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Composition of Optimal Nutrient Solution for Single-stemmed Rose 'Red velvet' in a Closed Aeroponic System

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Abstract. Experiments were carried out to develop an optimal nutrient solution for the single-stemmed rose (*Rosa hybrida* L.) 'Red velvet' in a closed aeroponic system. Plants were grown in 1/3, 1/2, 1, or 3/2 strength of the nutrient solution of National Horticultural Research Station in Japan (NHRS). Significantly less changes of pH and EC ($dS \cdot m^{-1}$) in the drainage were observed in 1/2 strength treatment as compared to other treatments. The NO_3-N, K, Ca, and Mg concentrations in the drainage solution of 1/2 strength treatment were maintained at optimal levels. These results indicated that the rose uptakes of both nutrients and water was more stable than those in other concentration. The concentration of macronutrients in nutrient solution were adjusted based on the ratio of nutrient:water (n/w) taken up by plants grown in the 1/2 strength solution. The composition of the new solution (classified the University of Seoul (UOS) solution) was as follow; NO_3-N 8.8, NH_4-N 0.67, P 2.0, K 4.8, Ca 4.0, Mg 2.0 $me \cdot L^{-1}$. To further evaluate new solution on crop growth, the rose 'Red Velvet' was grown again in 1/2, 1, and 2 strength UOS solution to compare with 1.0 strength PBG (proefstion voor bloemisterij en glasgroenpe) solution. Overall the plant growth, including the stem length and number of five-leaflet leaves was higher in 1.0 strength of UOS solution than other treatments. Results presented in this study indicate that the nutrients in the UOS solution are well balanced for the single-stemmed rose in the closed aeroponic system.

Key words : EC, Hydroponics, pH, Nutrient strength, Nutrient uptake, n/w absorption ratio

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Introduction

One alternative to bush-grown greenhouse roses are the self-rooted, single-stemmed roses developed from single-node cuttings, which produce large numbers of uniform shoots per unit area in short cultivation cycles (Anderson, 1990; Bredmose and Hansen 1996; Van Weel, 1996). The single-stemmed rose can improve the control of growth, development, and flowering of only one apical bud.

A nutrient solution for rose cultivation was developed in Holland in 1985 and has been widely used in hydroponics. A specific nutrient solution for the cut rose also developed in Holland in 1992. However, the nutrient composition in these solution was for an open (non-recirculating) system, which had a potential to pollute the soil by the leachate from drain hole (Kim, 1998). This resulted in development of new nutrient solution for a closed (recirculating) system (Sonneveld, 1992). Ho and Adams (1995) also recommended the reduction of nitrate in the nutrient solution of hydroponics not only for a healthy diet but also for reducing the soil and water pollution by the glasshouse industry. They proposed the recirculation of feed in the rockwool system and new formulas for hydroponic feed, such as the partial substitution of nitrate by chloride. A nutrient solution specified for an open system was developed in Japan (Gato, 1994) for growing rose plants in rockwool medium. More recently, a nutrient solution for cut rose that is suitable for a closed system has been developed at the university of Seoul in Korea (Kim, 1998). This solution contained the following nutrients: NO_3-N 7, NH_4-N 1, P 1.7, K 3.5, Ca 3.5, Mg 1.8, and S 1.8 $me \cdot L^{-1}$.

Several aeroponic systems have been used successfully for the propagation and maintenance of a variety of woody and herbaceous plants (Zobel et al., 1976; Callaham et al., 1979; Hubick et al., 1982; Peterson and Krueger, 1988; Martin et al., 1997; Burgess et al., 1998; Chang, 2004). The rose may be a suitable for hydroponic cultivation in which aeroponic systems can facilitate high yield. However, studies have not been done for adjusting and/or optimizing the nutrient solution for the single-stemmed rose in a closed system. The aim of this study was therefore to develop an optimum nutrient solution for cultivation of single-stemmed roses in a closed aeroponic system.

Materials and Methods

1. Development of an optimum nutrient solution for single-stemmed rose in a closed aeroponics

A rose (*Rosa hybrida* L.) 'Red velvet' was grown in the greenhouse at the farm of the University of Seoul. Single-node cuttings with one five-leaflet leaf and one axillary bud were excised prior to starting the experiment. The basal part of each cutting was treated with a commercial rooting powder containing auxin (Rootone, Union Carbide, USA). Plants were rooted and grown as single-stemmed plants in rockwool cubes (7.5 cm× 7.5 cm×6.5 cm, UR. Korea) in an ebb & flow system. Plants were transplanted into a closed aeroponic system after the roots had grown. The plants were fed with the solution developed in National Horticulture Research Station in Japan (NHRS solution), which consisted of NO_3-N 16.0, NH_4-N 1.3, PO_4-P 4.0, K 8.0, Ca 4.0, Mg 4.0 me · L^{-1}. The solutions were supplied to each culture bed through a hosepipe connected to a submersible pump (30 W) (Fig. 1). The stem base of the cuttings was misted intermittently with the nutrient solution within the fog nozzles. The nutrients were EC 0.9 (1/3 S; strength), 1.2 (1/2 S), 2.3 (1 S) and 3.7 dS · m^{-1} (3/2 S). The pH in solution of each treatment was adjusted to 6.0 with 1N H_2SO_4 or NaOH.

The nutrient-water uptake (n/w) ratio of the rose plant was calculated according to Yamazaki (1984).

$$n/w = a/w(y-y_1) + y_1 \qquad \text{if } y > y_1$$
$$n/w = y_1 - a/w(y_1-y) \qquad \text{if } y < y_1$$

where a is the initial volume of culture solution in each container, w is the amount of water absorbed by plant, y is the initial concentration of macronutrients in the culture solution (me · L^{-1}) and y_1 is the final concentration of macronutrients in the culture solution (me · L^{-1}).

The EC and pH were measured three times per week with an EC meter (CM-20E, TOA, Japan) and a pH meter (HM-20E, TOA, Japan). The amount of water absorbed by the plants was measured every week, then the solution was sampled for analysis of N, P, K, Ca, and Mg. Nutrient solutions were filtered with Whatman No. 6 filter paper before analyzing. The nutrient solution was analyzed for nutrient concentration through the method of soil and crop plant analysis (NIAST, 2000).

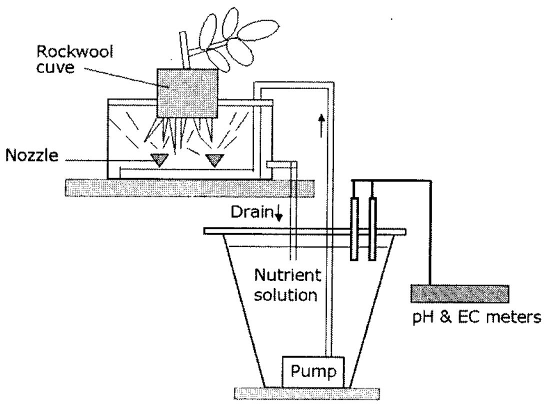

Fig. 1. Diagram of the closed aeroponic system used in this experiment.

The fresh weight, stem length, flower diameter, stem diameter, flower stalk, and number of five-leaflet leaves and three-leaflet leaves of the cut flower were measured.

The collected data were subjected to analysis of variance using the statistical analysis package SAS (Statistical Analysis Systems Institute Inc., Cary, NC, USA). Significant mean separation is indicated by the use of the least significant differences (LSD) using Duncan's multiple range tests.

2. Evaluation of the nutrient solutions for growth of single-stemmed rose

Single-stemmed rose was grown by newly developed nutrient solution (University of Seoul; UOS solution) compared with another solution such as proefstion voor bloemisterij en glasgroenpe (PBG) solution. Plants were grown in 1/2 S (EC: 0.7 dS · m^{-1}), 1 S (EC: 1.4 dS · m^{-1}) and 2 S (EC: 2.8 dS · m^{-1}) of UOS solution and 1 S of PBG solution (EC: 0.7 dS · m^{-1}).

The EC and pH were measured three times per week by an EC meter (CM-20E, TOA, Japan) and a pH meter (HM-20E, TOA, Japan). Chemical analysis of all nutrient solutions in the second experiment was performed by the same method as described in the first experiment. To

Table 1. Calculated n/w values of single-stemmed rose based on the Yamazaki's formula in closed aeroponics.

Nutrient con.	Items measured	Water (L)	Items measured	PO_4-P	K	Ca	Mg
				(me · L^{-1})			
1/3 S[z]	a	15.00	y	1.41	3.36	3.00	1.42
	W	17.30	y_1	1.21	4.87	3.06	2.02
	a/w	0.87	n/w[y]	1.38	3.56	3.01	1.50
1/2 S	a	15.00	y	2.01	4.67	4.02	1.99
	w	16.20	y_1	1.91	6.42	4.79	2.97
	a/w	0.93	n/w	2.00	4.80	4.08	2.06
1 S	a	15.00	y	3.88	9.18	7.71	3.80
	w	16.30	y_1	4.65	16.72	12.06	6.18
	a/w	0.92	n/w	3.94	9.78	8.06	3.99
3/2 S	a	15.00	y	6.72	16.14	13.02	6.48
	w	13.15	y_1	8.56	30.56	17.60	13.00
	a/w	1.14	n/w	6.46	14.11	12.38	5.56

[z]S: Ion strength of nutrient solution.
[y]n/w: The formula devised by Yamazaki to determine the amount of macronutrients and water uptake at regular intervals during growing period in closed aeroponic.
if $y > y_1$, $n/w = a/w\,[(y-y_1)] + y_1$; if $y<y_1$, $n/w = y_1 - a/w[(y_1-y)]$
a: Initial volume of culture solution in each container (*l*).
w: The amount of water absorbed by plants (*l*).
y: The initial concentration of macronutrients in culture solution (me · L^{-1}).
y_1: The final concentration of macronurients in culture solution (me · L^{-1}).

measure photosynthesis, diurnal measurements of the net CO_2 assimilation rate were performed on recent mature leaves in the upper canopy using a portable photosynthesis system (LI-6400, Li-Cor, USA). The fresh weight, stem length, flower height, stem diameter, flower stalk and number of five-leaflet leaves were also measured.

The collected data were subjected to analysis of variance using the statistical analysis package SAS (Statistical Analysis Systems Institute Inc., Cary, NC, USA). Significant mean separation by Duncan's multiple range tests is indicated by the use of alphabetical letters.

Results and Discussion

1. Development of an optimum nutrient solution for single-stemmed rose

In order to develop a nutrient solution suitable for single-stemmed rose in aeroponics a formula for nutrient-water (n/w) uptake by Yamazaki (1984) was used (Table 1).

The changes of EC in the drainage solution of 1/3 S and 1/2 S treatment were much less compared to those with 3/2 S and 1 S (Fig. 2). The ratio of the nutrient (n) to water (w) uptaken also indicated that the total concentrations of nutrients in both 3/2 S and 1 S treatment seem to be in excess level for growth of the single-stemmed rose grown in the aeroponic system. The changes of pH in drainage solution of 1/2 and 1 S treatment were less compared to those of 3/2 and 1/3 S treatment (Fig. 2). The change of pH in the solution was closely related to the result of NH_4^+-N absorption by plants in this study (Fig. 2, Fig. 3). It reconfirms previously reported results that rose plants have a higher affinity to the concentration of NH_4^+-N than NO_3^--N (Gato, 1994; Cabrera et al., 1995). The amount of NO_3^--N and NH_4^+-N taken up by plants in this study were monitored by analyzing the drainage solution. The concentration of NH_4^+ in the drainage solution declined sharply at 2 weeks after 3/2 S treatment (Fig. 3), whilst NO_3^- increased 2 weeks after 3/2 S and 1 S treatments (Fig. 3). Following flower harvest, the N uptake rate decreased even as the new flower shoots began to develop (Cabrera et al., 1999). However, there were no significant changes in NO_3^- and NH_4^+ in concentration of the drainage solution of 1/2 S and 1/3 S treatments until harvesting. These results proved that

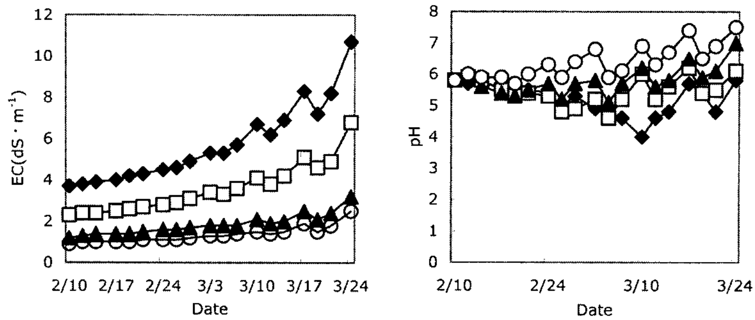

Fig. 2. Changes of EC and pH in the nutrient solution as influenced by the strength of nutrient solution in a closed aeroponics (NHRS 3/2 S, ◆ ; NHRS 1S, □ ; MHRS 1/2 S, ▲ ; and NHRS 1/3 S, ○).

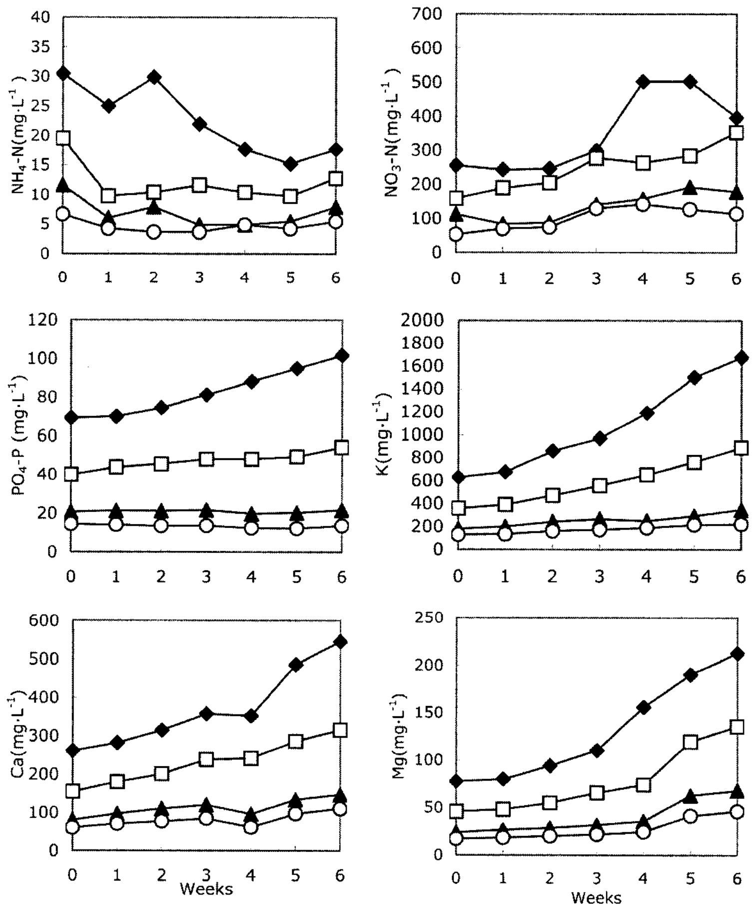

Fig. 3. Changes of macro-nutrient concentrations in the nutrient solution as influenced by the strength of nutrient solution (NHRS 3/2 S, ◆ ; NHRS 1S, □ ; NHRS 1/2 S, ▲ ; and NHRS 1/3 S, ○).

roses prefer NH_4^+-N to NO_3^--N, and the uptake rate is dependant on the total concentration of nutrients in the solution.

The uptake of P, K, Ca, and Mg were somewhat similar to that of NO_3^--N. Cabrera et al., reported that potassium, Ca, Mg and P followed the same pattern of uptake abserved for N in rose plant. The change of P concentration in the drainage solution was stable in all treatments tested, except for the 3/2 S treatment (Fig. 3). The concentration of K and Ca in the solution increased significantly in the treatment of both 1 S and 3/2 compared to these in the 1/2 S and 1/3 S. The Mg concentration in all treatments increased rapidly at 4 weeks after application (Fig. 3). It may be due to the relationship between Mg and other cations at the shoot development stage. Silberbush et al. measured the changes in uptake rate of nitirate nitrogen and potassium along a flower-cut cycle of rose, and the relationships between these changes and plant morphology. These results indicate that the nutrient uptake by plants decrease when they are grown in the high strength solution such as 3/2 and 1 S. These are intensified when the shoot elongation rate are at its maximum. Overall, the stable uptake of nutrients by plants was observed in the solution of 1/2 S concentration. It seems to be more ideal that formulation of nutrient solution should be decided not only by ion species but also by concentration. The ideal formulation of nutrient solution would lead to a balanced nutrient uptake resulting in improved flower quality and fertilizer efficiency.

The results presented in this study indicate that the 1/2 S of nutrient solution in aeroponics promotes the healthy growth of single-stemmed rose. This also means that nutrient composition should be based on ratio of nutrient: water (n/w) at the 1/2 S treatment. We formulated nutrient solution again based the results of 1/2 S treatment. The concentration of macro-elements were as follows; NO_3-N 8.8, NH_4-N 0,67, P 2.0, K 4.8, Ca 4.0, Mg 2.0 me · L^{-1} (Table 1). A further evaluation of this new solution (UOS solution) was conducted in the second experiment.

2. Evaluation of the nutrient solutions for growth of single-stemmed rose

To Evaluation of newly developed nutrient solutions (UOS) for growth of single-stemmed rose, the same variety of rose plant was grown in the same aeroponic system and compared with a different nutrient solution at various concentrations.

The nutrient concentrations in the drainage solution were not much changed at the early stage of crop growth, but those in the solution declined at later stage (Fig. 5). It is generally accepted that the EC in recirculated nutrient solution increase when crops are in later growing stage, such as harvesting stage (Gieling et al., 1994). However, our study, the EC values declined at 4 weeks after application in all treatments tested (Fig. 4). The reason for this decrease was not clear, but may be due to an effect of the volume in the tanks and the different growing systems. A sharp decrease of EC in the 2 S treatment of UOS solution was observed in the stage of anthesis (Fig. 4). The result of the pH at 2 S treatment in the second experiment was similar to that in the first experiment. The change of pH at 2 S and 1 S treatment were not stable compared to those in 1/2 S UOS or 1 S PBG (Fig. 4). A pH range between 5.5 and 6.5 is known to be suitable for growth of vegetables, vegetable fruits, and flowering plants in hydroponics (Kim, 1998). Numerous studies have proved that the pH of the nutrient solution has effects on absorption of salts in various ways. At a low pH, the hydrogen ions usually decrease the absorption of cations, while anion absorption may be stimulated. This is why hydrogen ions compete with cations for uptake sites. The hydroxyl or bicarbonate ions in a high pH compete with anions such as nitrate, phosphate (Schwarz, 1995). Thus,

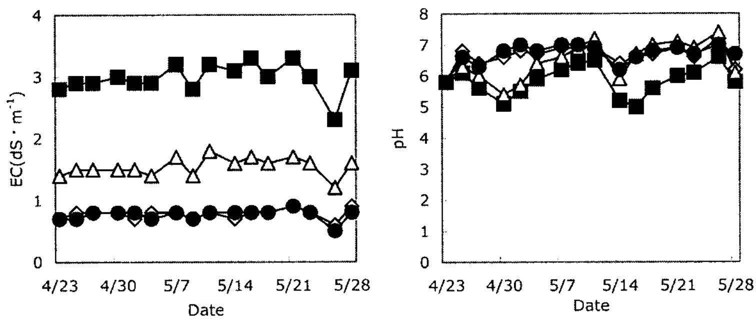

Fig. 4. Changes of EC and pH in the nutrient solution as influenced by different nutrient solutions and strength of nutrient solution in a closed aeroponics (UOS 2 S, ■ ; UOS 1S, △ ; UOS 1/3 S, ● ; and PBG 1 S, ◇).

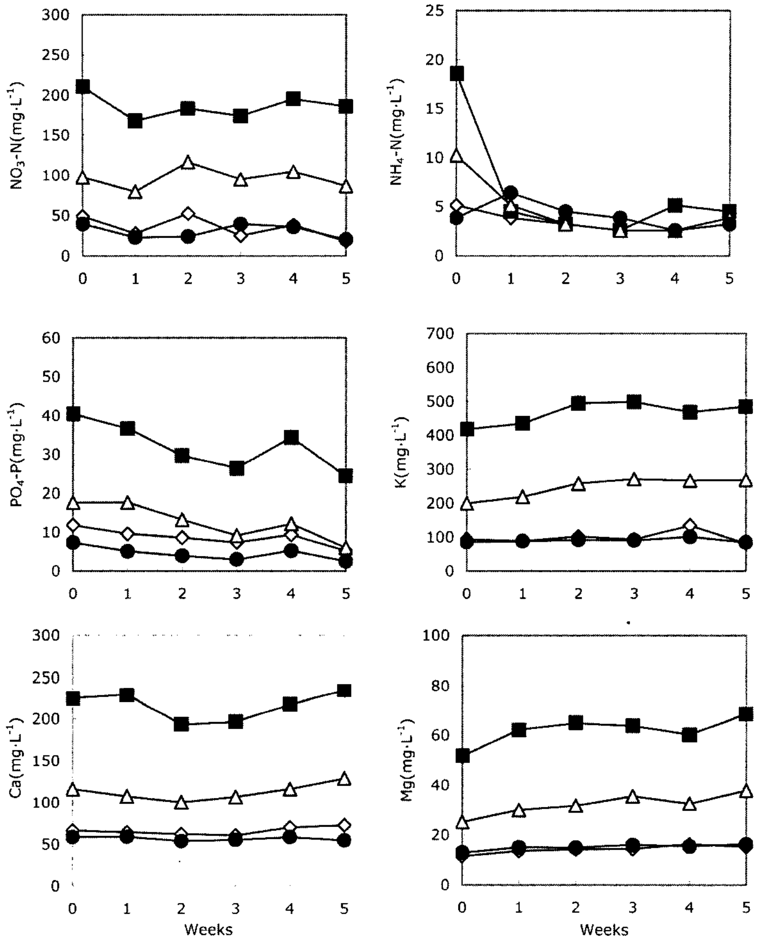

Fig. 5. Changes macro nutrient concentrations in the nutrient solution as influenced by different nutrient solutions and strength of nutrient solution in a closed aeroponics (UOS 2 S, ■ ; UOS 1S, △ ; UOS 1/3 S, ● ; and PBG 1 S, ◇).

in this study, plants seem to take up cations and anions in balance when they were grown up at the low nutrient concentrations such as 1/2 S UOS and 1 S PBG.

The absorption pattern of NO_3^- by the plants in the study did not show differences differ until week 5 in all treatments tested (Fig. 5). However, after week 1 the absorption of NH_4^+-N decreased abruptly in the treatments of 2 S and 1 S UOS (Fig. 5). The reason was that the pH of the high nutrient concentrations 2 S and 1 S UOS often declined compared to the other concentrations. In addition, a change of pH in most nutrient solutions has a strong relationship with plant stage. The vegetative development involves relatively high N uptake so that more N is needed at requiring elevated N concentration in fertilizer solution (Goto et al., 1996).

The concentration of P in 2 S declined slowly, which was similar to the result observed by Kim (1998). Gato (1994) suggested that plants grown in a relatively low concentration of P (2.0 me · L^{-1}) have good shoot growth, whilst plants grown in a high concentration of P (6.0 me · L^{-1}) do not have good foliage, but produce a high quality rose. A low P concentration seems to be better for the development of shoot growth in single-stemmed rose than a high P concentration.

Although K, Ca, and Mg in 2 S treatment of UOS solution maintained higher concentration more than those of other treatments, most of the nutrient uptake in all treatments of UOS and PBG solutions were constant (Fig. 5). According to Bloemhard et al. (1995), there was no direct relationship between the concentrations of K

Table 2. Effects of strength of nutrient solutions on the growth of single-stemmed rose in a closed aeroponics.

Con.	Fresh weight (g/plant)		Stem length	Flower dia.	Stem dia.	Flower stalk	Five-leaf-let leaves (No.)	Three-leaf-let leaves (No.)
	Stem	Root	(cm)					
1/3 S	30.16a[z]	0.93b	43.40a	9.01a	0.59a	8.98a	8.80a	2.20ab
1/2 S	25.87a	1.84b	41.40a	8.67a	0.56a	7.90a	10.20a	1.60b
1 S	29.98a	3.66b	44.00a	8.98a	0.58a	8.89a	10.00a	2.40a
3/2 S	29.14a	8.63a	43.40a	9.05a	0.57a	8.23a	10.20a	2.20ab

[z]The values followed by the same letter are not significantly different according to the Duncan's multiple range test ($P < 0.05$).

Table 3. Effects of different nutrient solutions and strength of nutrient solution on the growth of single stemmed rose in a closed aeroponics.

Nutrient solution	Con.	Fresh weight (g/plant)		Stem length	Stem dia.	Flower height	Flower stalk	Five-leaf-let leaves (No.)	Photosynthesis (μmol $m^{-2}s^{-1}$)
		Stem	Root	(cm)					
PBG[z]	1 S	17.58a[y]	2.07ab	38.00ab	0.49a	4.34a	7.86a	7.20ab	10.17a
UOS[x]	2 S	18.01a	3.19b	35.75ab	0.47a	4.14a	7.72a	6.75b	8.4a
	1 S	17.54a	3.98a	40.00a	0.52a	4.37a	8.65a	8.00a	11.77a
	1/2 S	14.25a	1.02ab	35.60b	0.52a	4.06a	5.94a	7.65ab	10.04a

[y]The values followed by the same letter are not significantly different according to the Duncan's multiple range test ($P < 0.05$).
[z]Nutrient solution of proefstation voor bloemisterij en glasgroenpe (Sonneveld and Straver, 1992).
[x]Nutrient solution of the university of Seoul (UOS).

and Ca in the nutrient solution supplied and in the root environment. The Ca, Mg and SO_4 in particular should be taken into consideration, as these ions are usually present in water sources and the input concentration could be higher than the uptake concentration (Goto et al., 1996). In general, a composition of high Ca and low NH_4^+-N concentration has a positive effect on Ca uptake by plants and on the longevity of the rose flowers and leaves (Nielsen and Starkey, 1999).

Overall plant growth such as fresh weight of above ground plant tissue and root, stem length, flower diameter, stem diameter, flower stalk and number of five-leaflet leaves and photosynthesis in all of the concentrations of UOS 1 S and PBG solution in both growing systems did not show significant differences among treatments (Table 3). As shown in Table 2 and 3, the growth of single-stemmed rose grown at 1 S was better than the other treatments. Stem length and number of five-leaflet leaves at 1 S UOS was particularly better than those in the other treatments. Although the changes in all of the nutrient solution at 1/2 S UOS were similar to these in the nutrient solution of PBG in week 5 in both growing systems, shoot fresh weight and stem length of single-stemmed rose grown in the nutrient solutions of PBG was better than that at 1/2 S UOS.

On the basis of all results presented in this study the optimum nutrient solution (UOS solution) for single-stemmed rose grown in aeroponics has been developed, and consists of the following the nutrients; NO_3-N 8.8, NH_4-N 0.67, P 2.0, K 4.8, Ca 4.0, Mg 2.0 me · L^{-1}. Further, the stability of solution was proved in the second experiment, although the first experiment and the second experiment were carried out in different seasons.

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