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ARTICLE

Growth effects of the application of new controlled-release fertilizers on *Phalaenopsis* spp.

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Abstract To develop a controlled-release fertilizer (CRF) suitable for nutrient absorption characteristics of *Phalaenopsis*, four kinds of new controlled-release fertilizer (NCRF 1–4) with different dissolution rates were developed and studied to determine the concentration and amount suitable for growth of *Phalaenopsis*. To make NCRF, new acryl-based polymers were developed and used as fertilizer coating solutions. In addition, a fluidized bed coater for coating fertilizer was developed and used in this study. To test the growth of *Phalaenopsis*, 10-month-old *Phalaenopsis* seedlings were planted in plastic pots (diameter 10 cm) filled with 100% *Sphagnum* moss and cultivated for approximately 100 days from May 29, 2015, to September 11, 2015. NCRF 1, NCRF 2, and Osmocote, an imported fertilizer, consistently exhibited release patterns of fertilizer nutrients in a directly proportional form; however, NCRF 3 and NCRF 4 displayed a sigmoid-like tendency of fertilizer nutrient release with a slower initial dissolution rate. Furthermore, leaf length, leaf width, fresh weigh, and root weight of *Phalaenopsis* were the highest when growing in 1.5 g/pot of NCRF 3 fertilizer, and the pH and electrical conductivity (EC) of the soil were stable at this concentration of NCRF 3. Based on our results, we suggest that 1.5 g/pot of NCRF 3 fertilizer is the ideal concentration and fertilizer for growing *Phalaenopsis*.

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Keywords Acryl-based polymers · Controlled-release fertilizer · Electrical conductivity · Fluidized bed coater · Fresh weight · Osmocote · Root weight

Introduction

Controlled-release fertilizer (CRF) is a fertilizer manufactured with an insoluble coat covering the surface of water-soluble fertilizer pellets [1]. It has the benefit of reducing fertilizer-induced pollution because fertilizer nutrients are gradually eluted through a semipermeable film as needed by crops [2]. There are three different types of CRF depending on the coating materials, which are sulfur, polymer resin, and sulfur/polymer-mixed resin. Recently, the use of CRF has sharply increased because the release speed of fertilizer nutrients can be adjusted to approximately 3–12 months by controlling the material and thickness of the coating.

CRFs are divided into two types, linear and sigmoid types. The linear type is a type in which the dissolution rate of the fertilizer is consistent from the beginning to the end, whereas in the sigmoid type, the fertilizer nutrients are eluded slowly at first and are eluted more quickly after a given period [3, 4]. Therefore, the sigmoid type of CRF can provide nutrients suitable for crop growth depending on the nutrient requirements of the crop, thus minimizing the loss of fertilizer nutrients [5].

To date, cultivation tests with CRFs have been conducted on a variety of horticultural and food crops, such as rice [5], strawberries [6], melons [7], peppers [8, 9], tomatoes [10], onions [11], citruses [12], and potatoes [13–15]. In most plants, the use of CRF was determined to be superior to that of short-acting fertilizer. However, the application of CRF to *Phalaenopsis* has not yet been studied.

Phalaenopsis is slow growing and does not need much fertilizer, and the improper use of fertilizer can cause physiological stress and adversely affect growth and flowering. The concentration level suitable for the *Phalaenopsis* growth is 175–200 kg/ha for nitrogenous fertilizer, 20–50 kg/ha for phosphoric fertilizer, and 50–100 ppm for potassium fertilizer. At these levels, *Phalaenopsis* exhibits good growth, as indicated by increased leaf area and the number of blossoms [16]. Studies on the method of fertilizer application in *Phalaenopsis* have been conducted; however, there are substantial differences in the reported levels of adequate fertilizer depending on the study [17–19].

In this study, to find the nutrient supply rate of the new slow-release fertilizer which is most suitable according to the growth period and growth characteristics of Phalaenopsis, we made four kinds of slow-release fertilizers with different dissolution rates of nutrients by 1%. The NCRF 1 and NCRF 2 treatments are linear pattern dissolving patterns in which the nutrient dissolution of the slow-release fertilizer is rapidly eluted from the early stage to the middle stage. The NCRF 3 and NCRF 4 treatments were applied to the pallet high sheath with the elution pattern of sigmoid type which was made very slowly at the beginning of the slow-release fertilizer and accelerated the release rate in the middle and late stage. And the growth environment of the paddy field was investigated.

Materials and methods

Plant and acrylic polymer preparation

To evaluate the quality and efficacy of the NCRFs, 10-month-old *Phalaenopsis* seedlings cultivated from Sejae Nanwon located in Dongtan-myeon, Hwaseong-si, Gyeonggi-do were purchased and grown for a 100-day growth measurement experiment from May 29, 2015, to September 11, 2015. An acrylic water-based emulsion polymer manufactured by POSTECH GLOBAL Co., Ltd. was used as the coating polymer resin for the production of the slow-release fertilizers. This polymer is a resin product with an inverted core/shell structure composed mainly of an acryl monomer and has excellent water resistance and weatherability. To allow gradual release of fertilizer nutrients within the coated fertilizer, CRF's nutrient release characteristic was improved by adjusting the degree of cross-linking and the shape of the resin. Styrene, 2-ethylhexyl acrylate, and methacrylic acid were used as the monomers for acrylic polymer preparation. Zinc solution was used to synthesize the final product and to strengthen the cross-linking and stiffening quality. The approximate quality of the final product can be quantified as having an outer coat composite solid content of 30 wt %, particle size of 150 nm, and viscosity of 120 cP.

Development of the NCRFs

The fluidized bed coater, a device used to manufacture CRFs, is shown in Fig. 1. A steam boiler was used for the heat source, and the working volume of the fluidized bed coater was set to 30 L, such that the flow of the granular compound fertilizer, with a specific gravity of 1.2 or 2 kg/batch, was not restricted inside the coater. The manufacturing process of CRF using the fluidized bed coater is as follows. Two kilograms of granular complex fertilizer with a particle size of 2–4 mm was placed in the fluidized bed coater, and the granular compound fertilizer was floated to the air at a flow rate of approximately 200 m^3/h and flow air temperature of 60 °C. After the preheating process, the amount of fluidized air was increased to 350 m^3/h and the coating material was sprayed on the surface of the fertilizer for approximately 1 h. The inner temperature of the coater was increased to 80 °C using the heater. The fertilizer was heated for 10 min, and the final product was allowed to cool. The raw materials used for manufacturing NCRF were conventional fertilizer 18(T-N)-17(P_2O_5)-15(K_2O) + TE, and only 2–4 mm size was

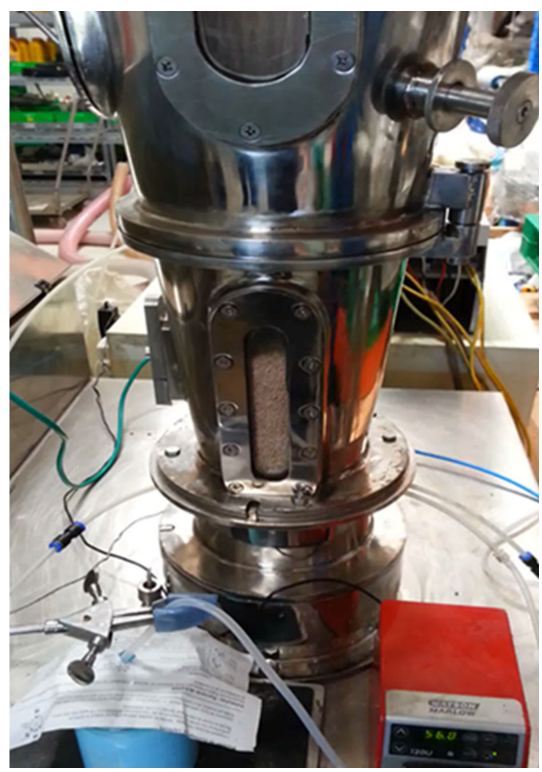

Fig. 1 Fluidized bed coater to produce controlled-release fertilizers

used to facilitate fertilizer coating. Polymer resin for fertilizer coating was coated with acrylic acid emulsion of water dispersion type and 10.2, 11.3, 12.1, and 13.0% of the weight of general practice fertilizer to produce final four kinds of NCRF slow-release fertilizer. In addition, Osmocote (14N–14P_2O_5–14K_2O, 5–6-month release time), a product manufactured by Scotts Company, USA, mainly used in domestic farms, was purchased and used for comparison with the quality of our products.

Nutrient release rate test

To measure the nutrient eluting rate of the newly produced slow-release fertilizer, the release rate tests in water and *Sphagnum* moss (New Zealand) were conducted while maintaining the temperature at 28 °C in a temperature- and humidity-controlled machine. The test was determined by placing 2.5 g of the CRF test sample in a 250-mL volumetric flask filled with distilled water. The amount of nitrogen released into the water was determined after a certain period. During the vegetative reproduction period of *Phalaenopsis*, it was necessary to maintain the temperature at least at 28 °C for growth and flowering of *Phalaenopsis*. Thus, the measurement temperature for the water release rate was set at 28 °C [20].

Dissolution rate test

The dissolution rate test was conducted in *sphagnum* moss, which is similar to the growth environment of *Phalaenopsis* in which CRF will be used as a fertilizer. As shown in Fig. 2, the CRF test sample (2.5 g) was placed in a seedling pot (diameter 10 cm) filled with *Sphagnum* moss and a *Phalaenopsis* culture and placed in a mesh bag with a diameter of approximately 1 mm^2. The mesh bag was placed on the *Sphagnum* moss, and the CRF was taken out of the mesh bag every hour to determine the nitrogen fertilizer composition. The temperature and humidity conditions were maintained at 28 °C and 80% relative humidity, and the water was adjusted to once every 2 days such that the water content of the *Sphagnum* moss soil was maintained at 45 wt%. Nitrogen analysis was conducted using the Kjeldahl distillation method after acid decomposition, according to the soil and plant analysis method [21]. *Sphagnum* moss incubated in plastic cultivation pots with 10 cm diameter was used, and the chemical composition of the *Sphagnum* moss prior to the experiment is shown in Table 1. Four different types of NCRF and Osmocote, a foreign product, were weighed to exactly 1.5 g and placed on the top surface of *Sphagnum* moss growing *Phalaenopsis*, and a *Phalaenopsis* with no additional fertilizer served as a control. As shown in Table 2, the six treatments, including the control with water only, Osmocote as the imported fertilizer, and NCRF 1–4, were repeated three times.

Chemical analysis and plant measurement

The pH and EC measurements of *Sphagnum* moss during the growth of *Phalaenopsis* were taken by dilution with distilled water at a ratio of 1: 5 (v/v) using a pH meter (OHAUS, ST300, USA) and an EC meter (OHAUS, ST300C, USA). The plant growth assay was conducted in a completely randomized manner by repeating the treatment three times per each treatment group. Leaf length, leaf number, leaf color (SPAD-502), weight, and fresh weight

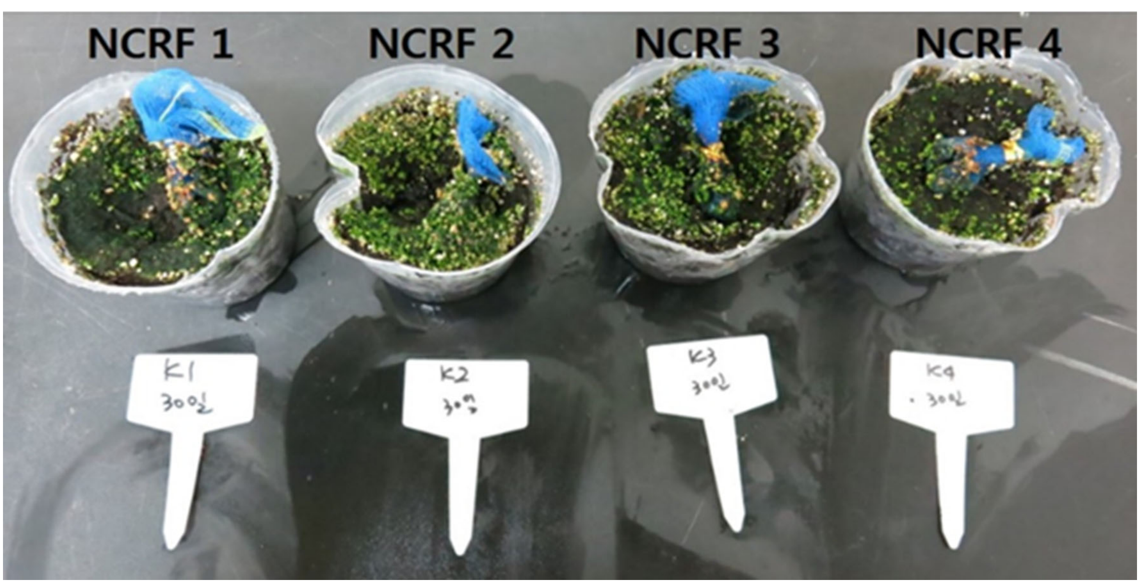

Fig. 2 Test for measuring nitrogen release rate of controlled-release fertilizer on the top surface of *Sphagnum* moss

Table 1 Chemical properties of *Sphagnum* moss used in this experiment

pH	Electrical conductivity	Total nitrogen	NH4^{+}-N	NO_3^{-}-N	Available P2O5	Exchangeable cations			Cation exchange capacity
						K	Ca	Mg	
1:5, v/v	1:5 dS $m^{-1,}$ v/v	%	%	mg/kg	mg/kg	$cmol_c/kg$			$cmol_c/kg$
5.2	0.21	0.75	0.05	398	1350	1.02	55.6	5.7	138

Table 2 Treatments and chemical properties of controlled-release fertilizer used in experiment

Treatment	Coating rate (%)[a]	Fertilizer nutrient (%)			Application rate (g/pot)
		T-N	P_2O_5	K_2O	
1. Control	–	–	–	–	–
2. Osmocote	12.4	16.5	16.3	11.4	1.5
3. NCRF[b] 1	10.2	17.8	15.8	14.0	1.5
4. NCRF 2	11.3	17.0	16.3	13.4	1.5
5. NCRF 3	12.1	16.5	15.9	13.7	1.5
6. NCRF 4	13.0	16.3	15.5	13.5	1.5

[a]Coating rate (%) = (total coated fertilizer weight – conventional fertilizer weight) ÷ conventional fertilizer weight

[b]*NCRF* new controlled-release fertilizer

were determined as per the National Institute of Standards and Technology [22]. To determine the inorganic components of *Phalaenopsis*, leaves of *Phalaenopsis* were dried in a dryer maintained at 80 °C for 3 days and analyzed after pulverizing. In addition, soil and plant analysis was conducted according to the Soil and Plant Analysis method of the Rural Development Administration [21].

Statistical analysis

Statistical analyses of the data were performed using Duncan's multiple-range test (DMRT, $p = 0.05$) using the SAS Enterprise Guide 3.0 statistical program.

Results and discussion

Nitrogen release rate of controlled-release fertilizer in water and on *Sphagnum* moss

The analytical results of the nitrogen release rate of NCRF underwater are illustrated in Fig. 3. NCRF 1, which had the thinnest coating, displayed the fastest fertilizer nitrogen release, whereas NCRF 4, which had the thickest coating, exhibited the slowest release time. In general, NCRF 1 and NCRF 2 had faster release rates, and NCRF 3 and NCRF 4 exhibited slower release rates compared to Osmocote. Although NCRF 1, NCRF 2, and Osmocote had a linear-type fertilizer nitrogen release pattern, NCRF 3 and NCRF 4 exhibited a sigmoid-type fertilizer nitrogen release

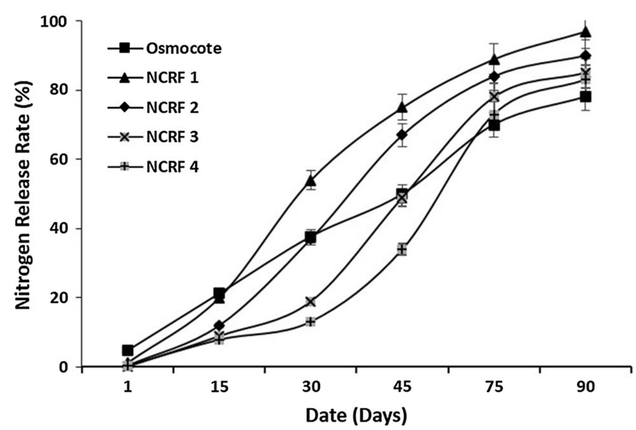

Fig. 3 Nitrogen release rate of controlled-release fertilizer in water

pattern in which the fertilizer nitrogen release rate remained low during the initial period, sharply increased during the intermediate period, and remained low during the final period.

In addition, the analytical result of nitrogen release rate of NCRFs on the top surface of *Sphagnum* moss is shown in Fig. 4. Because the nitrogen release experiment was on *Sphagnum* moss, NCRF 1, NCRF 2, and Osmocote displayed a pattern similar to the underwater release rates, which was a linear-type fertilizer nitrogen release pattern. On the other hand, NCRF 3 and NCRF 4, which followed a sigmoid-type fertilizer nitrogen release pattern underwater, released nitrogen faster than when underwater for the first

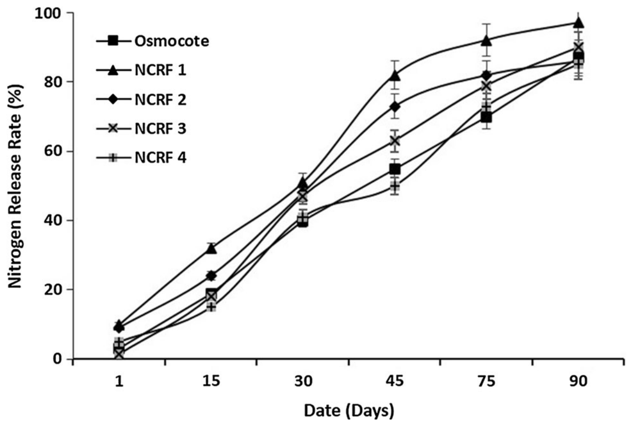

Fig. 4 Nitrogen release rate of controlled-release fertilizer on the top surface of *Sphagnum* moss

30 days, after which it displayed a similar pattern as that of the underwater release rates.

Effects of various CRFs on leaf growth of *Phalaenopsis*

The growth results of *Phalaenopsis* as a function of the use of CRF with different nutrient release rates and application amounts are displayed in Table 3. In general, leaf length tended to increase with the increase in the application amount of CRF, whereas leaf width and leaf number rarely increased. In addition, growth and development of *Phalaenopsis* were superior in the CRF pots than in the control pots with no fertilizer applied. With CRF of 0.5 g/pot, there was no significant difference for leaf length across all pots. Leaf width was greatest in the NCRF 3 pot, and leaf number in the NCRF 1 pot. With CRF of 1.0 g/pot, leaf length was greatest in the NCRF 3 pot, and leaf width was greatest in the NCRF 3 pot. Because leaf length and leaf width in the NCRF 3 pot exhibited statistically significant differences compared to other pots with CRF of 1.5 g/pot, it was confirmed that NCRF was most appropriate for the growth and development of *Phalaenopsis* and the most appropriate application amount was 1.5 g/pot.

Poole and Sheeley [23] reported that applying 4 g of Osmocote in a 10-cm-diameter pot resulted in better seedling growth than applying 16 N–1.7 P–10.3 K water-soluble nutrient fertilizer three times per month using a 200 mg/L concentration. The growth difference resulted from the CRF providing nutrients consistently, whereas the water-soluble nutrient fertilizer failed to provide nutrients consistently that were most appropriate to the growth of *Phalaenopsis*. Therefore, the application rate and application amount of CRF were different from those of this test.

Effects of various CRFs on top and root fresh weight of *Phalaenopsis*

The fresh weight of the aboveground parts and root weight of the underground parts are shown in Table 4. The fresh weight of the aboveground parts was estimated to vary between 74.3 g and 111.2 g, and the root weight in the underground part varied between 32.8 and 71.5 g. Because there were significant differences depending on the type and application amount of CRF, we confirmed that *Phalaenopsis* is sensitive to the concentration of fertilizer nutrients and that it is important to choose the most appropriate CRF. In general, compared to the control pot with no fertilizer applied, the CRF pots showed superior results in both aboveground and underground growths.

The growth of underground roots was significantly less than that of the control at 1.5 g/pot of Osmocote, indicating that concentration damage because of the fertilizer occurred. This was consistent with previous findings, which reported that applying the imported CRF in amounts exceeding 1.0 g/pot resulted in significant deterioration of underground growth, decomposition of the growing roots, and the tendency of growth suspension among the growing roots at the surface of the seedling culture [24]. Conversely, it was confirmed that the underground and

Table 3 Effects of various controlled-release fertilizers on leaf growth of *Phalaenopsis* after 3-month cultivation

Treatment	0.5 g/pot			1.0 g/pot			1.5 g/pot		
	LL (mm)	LW (mm)	LN (ea)	LL (mm)	LW (mm)	LN (ea)	LL (mm)	LW (mm)	LN (ea)
Control	139.7^{a*}	67.3^{a}	6.7^{ab}	139.7^{a}	67.3^{a}	6.7^{a}	139.7^{a}	67.3^{a}	6.7^{a}
Osmocote	146.0^{a}	71.7^{ab}	6.7^{ab}	149.3^{ab}	73.3^{ab}	7.0^{a}	156.3^{ab}	73.7^{b}	6.7^{a}
NCRF 1	142.3^{a}	67.7^{a}	7.7^{b}	149.7^{ab}	72.0^{ab}	6.3^{a}	155.0^{ab}	71.3^{ab}	7.0^{a}
NCRF 2	148.7^{a}	74.7^{ab}	7.0^{ab}	154.0^{ab}	73.3^{ab}	6.3^{a}	161.0^{bc}	72.0^{ab}	6.7^{a}
NCRF 3	153.3^{a}	78.3^{b}	6.0^{a}	166.0^{b}	77.0^{b}	6.3^{a}	176.7^{c}	79.3^{c}	6.7^{a}
NCRF 4	149.0^{a}	73.3^{ab}	6.3^{a}	158.3^{ab}	72.3^{ab}	6.3^{a}	142.3^{ab}	70.3^{ab}	7.0^{a}

LL leaf length, *LW* leaf width, *LN* leaves number

*Those marked with different letters in each column are significantly different at $p < 0.05$ as analyzed by Duncan's multiple-range test

Table 4 Effects of various controlled-release fertilizers on top and root fresh weight of *Phalaenopsis* after 3-month cultivation

Treatment	0.5 g/pot		1.0 g/pot		1.5 g/pot	
	Fresh weight (g/pot)		Fresh weight (g/pot)		Fresh weight (g/pot)	
	Plant	Root	Plant	Root	Plant	Root
Control	74.9a*	43.9a	74.9a	43.9a	74.9a	43.9b
Osmocote	83.7b	61.3c	102.8c	52.7b	88.9b	32.7a
NCRF 1	97.9c	71.8d	101.2c	58.3c	75.9a	44.0b
NCRF 2	94.1c	61.6c	101.3c	60.7c	86.8b	39.5b
NCRF 3	83.8b	50.5b	103.6c	63.2c	111.6c	63.4d
NCRF 4	100.3c	64.5c	89.9b	46.1a	89.7b	53.0c

*Those marked with different letters in each column are significantly different at $p < 0.05$ as analyzed by Duncan's multiple-range test

aboveground growths of *Phalaenopsis* were best in NCRF 3, which was developed for this experiment, at 1.5 g/pot.

Leaf characteristics of *Phalaenopsis* as affected by various CRFs

The analytical results of inorganic concentrations in the *Phalaenopsis* leaves are shown in Table 5. In general, there was no notable difference among tested plants, and the mineral concentration in the *Phalaenopsis* leaf was the highest in the 1.0 g/pot of NCRF 2 and the 1.5 g/pot of NCRF 3. However, the N, P, and Mg concentrations were low, and the K and Ca concentrations were high, similar to the mineral concentration in the *Phalaenopsis* leaf analyzed by Kim et al. [25]. In particular, the concentration level of K was higher than that of N and P. According to the findings of Zheng et al. [26], the reason why the concentration level of K is high in orchids, regardless of the type, is that it plays an important role in osmoregulation in orchids, which have stronger drought resistance than other plants. Poole and Seeley [27] reported that the concentration level of K was 3–4 times higher than that of N in *Phalaenopsis* being an epiphytic orchid, and it was 0.5 times higher in *Cymbidium* as well.

Table 5 Leaf macronutrient contents of *Phalaenopsis* as affected by various controlled-release fertilizers after 3-month cultivation

Treatments	Content (%)					
	N	P	K	Ca	Mg	Sum
Control (Mock)	0.98a*	0.29a	2.02a	3.05b	0.38b	6.72b
Osmocote 0.5 g/pot	1.43b	0.29a	1.92a	2.98b	0.42b	7.04b
NCRF 1 0.5 g/pot	1.43b	0.31a	2.12a	3.31b	0.41b	7.58b
NCRF 2 0.5 g/pot	1.01a	0.30a	2.82c	3.35b	0.41b	7.89c
NCRF 3 0.5 g/pot	0.97a	0.33a	2.79b	3.09b	0.43b	7.61c
NCRF 4 0.5 g/pot	1.05a	0.29a	1.99a	3.28b	0.40b	7.01b
Osmocote 1.0 g/pot	1.02a	0.31a	2.32b	4.11c	0.38b	8.14c
NCRF 1 1.0 g/pot	0.92a	0.54c	2.89c	2.78a	0.25a	7.38b
NCRF 2 1.0 g/pot	0.97a	0.36b	2.82c	3.85c	0.53c	8.53c
NCRF 3 1.0 g/pot	0.80a	0.29a	2.43b	3.66c	0.47b	7.65c
NCRF 4 1.0 g/pot	0.82a	0.31a	1.76a	2.48a	0.42b	5.79a
Osmocote 1.5 g/pot	0.96a	0.34a	2.68b	3.05b	0.40b	7.43b
NCRF 1 1.5 g/pot	0.98a	0.32a	2.23b	3.43b	0.45b	7.41b
NCRF 2 1.5 g/pot	1.26b	0.27a	2.41b	3.53b	0.46b	7.93c
NCRF 3 1.5 g/pot	1.87c	0.29a	2.04a	3.56b	0.43b	8.19c
NCRF 4 1.5 g/pot	0.96a	0.25a	1.98a	3.31b	0.36b	6.86b

*Those marked with different letters in each column are significantly different at $p < 0.05$ as analyzed by Duncan's multiple-range test

Because the 1.5 g/pot concentration was confirmed to be the closest to the ideal CRF concentration, according to the above-detailed results, leaf color was measured using the 1.5 g/pot plants and these data are shown in Table 6. From May, when the fertilizer application started, to July, leaf color fell slightly. However, leaf color fell dramatically beginning in August, as temperature remained high. There was no statistically significant difference in leaf color across experimental pots compared to the control pot. Only the leaf color from the Osmocote pot measured on July 24 exhibited a statistically significant difference.

Soil pH and EC changes of *Sphagnum* moss as affected by various CRFs

The pH and EC levels within the culture soil during the *Phalaenopsis* growth period are displayed in Figs. 5 and 6. Until the beginning of July, when the heat wave started, the pH of *Phalaenopsis* culture soil was unchanged and slightly increased at the end of July and then dramatically fell beginning in August. Because the pH level in some pots tended to decrease with an increase in fertilizer, it was confirmed that more hydrogen ions were eluted from fertilizer because of the high temperatures during summer. Helton [28] reported that the soil pH level most appropriate for *Phalaenopsis* growth was 4.5–5.5, and Wang and Gregg

Table 6 Leaf greenness of *Phalaenopsis* as affected by various controlled-release fertilizers for 3-month cultivation

Treatments	June 12	June 26	July 10	July 24	August 10	September 11
Control	66.2[a*]	66.5[a]	65.8[a]	63.2[a]	55.7[a]	55.4[a]
Osmocote	70.8[a]	69.8[a]	69.1[a]	70.7[b]	63.0[a]	61.7[a]
NCRF 1	65.7[a]	68.6a	69.4[a]	68.3[ab]	58.9[a]	56.2[a]
NCRF 2	67[a]	63.7[a]	65.2[a]	61.9[ab]	54.2[a]	54.8[a]
NCRF 3	67.9[a]	69.1[a]	67.8[a]	66.9[a]	56.3[a]	54.5[a]
NCRF 4	64.6[a]	66.1[a]	65.5[a]	64.6[ab]	55.3[a]	54.2[a]

(Unit: SPAD)

*Those marked with different letters in each column are significantly different at $p < 0.05$ as analyzed by Duncan's multiple-range test

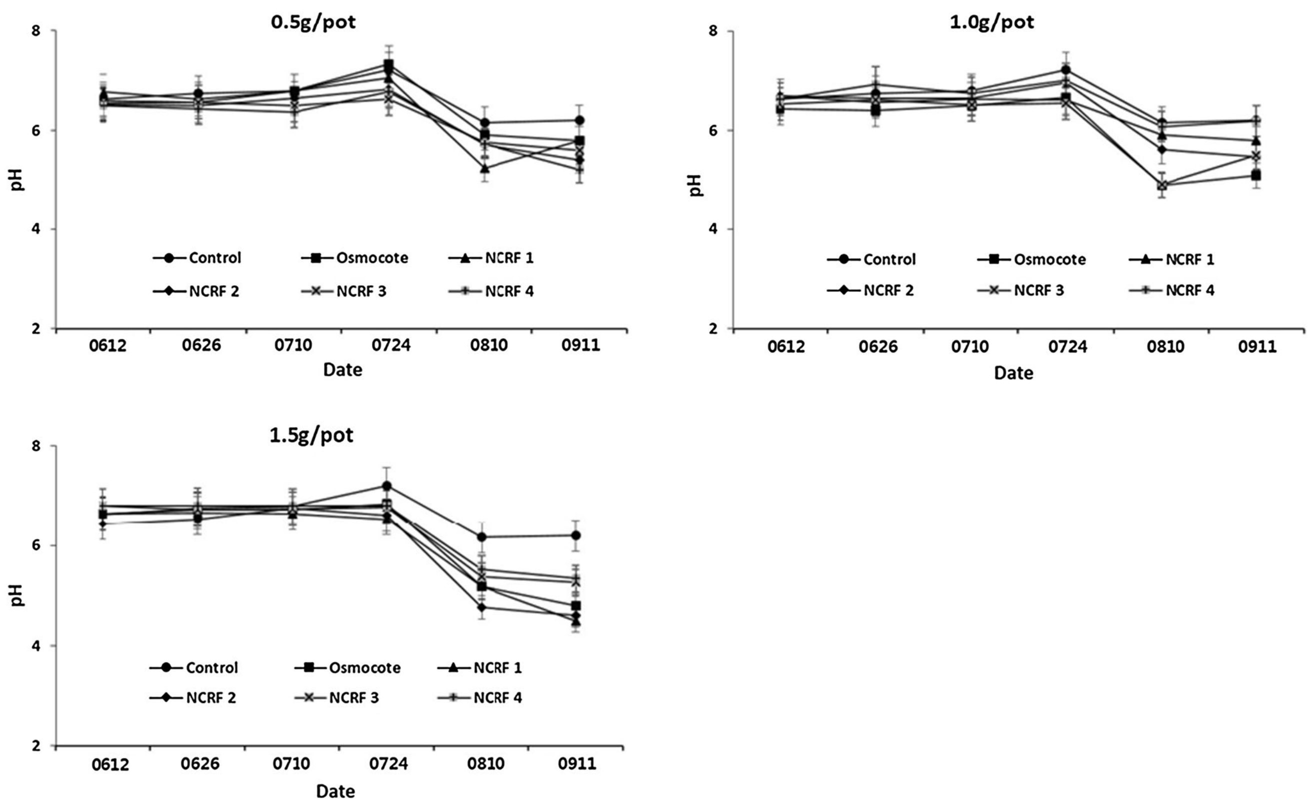

Fig. 5 Soil pH changes in *Sphagnum* moss as affected by various controlled-release fertilizers for 3-month cultivation

[29] reported that the *Phalaenopsis* leaf and flower displayed the greatest growth when the pH level of decomposed pine bark was 4.4. The pH of *Sphagnum* moss in this experiment was approximately 6–7 until August and 5–6.5 beginning in August. Furthermore, similar to the findings of Wang [30], who reported that when the fertilizer concentration level in the *Phalaenopsis* culture soil was high then the pH level decreased, the pH level within the culture soil in this experiment decreased as the EC dramatically increased after August. In addition, the EC level of the *Phalaenopsis* culture soil tended to increase with increasing fertilizer application rate, which was remarkable in NCRF 1 and NCRF 2. Additionally, in the Osmocote 1.5 g/pot, EC increased to a maximum of 3.0 ds/m, resulting in partial root damage because of high fertilizer concentration during summer. Yao [31] showed that as fertilizer concentration increased, pH of the moss after the initial fertilization declined more. This may be the result of the ion exchange between the substrate and the nutrient solution. Sphagnum moss is a natural material, which has numerous negatively charged sites that attract H^+. On fertilizing, the cations in the fertilizer replace the H^+ on these sites. Therefore, as fertilizer concentration increases, more H^+ is released by the moss, causing the pH of the moss substrate to decline more [32]. Therefore, it was confirmed that to prevent *Phalaenopsis* root damage because of the

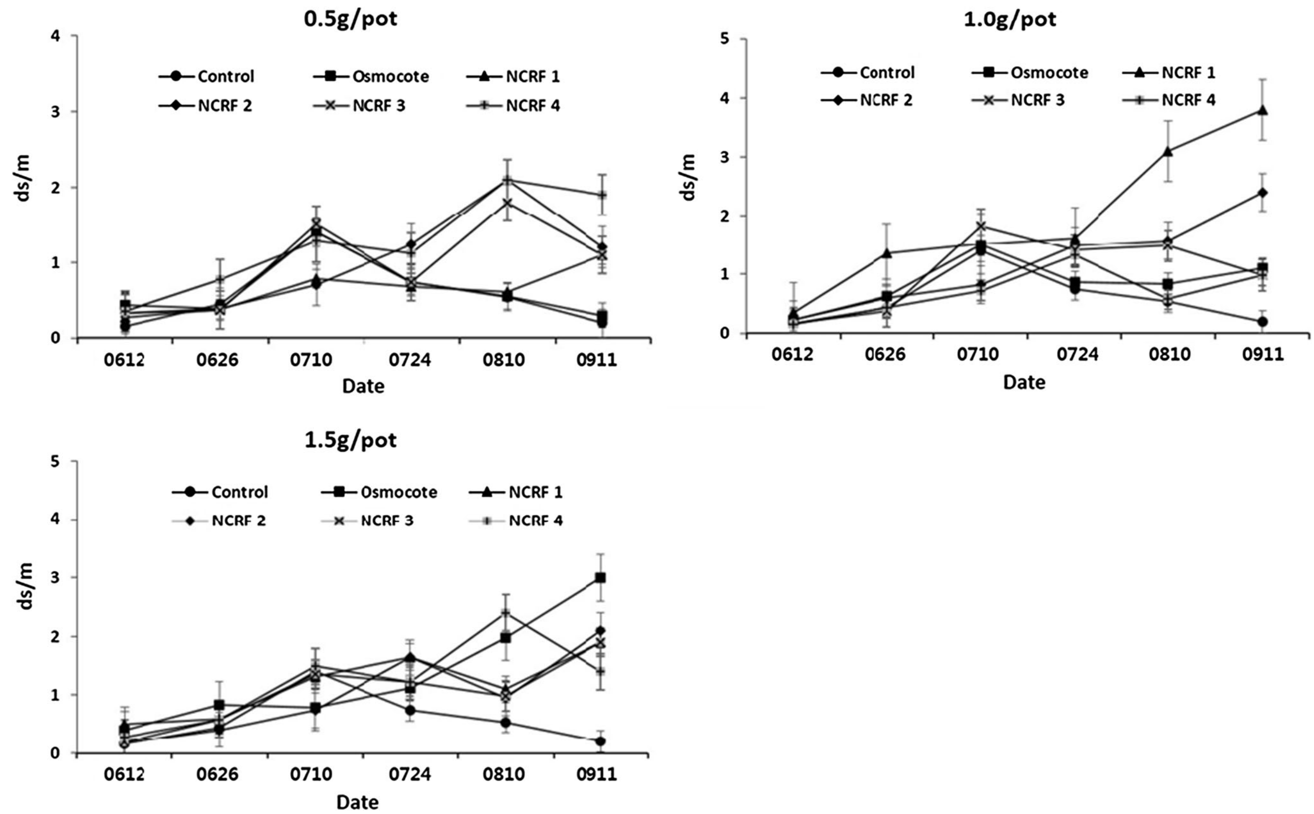

Fig. 6 Soil EC changes in *Sphagnum* moss as affected by various controlled-release fertilizers after 3-month cultivation

application of high concentration fertilizer during summer, it is crucial to use the NCRF appropriate to the nutrient absorption characteristic of *Phalaenopsis* while adjusting its dissolution rate.

In summary, four types of NCRFs with different dissolution rates were self-developed. An analysis on the effects of these NCRFs on *Phalaenopsis* growth revealed that the *Phalaenopsis* growth (leaf length, leaf width, fresh weight, and root weight) was the best in the NCRF 3 1.5 g/pot, and the soil pH and EC levels were stable, providing the most appropriate environment for *Phalaenopsis* growth.

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