with (diameter 2-5 mm), and coir imported from Sri Lanka. Two root media, peat moss + perlite (7:3, v/v, PP) and coir dust + perlite (7:3, CP), were formulated. The total porosity, container capacity and air-filled porosity of the PP medium, measured after formulation were 86.7, 79.0 and 7.68%, respectively, and those of the CP medium were 84.6, 73.2 and 11.4%, respectively.

Pre- and Post-plant Fertilization

In order to set the fertilizer levels in the two root media, 9.615 g of 18-18-18 fertilizer (N-P_2O_5-K_2O), 45 mg of $MgSO_4 \cdot 7H_2O$, 9.15 mg of H_3BO_3, 9.15 mg of Fe-EDTA, 4.5 mg of Mn-EDTA, 2.7 mg Zn-EDTA, 1.8 mg Cu-EDTA, 0.45 mg of Na_2MoO_4, and 9.05 mg of H_3PO_3 were dissolved in water and sprayed on a liter of root medium. The 0.202 g of KNO_3, 0.189 g of $Ca(NO_3)_2$, 2.284 g of dolomite, and 0.63 g of calcium carbonate were incorporated into root media as granules or powder. After formulated, the pH and EC of PP were 7.09 and 1.127 $dS{\cdot}m^{-1}$ and those of CP were 7.17 and 3.210 $dS{\cdot}m^{-1}$. The concentrations of NH_4-N, NO_3-N, PO_4-P, K, Ca and Mg in PP were 16.7, 295.0, 250.4, 19.9, 14.0, and 7.46, respectively, and those in CP were 14.2, 339.7, 78.0, 233.9, 2.6, and 5.79, respectively.

The seeds of the rootstock and scion were sown in 50- and 105-cell plug trays, respectively, in which plugs had been packed with each of the two root media. After germinating of the seeds in a room with temperature between 27-28°C, the trays were moved into the greenhouse. Fertilizers, either 14-0-14 or 20-10-20 (Planta Co., Schwanenstrasse, Germany), were applied weekly with N-concentration of 50 $mg \cdot L^{-1}$ in Stage 2, 120 $mg \cdot L^{-1}$ in Stage 3, and 200 $mg \cdot L^{-1}$ in Stage 4. In separation of the plug stages, we followed the method suggested by Styer and Koranski (1997). The two fertilizers were applied in turns over the entire growth with the leaching fraction (LF) in each fertilization or irrigation varied to 0, 0.25, 0.50, 0.75 and 0.90 (Ku and Hershey, 1991). For the controlling of LFs, we prepared the extra plug trays and applied solution. Then, fertigation time and amount of solution leached were measured. By controlling of the time, LFs were adjusted in the each treatment of experiment.

The seedlings were grafted 31 days after sowing. For grafting, the stems of the root-stock plants were cut with a razor blade between 1 cm above the cotyledon, at 45 degrees, and just above the root zone. For scion plants at growth Stage 5 to 6, true leaves were also cut 1 cm above the cotyledon. The two plants were joined and secured with a clip. The grafted seedlings were planted in 50-cell plug trays, which contained of the root media. The LFs during the seedling growth of root stock and scion in before grafting stage were adjusted to 0.25.

The plug trays were placed in enclosed polyethylene tunnels, which were covered by 1 mm thick polyethylene sheets and polypropylene shading cloth. A reduction in water loss from leaves was accomplished by increasing the relative humidity. To reduce the heat load, shading regulated the penetration of light through the enclosed polyethylene tunnels. The two layers of shading curtains were located 1.5 m above the polyethylene tunnels. The light-intensities, during formation of the grafted unions, ranged between 5.33 and 8.88 $\mu mol \cdot m^{-1} \cdot s^{-1}$. Air temperatures ranged between 12.5 and 30.0°C. The shading curtains were removed progressively from 4 days after grafting. The seedlings in trays were moved to a greenhouse bench 7 days after grafting and cultured until 31 days after grafting.

Fertilizer, either 14-0-14 or 20-10-20 (Planta) was applied weekly with N-concentrations 50, 100, 150 or 200 after moving the grafted seedlings to a greenhouse bench. The two fertilizers were applied in turns over the entire seedling growth period and the leaching fraction in each fertilization or irrigation was set from 0.25 to 0.35.

Growth measurements on each investigation date followed the method described by Choi et al. (2007). Root media were extracted 31 days after sowing and 13 and 31 days after grafting in the manner described by Warncke (1986). The pH and EC levels, and macronutrient concentrations, were determined directly from this extract and all procedures followed the method described by Choi et al. (2011).

The dates of each experiment were April 15, 2009 for seed sowing of rootstocks and scions, May 16, 2009 for grafting, and May 29, 2009 for beginning in the experiment of various N concentrations. The all experiments were ended on June 29, 2009.

Data from growth measurements and soil analysis were subjected to a randomized complete block analysis of variance, and means were separated by the LSD test at $p \leq 0.05$. The data were also subjected to polynomial regression analysis. We regarded the equation with the highest R^2 and incremental F-value among linear and quadratic equations as the best. Data analysis was conducted using CoStat (CoHortSoftware V. 6.3, Monterey, CA, USA).

Results

Table 1 shows the growth of rootstock and scion plants 31 days after sowing and those of grafted seedlings 13 days after grafting. The fresh weights of rootstocks in the PP medium were not influenced, but those in the CP medium were significantly influenced by leaching fractions. The fresh weight was 4.31 g per plant in the 0.75x treatment with the CP medium and this was the highest among the LF treatments with the CP medium. In the case of the scion plants, the LF treatments in the CP medium did not show statistical differences in fresh weight, but those in the PP medium did. The fresh weight for the 0.25x and 0.5x LF treatments were 4.01 and 4.00 g per plant, respectively, and those were the highest among treatments. The growth of grafted seedlings, in terms of plant height, stem diameter, and fresh weight; showed lineally increasing tendencies as leaching fractions were elevated for the two kinds of root media. The growth of rootstocks, scions, and grafted seedlings were significantly higher in the PP medium than in the CP medium when the two root media had equal leaching fractions.

The results of soil analysis 31 days after sowing the rootstock and scion plants, as well as 13 days after grafting, are shown in Table 2. As the LF of media for rootstocks, scions and grafted seedlings were elevated, the EC and concentrations of NO_3-N, K, and Na in soil-solution, decreased lineally in both the PP and CP media. The ECs and concentrations of NO_3-N, K, and Na; were significantly higher in the CP medium than in the PP medium when the LF was kept equal in the two kinds of root media. The reason for the higher EC in the CP medium was that the concentrations of K and Na were abnormally high in coir dust and this resulted in higher EC levels than in the PP medium.

The growth of grafted seedlings and results of soil analysis, as influenced by post-planting fertilizer concentrations, are shown in Table 3. When the fertilizer concentrations were

Table 1. Growth characteristics of tomato rootstock 'J3B' and scion 'Sunmyung' 31-days after sowing in 50- and 105-plug trays, respectively, and of grafted seedlings (rootstock 'J3B'/scion 'Sunmyung') 13 days after grafting and planting in 50-plug trays as influenced by leaching fractions in each irrigation or fertigation.

RM	LF	Rootstocks			Scions			Grafted seedlings		
		Plant height (cm)	Stem diameter (mm)	Fresh weight (g/plant)	Plant height (cm)	Stem diameter (mm)	Fresh weight (g/plant)	Plant height (cm)	Stem diameter (mm)	Fresh weight (g/plant)
PP	0.00	14.5 a[z]	4.12 ab	5.85 a	8.64 a	3.29 a	3.33 c	11.4 d	4.05 a	2.77 c
	0.25	16.2 a	4.03 ab	5.88 a	8.47 a	3.35 a	4.01 a	13.4 c	4.00 ab	2.54 d
	0.50	15.6 a	4.41 a	5.74 a	8.76 a	3.45 a	4.00 ab	13.6 c	3.76 cd	3.54 b
	0.75	16.0 a	4.21 a	5.78 a	8.09 ab	3.33 a	3.59 abc	15.3 b	3.88 bc	3.58 b
	0.90	14.6 a	3.77 b	5.52 a	7.60 b	3.22 a	3.44 bc	17.6 a	3.72 d	3.86 a
F-significance		NS	*	NS	*	NS	*	***	***	***
Linear		NS	NS	NS	**	NS	NS	***	***	***
Quadratic		NS	*	NS	**	NS	NS	***	***	***
CP	0.00	7.94 a	3.36 b	3.36 c	5.96 ab	2.95 a	1.79 a	11.4 b	2.90 c	1.96 d
	0.25	7.85 a	3.28 b	3.51 bc	5.90 ab	2.93 ab	2.01 a	14.0 a	3.12 b	2.21 c
	0.50	8.60 a	3.61 a	4.17 ab	5.83 ab	2.69 c	2.17 a	14.6 a	3.29 ab	2.36 bc
	0.75	8.49 a	3.60 a	4.31 a	6.11 a	2.77 bc	2.13 a	15.2 a	3.18 b	2.67 a
	0.90	8.30 a	3.29 b	3.22 c	5.42 b	2.84 c	1.79 a	15.4 a	3.46 a	2.52 ab
F-significance		NS	***	*	NS	*	NS	***	***	***
Linear		NS	NS	NS	NS	NS	NS	***	***	***
Quadratic		NS	*	*	NS	*	NS	***	***	***
RM		***	***	***	***	***	***	NS	***	***

[z]Mean separation within columns for each root medium by Duncan's multiple range test ($p \leq 0.05$).
RM, root media; LF, leaching fraction; PP, peat moss + perlite (7:3, v/v); CP, coir + perlite (7:3, v/v).
NS,*,**,***Nonsignificant or significant at p = 0.05, 0.01, and 0.001, respectively.

Table 2. The characteristics in soil chemical properties of various root media at 31 days after sowing of tomato rootstock 'J3B' and scion 'Sunmyung' in 50- and 105-plug tray, respectively, and at 13 days after grafting and planting (rootstock 'J3B'/scion 'Sunmyung') in 50-plug trays as influenced by leaching fraction in each irrigation or fertigation.

RM	LF	Rootstocks				Scions				Grafted seedlings			
		EC ($dS \cdot m^{-1}$)	NO_3-N ($mg \cdot L^{-1}$ SPME)	K	Na	EC ($dS \cdot m^{-1}$)	NO_3-N ($mg \cdot L^{-1}$ SPME)	K	Na	EC ($dS \cdot m^{-1}$)	NO_3-N ($mg \cdot L^{-1}$ SPME)	K	Na
PP	0.00	0.714	90.9	21.1	118.6	0.863	166.7	18.5	114.5	1.211	65.9	24.4	322.7
	0.25	0.687	81.7	18.2	143.0	0.855	110.3	26.0	125.0	1.061	41.4	21.2	388.3
	0.50	0.688	66.1	19.1	125.4	0.727	78.8	25.4	148.7	0.981	36.9	19.2	212.7
	0.75	0.615	50.8	21.5	126.2	0.614	71.7	18.0	110.2	0.922	33.1	18.4	201.2
	0.90	0.555	49.7	17.6	111.5	0.582	50.3	16.2	107.1	0.833	26.7	15.0	174.4
F-Significance		***	***	***	*	***	***	***	**	**	***	***	***
Linear		***	***	***	NS	***	***	NS	NS	***	***	***	***
Quadratic		***	***	***	*	***	***	**	*	***	***	***	***
CP	0.00	3.343	404.8	359.4	419.8	2.903	305.8	223.1	360.4	4.073	292.8	562.7	464.0
	0.25	3.243	362.3	362.2	345.7	2.497	160.6	270.8	381.5	4.057	113.6	485.1	443.0
	0.50	3.000	231.3	334.9	304.8	2.543	49.7	228.2	353.6	3.887	75.3	394.3	386.4
	0.75	2.883	216.3	349.1	250.8	2.273	44.8	205.3	345.8	3.797	70.8	317.5	323.6
	0.90	2.470	110.4	294.7	221.6	1.948	9.7	91.3	331.0	2.923	35.6	296.1	341.7
F-Significance		***	***	***	***	***	***	***	***	***	***	***	***
Linear		***	***	***	***	***	***	***	**	***	***	***	***
Quadratic		***	***	***	***	***	***	***	**	***	***	***	***
RM		***	***	***	***	***	**	***	***	***	***	***	***

RM, root media; LF, leaching fraction; SPME, saturated paste medium extract; PP, peatmoss + perlite (7:3, v/v); PV, peatmoss + vermiculite (5:5, v/v); CP, coir + perlite (7:3, v/v); CV, coir + vermiculite (5:5, v/v).
NS,*,**,***Nonsignificant or significant at p = 0.05, 0.01, and 0.001, respectively.

elevated from 0 to 50 $mg \cdot L^{-1}$, the fresh weights of the grafted seedlings showed quadratic and linear decreases in the PP and CP media, respectively. The treatments yielding the highest fresh weights were 50 and 0 $mg \cdot L^{-1}$ in PP and CP media, respectively. Regarding soil solution analysis, the elevation of fertilizer concentrations resulted in the linear increase in EC, and the concentrations of NO_3-N, PO_4-P, K, Ma, and Na; in both the PP and CP media. The concentrations of K and Na were higher in the CP than in the PP medium, and these trends were similar to those shown in the rootstocks and scions 31 days after sowing, and in the grafted seedlings 13 days after grafting.

Discussion

In our research, the seedling growth of rootstock and scion plants, before grafting, were higher in the PP than in the CP (Table 1). The seedling growths in terms of fresh weight in the treatments of LF 0.25 of the PP and 0.75 of the CP were the highest among treatments of LF in each root medium. The electrical conductance of the CP was about 3-times higher than that of the PP (Table 2) when LFs were kept equal for the two root media. These results imply that LF should be elevated when raising seedling grafts using the CP medium.

As explained by Nelson (2003) and Shin et al. (2012), coir dust has higher K, Na, and Cl concentrations than peat moss. This would result in a decrease of tissue Ca and Mg content and suppress seedling growth by antagonism in absorption of cations. When the cation concentrations of the soil-solution in the root media are unbalanced, a common correction method is to elevate the LF by irrigation with fertilizer solution (fertigation). As a result, Na at cation exchange sites is replaced by Ca and Mg supplied by fertigation, then the Na is leached out through the drain hole at the bottom of the container. This also decreases the EC of the soil solution in the root media (Styer and Koranski, 1997).

The concentrations of macro-anions such as NO_3-N, were severely influenced by LF in irrigation and fertigation. As the LFs were elevated, the decrease in NO_3-N concentration was more severe in the CP than in the PP. The main reason for this difference is that the CP has lower water holding capacity than the PP does. Therefore, when a root medium

Table 3. Growth characteristics of tomato grafted seedlings (rootstock 'J3B'/scion 'Sunmyung') 31 days after cut grafting and planting in 50-plug tray as influenced by post-planting fertilizer concentrations.

RM	PPFC	Seedling growths			Root medium analyses						
		Plant height	Stem diameter	Fresh weight	EC	NO_3-N	PO_4-P	K	Ca	Mg	Na
		(cm)	(mm)	(g/plant)	($dS \cdot m^{-1}$)	($mg \cdot L^{-1}$ SPME)					
PP	0	18.0 b[z]	2.96 c	6.77 b	0.630	78.5	124.0	13.2	35.1	8.0	259.9
	50	19.8 a	3.80 a	7.11 a	0.660	78.8	162.4	15.5	26.4	4.4	190.0
	100	20.0 a	3.65 a	6.37 c	0.695	81.5	166.5	16.1	23.6	4.0	177.3
	200	21.2 a	3.24 b	5.57 d	1.050	166.0	184.3	29.7	23.6	4.4	154.9
F-significance		***	***	***	***	***	*	***	***	*	***
Linear		*	NS	***	NS	**	**	*	***	*	**
Quadratic		***	***	***	*	***	**	***	***	***	***
CP	0	15.9 a	3.36 c	5.26 a	1.423	30.5	236.4	97.8	25.4	7.9	420.9
	50	15.4 a	3.39 c	4.30 b	2.300	77.5	277.5	180.4	26.2	5.8	397.1
	100	15.0 a	3.87 b	4.27 b	2.940	131.1	325.5	208.4	23.9	5.8	222.4
	200	15.6 a	4.25 a	3.62 c	3.517	155.4	329.6	237.7	22.6	5.6	208.7
F-significance		NS	***	***	***	***	**	***	NS	***	***
Linear		NS	***	***	*	NS	***	**	NS	***	NS
Quadratic		NS	***	***	*	*	***	**	NS	***	***
RM		***	**	***	***	***	***	**	***	***	***

[z]Mean separation within columns for each root medium by Duncan's multiple range test ($p \leq 0.05$).
RM, root media; PPFC, post-planting fertilizer concentrations; PP, peatmoss + perlite (7:3, v/v); CP, coir + perlite (7:3, v/v); SPME, saturated paste medium extract.
NS,*,**,***Nonsignificant or significant at p = 0.05, 0.01, and 0.001, respectively.

has low water holding capacity, and LF is high during crop production, the concentrations of nutrients in the fertilizer solution have to be elevated, as explained by Nelson et al. (1996). The growth of grafted seedlings (in terms of fresh weight) during the acclimation stage was highest at 50 $mg \cdot L^{-1}$ (in the PP) and at 0 $mg \cdot L^{-1}$ (in the CP).

For the experiment in the acclimation stage, the amount of pre-planting fertilizers were also elevated in the two root media as explained in "Material and Methods" because we wanted to make root media legal system parallel to Korean growers our own. During the growth of grafted seedlings in the CP medium, the elevation of nutrient concentrations in the fertilizer solution resulted in the decrease in seedling growth 31 days after grafting. When grafted seedlings in the two media were compared, they were found to grow better in the PP, than in the CP medium. This indicates that the excessively high EC in the CP-soil-solution detrimentally influenced the growth of grafted seedlings. These results indicate that the LF should be elevated to a level higher than 0.75.

Acknowledgement: This research was supported by Technology Development Program for Agriculture and Forestry, Ministry for Food, Agriculture, Forestry and Fisheries, Republic of Korea (Project No. 312034-04).

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