https://doi.org/10.7235/HORT.20190038

Changes in Chemical Characteristics of Drainage Solution as Influenced by Years of Root Media Use in Successive Hydroponic Cultivations of 'Seolhyang' Strawberries

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Abstract

Changes in the pH, electrical conductivity (EC), and concentrations of essential nutrients have to be analyzed to enable reuse of the drainage solution (DS) in closed hydroponic cultivation of a crop because the chemical characteristics (CC) of drainage vary in relation to the kind of crop grown and the root media used. The objective of this research was to investigate changes in the CC of DS during cultivation of 'Seolhyang' strawberries. The root medium is composed of coir dust, peat moss, and perlite in the ratio 6:2:2 (v/v/v), and the composition of the nutrient solution applied for crop cultivation is N, P, K, Ca, and Mg at 15, 5, 7, 6, and 2 $mg \cdot L^{-1}$, respectively. The changes in the CC of the DS as well as the growth, yield, and fruit quality were investigated in relation to the number of years the root media used. The pH of the DS decreased as the number of years of root medium usage increased. The ECs of DS in all treatments were in the range of 0.8 to 1.5 $dS \cdot m^{-1}$ during the growing season and tended to rise as the number of years of usage in the root medium increased. The concentrations of NO_3 and Ca in the DS ranged from 200 to 600 $mg \cdot L^{-1}$ and 52 to 176 $mg \cdot L^{-1}$, respectively. The K concentration in the DS was in the range of 104 to 221 $mg \cdot kg^{-1}$ in all treatments during the growing season. The concentrations of P and Mg in the DS were 15 to 60 $mg \cdot L^{-1}$ and 18 to 48 $mg \cdot L^{-1}$, respectively. As the number of years of root media usage increased, the concentrations of NO_3, P, Ca, and Mg tended to rise, whereas that of K tended to decrease. The different treatments with varying number of years of root medium usage did not lead to significant differences in plant growth, tissue nutrient content, budding and flowering date, and total yield. The results from this research, the changes in nutrient composition of the DS and their effect on tissue nutrient content, can be used to modify the nutrient composition in the DS when the solution is reused in closed hydroponic cultivation of 'Seolhyang' strawberries.

Additional key words: EC, hydroponics, nutrient concentrations, pH, recycling

Received: July 23, 2018
Revised: March 17, 2019
Accepted: April 2, 2019

OPEN ACCESS

HORTICULTURAL SCIENCE and TECHNOLOGY
37(3):375-383, 2019
URL: http://www.kjhst.org

pISSN : 1226-8763
eISSN : 2465-8588

This research was supported by the Technology Development Program for Agriculture and Forestry, Ministry for Food, Agriculture, Forestry and Fisheries, Republic of Korea (Project No. 315084-03).

Introduction

The area devoted to hydroponic strawberry cultivation in Korea has steadily increased from 99 ha in 2008 to 1,575 ha in 2017 (informally announced data, Rural Development Administration, Korea) due to the higher yield and lower labor cost per unit area possible with hydroponic cultivation compared to soil cultivation (Yoon, 2010). Studies related to growth and yield, nutrient composition, and nutrient concentration for hydroponic cultivation of strawberries have been reported (Jun et al., 2006; Jun et al., 2013; Choi et al., 2014; Park et al., 2018a; Park et al., 2018b). Korean strawberry growers have installed the non-recycled (open) hydroponic system that releases drainage solution (DS) containing high concentrations of plant nutritional chemicals to groundwater, rivers, lakes, and oceans, contaminating the natural environment. Researchers aware of these problems have performed various studies that include nutrient absorption characteristics of various strawberry cultivars, pH changes of DS and root activity, and the changes in nutrient composition of the DS to develop a closed hydroponic system for the reuse of drained nutrient solution (Jun et al., 2011a; Jun et al., 2011b; Lee et al., 2017).

The physico-chemical properties of the root media in closed and open hydroponic systems greatly influence strawberry growth and yield (Bohme, 1995). Korean strawberry growers prefer coir dust compared to peat moss as a root medium component due to low cost. Furthermore, foreign strawberry growers frequently change the root medium every year, whereas Korean growers use the same root medium for several years to reduce production costs (Jeong, 2000). The repeated use of the root medium changes physico-chemical properties due to the successive decomposition of the medium components; these particles can break down from physical force or from the effect of microorganisms (Raviv and Lieth, 2008). The successive use of a particular root medium decreases the growth and yield of the strawberries and changes the nutrient composition of the DS, but detailed research on this is not available.

In this study, we investigated the changes of chemical properties in the DS and its influence on growth, yield, and fruit quality of strawberries by reusing the root medium in hydroponic cultivation for three consecutive years.

Materials and Methods

Experimental Design and Growth Management

In the greenhouse of the Nonsan Strawberry Research Institute, fresh root medium and 1- and 2-year-old used media were placed separately in Styrofoam beds (length × width × height = 100 × 25 × 14 cm), followed by mulching with blue vinyl. All the root media had an equal quantity of coir dust, peat moss, and perlite (6:2:2, v/v/v), and the amount of root medium in the bed for each treatment was 330 L. Strawberries were cultivated from early September to late March in 1-year used medium, and this medium was also used in second year. Before transplanting the strawberries, parts of old plants, such as roots and above ground tissues, were removed and the root media were washed for 2 days with groundwater.

The seedlings of ‘Seolhyang’ strawberries were transplanted with 20-cm planting distance on September 6, 2016. The experiment was conducted with three replications and 30 plants per replication (3 treatments × 3 replications × 30 plants/replication = 270 plants). Further, fertilizer solution was supplied in drip hoses arranged in intervals of 10 cm using a 1.0 hp (~746 W) motor. The amount of fertilizer solution per plant was 200 $mL \cdot d^{-1}$ from September to November, followed by 150 $mL \cdot d^{-1}$ from December to January, and 300 $mL \cdot d^{-1}$ from February to March. The composition of the nutrient solution was N, P, K, Ca, and Mg at 15, 5, 7, 6 and 2 $me \cdot L^{-1}$ with NH_4 and NO_3 in a ratio of 1:4 (Sonneveld and Voogt, 2009). The electrical conductivity (EC) of the nutrient solution was adjusted to a range of 0.7 to 1.0 $dS\cdot m^{-1}$ in September, followed by 1.2 to 1.5 $dS\cdot m^{-1}$ from October to November and 1.0 to 1.3 $dS\cdot m^{-1}$ from December to March. This was performed with a controlling venturi mixer for mixing A and B stock solutions with ground water. The pH of the supplied nutrient solution was adjusted to 6.0. The average day and night temperatures from September to November, December to January, and February to March were 23.0 and 16.8°C, 15.7 and 10.7°C, and 17.7 and 12.1°C, respectively. The average day and night relative humidity in September to November, December to January, and February to March was 50.2 and 69.3%, 55.8 and 59.4%, and 50.8 and 61.1%, respectively.

Growth, Yield, and Fruit Quality

Petiole length, leaf length, and leaf width were investigated in three replicates with 30 plants per treatment on November 27 (beginning of harvest) and on February 27 (middle of harvest). The time of budding and flowering was defined as the date when it proceeds to 40% anthesis stage. Yields were calculated from November 18, 2016 to March 10, 2017 and converted to kilograms per 10 a area. Fruit quality was investigated at three time points in February with three repeats per treatment. The firmness was expressed in grams per square millimeter using a Rheotex meter (Type SD-700, Shimadzu, Japan). The soluble solids and acidity were measured using a SAM-7300 meter (SAM-7300, G-won, Korea), represented in °Brix and percentage, respectively (Jun et al., 2013).

Analysis of Drainage Solution, Leaf Tissue, and Root Media

The drainage solution (DS) from 30 plants was collected weekly from the Styrofoam bed on the last day of each week. The collected drainage solutions were filtered with No. 2 filter paper. The pH was measured with a pH meter (IQ-150, IQ-Scientific Instrument, USA), and EC was measured with a EC meter (ECtestr11, Spectrum Technologies, USA; in $dS\cdot m^{-1}$). The NO_3 of the DS was analyzed using a NO_3 meter (RQflex 10, Merck, Germany), and P, K, Ca, and Mg were analyzed using an inductively coupled plasma spectrometer (ICP, Intergra XL, GBC Scientific Equipment, Australia).

The recently fully expanded leaves (2nd or 3rd) were collected from 10 plants and mixed for analysis of tissue nutrient content (three replications per each treatment). The collected tissue samples were analyzed four times from November to March and analyzed according to the RDA (NIAST, 2000) plant analysis method. The samples were dried at 75°C for 24 h and then pulverized. The T-N was analyzed using an elemental analyzer (Vario MAX CN, Elenenter, Germany). The other nutrients, such as P, K, Ca, and Mg, were analyzed by ICP after decomposing 1 g of a ground sample with HNO_3, $HClO_2$, and HCl and then diluted to 100 times.

The root media samples were collected after hydroponic cultivation of ‘Seolhyang’ strawberry and air dried for 7 days. The pH and EC were analyzed by mixing 20 mL of the air-dried medium in 100 mL of distilled water followed by shaking for 30 minutes, filtering with No. 2 filter paper, and measuring the pH by IQ-150 and EC by the ECtestr11 meter. For the NO_3 concentration, 100 mL of air-dried root medium was saturated with 100 mL of distilled water for 2 hours and then the solution was obtained by squeezing the saturated medium and filtering with a No. 2 filter paper followed by analysis with Rqflex 10 (Merck, Germany). The P, K, Ca, and Mg concentrations of the root media were analyzed by blending 20 mL of air-dried sample with 1 M solution of CH_3COONH_4 (77.08 g per one L of distilled water) followed by shaking for 30 minutes, filtering with a No. 2 filter paper, and analysis using ICP.

Statistical Analysis

Statistical analyses were performed using SAS 9.0 software. Data were subjected to one-way analysis of variance (ANOVA) using Duncan's multiple range test. Differences were considered to be significant at $p \leq 0.05$.

Results and Discussion

The pH and EC of the Drainage Solution

When the pH of the supplied nutrient solution was 6.0, the pH of the root media ranged from 5.81 to 7.09. During the growing season, the pH increased from approximately 6.0 at the early stage of growth to 7.0 at mid-stage and then decreased after mid-January (Fig. 1). This result suggested that the increase of the medium pH at the mid-growth stage is due to the increased uptake of negative ions such as NO_3 and that the lower pH after mid-February was due to the increased uptake of cations. The reason why the pH during the early growth stage is lower than 6.0 was considered to be due to the high EC of the nutrient solution at the early growth stage. This is similar to the results of a study conducted by Jun et al. (2011b), who reported that the pH of the strawberry DS lowers when the EC of the nutrient solution is high. The pH of the DS according to the root media was 6.43 in the fresh medium, 6.23 in the 1-year used medium, and 6.13 in the 2-year used medium. Thus, pH tended to decrease with the number of years of root medium usage (Fig. 1). The reason pH goes down as the number of years of root medium usage goes up is thought to be due to the accumulation of protons (H^+) in the root media. In this study, the ratio of NH_4 to NO_3 in the supplied nutrient solution was 1:4 and the H^+ produced by plant roots during NH_4 uptake (Marschner, 2012) replaced the Ca or other cations at cation exchange sites in the root media. As indicated by Raviv and Lieth (2008), plants absorb more NH_4 than NO_3 when plants are in juvenile phase and also when root environmental temperature is low. This resulted in a decrease in pH in the early growth stage of strawberries. The competition between H^+ ions produced during nutrient absorption, and other cations supplied in the fertilizer solution, caused replacement of the cations at the cation exchange sites, and the detached cations (especially Ca) leached out when the fertilizer solution was applied. This could be confirmed by the increased Ca concentration in the DS (Fig. 2). The low pH in the 2-year used medium than the fresh one is due to increased surface area of the root medium. This is because the components of the root media are broken down into

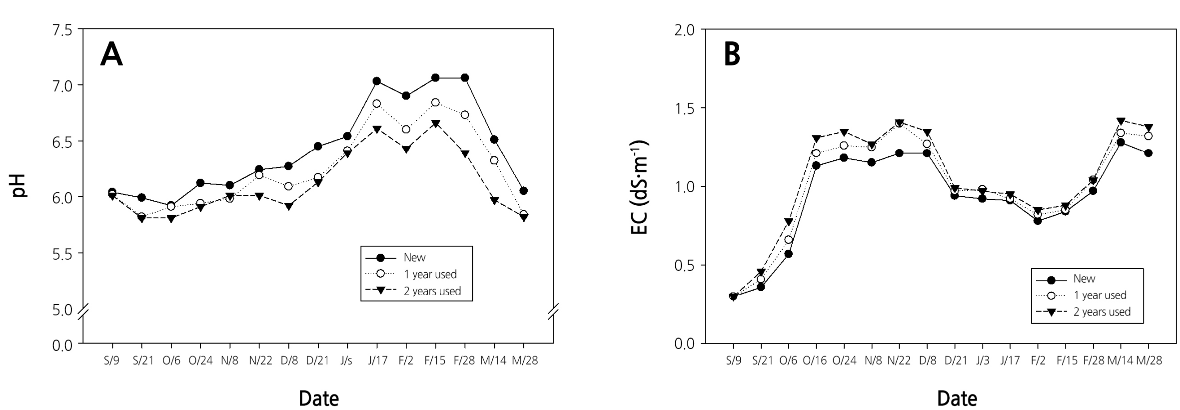

Fig. 1. Changes in the pH (A) and EC (B) of the drainage solution during the growing season of 'Seolhyang' strawberries as influenced by the number of years of root medium usage in successive hydroponic cultivations. S, September; O, October; N, November; D, December; J, January; F, February; M, March.

smaller particles by physical force and microbial action when the root medium is used successively over a number of years (Raviv and Lieth, 2008). As the surface area increases, the amount of Ca detached from CEC sites and leached out increases, resulting in the decreasing of pH of the medium.

The EC of the DS during the growing season was 0.8 to 1.5 $dS \cdot m^{-1}$ in all the root media. The mean EC of the DS was 1.27 $dS \cdot m^{-1}$ in October and November and 0.91 $dS \cdot m^{-1}$ in January and February (Fig. 1). This was because the nutrient solution was controlled to provide EC of 1.2 to 1.5 $dS \cdot m^{-1}$ in October and November and EC of 1.0 to 1.2 $dS \cdot m^{-1}$ in January and February. The EC was low in the fresh medium and high in the 2-year used medium, indicating that EC tends to increase with the number

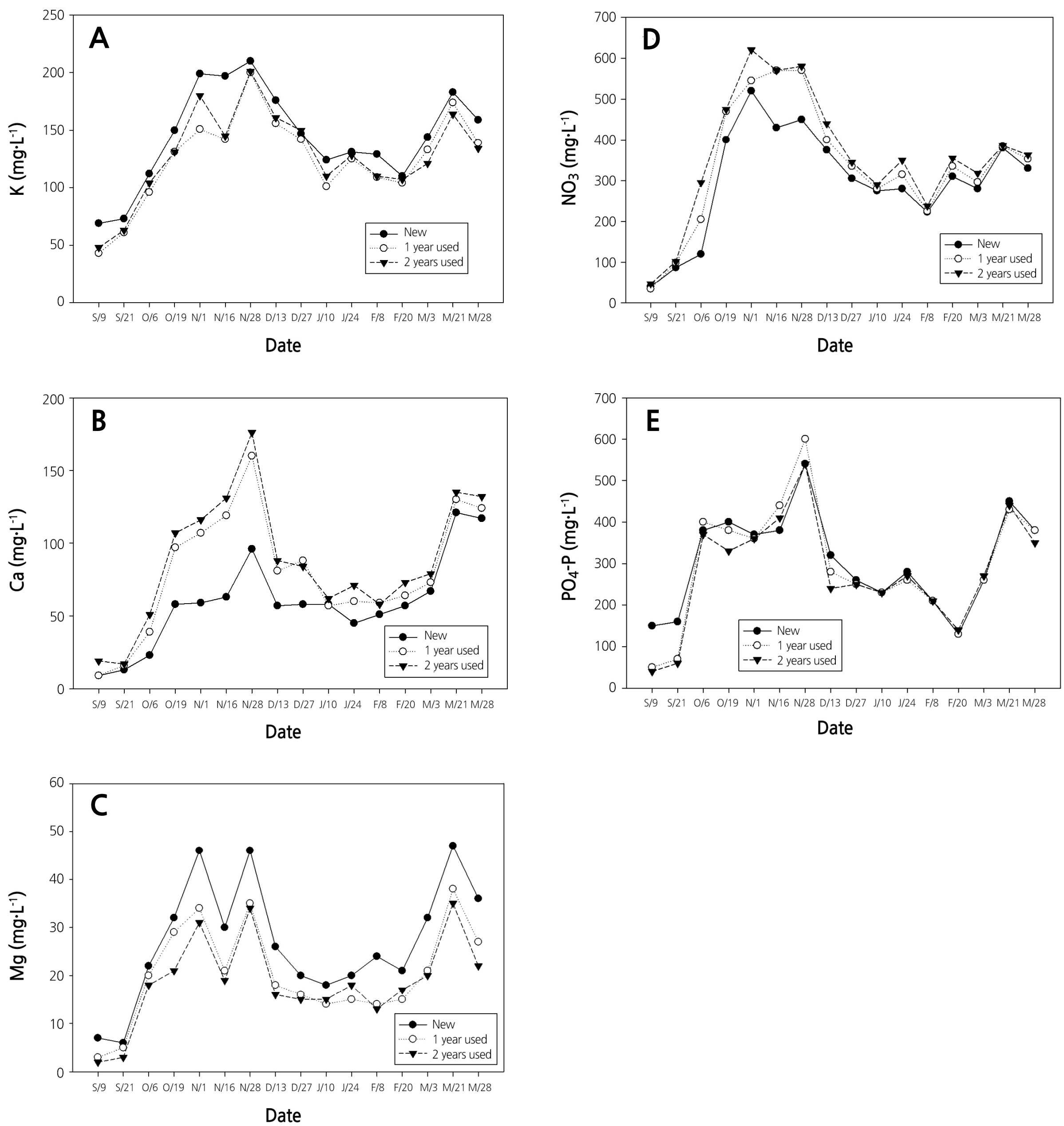

Fig. 2. Changes in the concentrations of K (A), Ca (B), Mg (C), NO_3 (D), and P (E) in the drainage solution during the growing season of 'Seolhyang' strawberries as influenced by the number of years of root medium usage in successive hydroponic cultivations. S, September; O, October; N, November; D, December; J, January; F, February; M, March.

of years the root medium is used (Fig. 1). The root media used for two successive years could hold more nutrients because of the increased surface area of the components, as explained above.

Composition of the Drainage Solution

The NO_3 concentration in the DS according to the root media was 341 mg·L^{-1} on average and increased starting in the middle of November and decreased in December (Fig. 2). This was because the EC of the nutrient solution was kept in the range of 1.2 to 1.5 dS·m^{-1} in October and November and 1.0 to 1.2 dS·m^{-1} in January and February. The change in the concentrations of P, K, Ca, and Mg in the DS showed the same trend. The NO_3 concentration of the DS increased with the number of years of root media usage. The mean concentration was 309 mg·L^{-1} in the new medium (the lowest), whereas it was 370 mg·L^{-1} in the 2-year used medium (the highest) (Fig. 2). In contrast, the difference in the concentration of P was not significant. The mean P concentration of the drainage was 31 mg·L^{-1} in the fresh medium, 30 mg·L^{-1} in the 1-year used medium, and 29 mg·L^{-1} in the 2- year used medium. The range in the P concentration was 15 to 60 mg·L^{-1} during the growing period (Fig. 2). This is because PO_4-P, which is an anion, easily leached when water is supplied to the root media (Bar-Yosef, 2008). The range of the K concentration in the DS is 104 to 221 mg·L^{-1} and showed a trend similar to that of the EC. The concentration of K in the DS according to the number of years of root media usage was the highest in the fresh medium (149 mg·L^{-1}) (Fig. 2). The K content is thought to be high in the new medium (based on the research findings) because the coir dust has high K content (Yoon et al., 2012). The Ca concentration in the DS is 52 to 176 mg·L^{-1}. The mean (90 mg·L^{-1}) was the highest in the 2-year used medium (83 mg·L^{-1} in the 1-year used medium and 59 mg·L^{-1} in the new medium) (Fig. 2). This result showed that the greater the number of years of root medium usage, the higher the Ca content. Even though particle size distribution in root media was not analyzed in our experiment, the rate of small particles gets higher as the number of years of same medium usage increased because of physical and microbial breakdown of root medium components (Raviv and Lieth, 2008). The unit volume of root medium composed of small particles have more surface area and cation exchange capacity when compared to same volume of a medium composed of larger particles (Bunt, 1988). The changes of root medium components result in the attachment of more cations, especially in calcium. This has been reported previously by Raviv and Lieth (2008), who noted that Ca concentration in DS gets higher as plants grow. The concentration of Mg in the DS was 18 to 48 mg·L^{-1} (26 mg·L^{-1} in the new medium, 22 mg·L^{-1} in the 1-year used medium, and 20 mg·L^{-1} in the 2-year used medium) (Fig. 2). These results showed that Mg concentration in DS tends to decrease as the years of root medium usage increase.

Nutrient Concentrations in Leaf Tissue and Root Media

Among the inorganic nutrients in strawberry leaves, the nitrogen concentration was the highest, followed by K, Ca, P, and Mg (Table 1), as also reported by Jang et al. (2012). In terms of numerical values, the T-N and Ca contents of the strawberry leaves tended to get higher with the number of years of root medium usage. This trend was similar to the changes seen in the DS concentrations, as shown in Fig. 2. In contrast to the case with NO_3 and Ca, the K content of the strawberry leaves was the highest (2.66%) in the new root medium and was the lowest (2.46%) in the 2-year used medium. The P and Mg contents of the strawberry leaves were different among three treatments. However, the differences in tissue T-N, P, K, Ca, and Mg contents were not significant when the means of three treatments were compared by Duncan's multiple range test at $p \leq 0.05$. The trends of change in the inorganic nutrient content of strawberry leaves as influenced by the number of years of root medium usage were the same as those in the DS, except for Mg. The Mg concentration was the highest in the DS of new root medium, but not so in the strawberry leaves. This is thought to be because the difference of Mg content in relation to the number of years of root medium usage is not large enough to cause a difference in the leaf Mg content. Results of our research show that the application of magnesium sulfate to strawberries increased the Mg concentration in the root medium, but not in the leaves (Lee et al., 2012).

Analysis of chemical properties of root substrate after cultivation of 'Seolhyang' strawberry showed that the pH gets lower and the EC gets higher as the number of years in root medium usage was increased (Table 6). The increase in root medium usage also resulted in the significant increase in the concentrations of inorganic ions such as NO_3, P, K, and Ca, but not Mg. The increased concentrations of the ions in root media led to a rise in EC.

Growth Characteristics

The growth of the strawberries in relation to the number of years of root medium usage was investigated in the early harvest season of November and in the middle harvest season of February (Table 2). The petiole length, leaf length, and leaf width in November were not significantly influenced by the number of years of root medium usage. However, leaf length measured in February was high in the 2-year used medium and found to be the lowest in the fresh medium. As indicated by Jang et al. (2012), the most important inorganic element in the growth of strawberries is nitrogen. As shown in Fig. 2, the NO_3 concentration in the DS from 2-year used medium was relatively higher than that of the 1-year used and new root media. This indicates that more NO_3 accumulated in 2-year used medium than in 1-year used and new media, which resulted in increased uptake. This also resulted in elevated accumulation of NO_3 in the leaves and enhanced growth of the aerial parts of the strawberries. This could lead to increased growth of strawberries in the treatment with 2-year used medium. However, the budding and flowering times of the strawberries in all treatments are October 14 and October 27, respectively (Table 3), and there were no statistical differences. From these results, it was assumed that the continuous usage of root media for multiple

Table 1. Nutrient contents based on the dry weight of fully expanded leaves of 'Seolhyang' strawberries as influenced by the number of years of root medium usage (NYRMU) in successive hydroponic cultivations[z]

NYRMU	T-N	P	K	Ca	Mg
	(%)				
New	3.32[y]	0.60	2.66	1.04	0.38
1 year	3.37	0.60	2.52	1.21	0.37
2 years	3.41	0.60	2.46	1.25	0.38

[z]The composition of the root media was 60 coir dust + 20 peat moss + 20 perlite (v/v/v).
[y]Means are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

Table 2. Petiole length, leaf length, and leaf width during the growing season of 'Seolhyang' strawberries as influenced by the NYRMU in successive hydroponic cultivations[z]

NYRMU	November 17, 2016			February 27, 2017		
	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)
New	18.4 a[y]	12.6 a	10.0 a	15.5 a	8.2 b	6.9 a
1 year	18.7 a	12.6 a	10.3 a	15.7 a	8.6 ab	7.0 a
2 years	19.1 a	12.7 a	10.2 a	15.9 a	8.7 a	7.2 a

[z]The composition of the root media was 60 coir dust + 20 peat moss + 20 perlite (v/v/v).
[y]Means followed by the same letter are not significantly different compared to Duncan's multiple range test at $p \leq 0.05$.

years influenced the inorganic nutrient content of the root media, but it did not affect the time of budding and flowering.

Yield and Fruit Quality

There are no significant differences in yield and fruit quality in relation to the usage of root medium for multiple years (Table 4). Based on the numerical value, the yield in the early harvest season (December) was high in the treatments of fresh and 1-year used root media, and the yield of the middle harvest season (January) was high in the 2-year used root medium. However, the total yields by March were not statistically different compared to Duncan's multiple range test at $p \leq 0.05$ (Table 4). The usage of root medium for several years did not significantly influence the fruit quality in February, in terms of firmness, sugar content, and acidity (Table 5).

In summary, our results indicate that the EC and concentrations of NO_3 and Ca in the DS are a little higher in the 2-year used root medium than those in the 1-year used and fresh media. However, the growth and fruit quality of the strawberries did not vary significantly in relation to the years of root medium used.

Table 3. Date of budding and flowering of 'Seolhyang' strawberries as influenced by the NYRMU in successive hydroponic cultivations^z

NYRMU	Budding date	Flowering date
New	October 14^y	October 27^y
1 year	October 14	October 27
2 years	October 14	October 27

^{z}The composition of root media was 60 coir dust + 20 peat moss + 20 perlite (v/v/v), and seedlings of the 'Seolhyang' strawberries were transplanted with 20-cm planting distance on September 6, 2016.
^{y}Dates on which budding and flowering progressed by 40% in anthesis stage.

Table 4. Yield of 'Seolhyang' strawberries as influenced by the NYRMU in successive hydroponic cultivations^z

NYRMU	Yield (kg/10a)				
	December	January	February	March	Total
New	1,039 a^y	117 a	893 b	176 a	2,225 a
1 year	1,072 a	120 a	1,104 a	101 a	2,397 a
2 years	914 a	150 a	973 ab	169 a	2,206 a

^{z}The composition of the root medium was 60 coir dust + 20 peat moss + 20 perlite (v/v/v), and seedlings of 'Seolhyang' strawberries were transplanted with 20-cm planting distances on September 6, 2016.
^{y}Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

Table 5. Firmness, soluble solids, and acidity of 'Seolhyang' strawberries as influenced by the NYRMU in successive hydroponic cultivations^z

NYRMU	Firmness (g/mm^2)			Soluble solids (°Brix)			Acidity (%)		
	Feb. 21	Feb. 24	Feb. 28	Feb. 21	Feb. 24	Feb. 28	Feb. 21	Feb. 24	Feb. 28
New	10.5^y	8.6	7.1	11.6	10.0	10.0	0.69	0.65	0.77
1 year	10.6	9.4	7.9	11.4	9.7	9.4	0.72	0.72	0.62
2 years	10.8	9.8	8.4	11.1	9.2	9.2	0.71	0.69	0.74

^{z}The composition of the root media was 60 coir dust + 20 peat moss + 20 perlite (v/v/v), and the seedlings of 'Seolhyang' strawberries were transplanted into two rows with 20-cm planting distances on September 6, 2016.
^{y}Means are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

Table 6. Results of root medium analysis after successive hydroponic cultivations of 'Seolhyang' strawberry as influenced by the NYRMU[z]

NYRMU	pH	EC ($dS \cdot m^{-1}$)	NO_3	P	K	Ca	Mg
			($mg \cdot L^{-1}$)				
New	5.48 a[y]	0.20 b	59.7 b	7.0 b	795 c	1,274 b	169 a
1 year	4.74 b	0.27 b	126.3 b	6.0 b	1,426 b	1,327 b	131 b
2 years	4.46 c	0.93 a	533.3 a	17.2 a	1,782 a	1,465 a	122 b

[z]The composition of the root medium was 60 coir dust + 20 peat moss + 20 perlite (v/v/v), and seedlings of 'Seolhyang' strawberries were transplanted with 20-cm planting distances on September 6, 2016.

[y]Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

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