Nitrogen, Phosphorus, and Potassium Requirements for Optimizing Growth and Flowering of the Nobile *Dendrobium* as a Potted Orchid

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Abstract. Experiments were conducted to determine how nitrogen (N), phosphorus (P), and potassium (K) rate and fertilizer termination time affect the growth and flowering of a *Dendrobium nobile* Lindl. hybrid, *Dendrobium* cv Red Emperor ‘Prince’. Nitrogen, P, and K were tested in separate experiments as a factorial combination of five rates and three termination dates (1 Sept., 1 Oct., and 1 Nov. 2005). Nitrogen and K rates were 0, 50, 100, 200, and 400 mg·L⁻¹. Phosphorus rates were 0, 25, 50, 100, and 200 mg·L⁻¹. Levels of the nutrients not being tested were held constant. For all nutrients, ending fertilization on 1 Sept. resulted in greater or similar pseudobulb thickness compared with ending fertilization on 1 Oct. or 1 Nov. Pseudobulbs grew taller as the N rate increased, peaking at 100 and 200 mg·L⁻¹. There were interactions between the N rate and fertilizer termination time on all reproductive characteristics. For all fertilizer termination times, flower number increased once N was applied. When ended on 1 Nov., 200 and 400 mg·L⁻¹ N caused a delay to reach anthesis. All P rates resulted in taller plants with equally more nodes when compared with 0 mg·L⁻¹. As the K rate increased from 0 to 100 mg·L⁻¹, plant height increased, with no further increase at higher rates. The number of leaves remaining increased as N and K rates increased up to 200 mg·L⁻¹. Total flower number and flowering node number increased as the K rate increased to 100 mg·L⁻¹ (terminated on 1 Sept.) or 50 mg·L⁻¹ (terminated on 1 Oct. or 1 Nov.). In the fourth experiment, only N was ended at four termination times, whereas all other nutrients continued to be supplied until flowering. Control plants received all fertilizer elements until flowering. The duration of N application did not affect vegetative or flowering characteristics. No aerial shoots were observed as a result of prolonged application of N at all rates. In summary, 100 mg·L⁻¹ N, 25 mg·L⁻¹ P, and 100 mg·L⁻¹ K are recommended for optimal vegetative growth and reproductive development of *Dendrobium* cv Red Emperor ‘Prince’.

The production of potted orchids has increased since the early 1990s because of advances in propagation and cultivation techniques and consumer demand. Orchids are recognized as a profitable crop by commercial growers (Britt, 2000). In 2006, the USDA estimated the wholesale value of orchids in the United States to be \$144 million (USDA, 2006), with *Phalaenopsis* Blume constituting the majority of production.

Although *Phalaenopsis* remains the most popular potted orchid sold, the types of orchids on the market are becoming more diversified. Potted hybrid *Dendrobium* Sw. plants are being cultivated at an ever-increasing rate. The species *Dendrobium nobile* Lindley (the nobile dendrobium) is native to Burma, India, Indochina, and Thailand (Baker and Baker, 1996), and is one of the most frequently cultivated because of its potential to flower abundantly when grown under favorable conditions. Hybrids made from *D. nobile* have the potential to become very popular in the flowering potted plant market because, as tastes of the consumer change, the demand for other types of orchids emerges.

In the past, most orchid production research in the United States focused on *Phalaenopsis* to help growers produce them more efficiently (Wang, 1996; Wang, 2000; Wang and Konow, 2002). In contrast to *Phalaenopsis*, information about the produc-

tion requirements for hybrid nobile dendrobium remains largely unknown. One study found that when grown in *Sphagnum magellanicum* Brid. or hemlock (*Conium maculatum* L.) bark, pseudobulb number, length, and width, as well as leaf number, were all highest at 1000 mg·L⁻¹ N (Miwa and Ozaki, 1975). However, plants that received 1000 mg·L⁻¹ N produced the least flowering nodes and resulted in the greatest number of aerial shoots. This N rate seems unrealistically high and could have caused root injury (Wang, 1998). Lack of P resulted in decreased pseudobulb number, length and width, and leaf number. Flowering node number and number of flowers per node decreased and flowering was delayed when no P was applied. Potassium at any level, including 0 mg·L⁻¹, was shown to have no effects on plants (Miwa and Ozaki, 1975). The requirements for mineral nutrients, particularly N, P, and K, temperature, and light of the more modern nobile dendrobium cultivars require investigation. The nutrient termination time is important in this species to produce a flower rather than an aerial shoot from a pseudobulb node (Yamamoto Dendrobiums, 2006).

The objective of this study was to determine how various rates of N, P, and K and nutrient termination times would affect the growth and flowering of *Dendrobium* cv Red Emperor ‘Prince’.

Materials and Methods

One-year-old *Dendrobium* cv Red Emperor ‘Prince’ liners, each having a single pseudobulb, were received from Yamamoto Dendrobiums (Mountain View, HI) on 3 Feb. 2005. The young plants were propagated from single-node stem cuttings in 72-cell plug trays filled with sphagnum moss as the root substrate. After arrival, plants were potted singly in 10.2-cm (top diameter, 414 mL vol.) standard round green plastic pots on 4 Feb. 2005 in a root substrate consisting of 2 coarse sphagnum peat:1 perlite (no. 3):1 diatomite (no. 3; 90% silicon dioxide, 10% elemental minerals; Diatomite USA, Elma, NY; by volume) with 0.5 g·L⁻¹ Micromax (a micronutrient source; The Scotts Company, Marysville, OH), and 5.0 g·L⁻¹ powdered dolomite.

Immediately after potting, plants were watered with reverse osmosis (RO) water containing a fungicide (Banrot 40% WP; Scotts-Sierra Crop Protection Company, Marysville, OH) at a rate of 59.8 mg·L⁻¹ to prevent root rot. Plants continued to be watered with RO water until 22 Feb. 2005 when treatments commenced.

Three experiments were conducted simultaneously because of availability of plant materials. Each of the N, P, and K experiments was a factorial treatment combination of five N, P, or K rates and three fertilizer termination times. The five rates for N and K were 0, 50, 100, 200, and 400 mg·L⁻¹ and for P were 0, 25, 50, 100, and 200 mg·L⁻¹. In 0 mg·L⁻¹ rates, only the nutrient being tested

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was eliminated. Each experiment was designed to allow for only N, P, or K rate to change while all other nutrient rates were held constant (Table 1). N stayed constant at 100 mg·L⁻¹ in the P and K experiments. P was held constant at 200 mg·L⁻¹ in the N experiments and at 250 mg·L⁻¹ in the K experiments. K was kept constant at 250 mg·L⁻¹ in the N and P experiments. Analytical grade CaCl₂·H₂O, KH₂PO₄, KNO₃, MgSO₄·7H₂O, NH₄NO₃, and NH₄H₂PO₄ were used to add nutrients to the fertilizer solution.

The three fertilizer termination times for all experiments were 1 Sept. [FT-1, 209 d after planting (DAP)], 1 Oct. (FT-2, 239 DAP), and 1 Nov. (FT-3, 270 DAP) 2005. At each fertilizer termination time, fertilizer application was ended and plants received only plain water when watering was needed.

A single plant represented an experimental unit and each treatment was replicated 10 times in a randomized complete block design within each experiment. There were 150 plants in each experiment.

At the beginning of the experiment, 15 pots were placed in each 29.5 × 50.5-cm molded carrying tray (4.00 AZ Transport Tray; Landmark Plastic Corporation, Akron, OH), spaced 7.6 cm apart to simulate commercial growing conditions. To prevent lodging, plants were supported in July 2005 with bamboo stakes (Bamboo Stake Co., Lakeland, FL) cut at 30.5 cm. On 6 Aug. 2005, plants from the middle row of the carrying trays were removed and placed in additional trays to improve spacing and air circulation. In mid-December 2005, to prepare for flowering, each of the 10.2-cm pots was placed inside a 14.6-cm (1.77 L) pot surrounded by pea gravel and was given additional support with longer bamboo stakes. Pots were spaced at 232 cm²/pot.

For all experiments, pots were watered by hand as needed when the medium was dry, and the surface was light in color by applying 100 mL/pot of the designated nutrient solution with 50% leaching fraction. As plants grew, 150 mL with 50% leaching fraction of the nutrient solution was applied per pot. After the termination of fertilization, plants

were watered with plain RO water by a hand-held hose. Insecticides [Azadirachtin (Azatin) and Cyfluthrin (Decathlon); Olympic Horticulture Products, Mainland, PA] and a fungicide [Iprodione (Chipco); Bayer Environmental Science, Montvale, NJ] were applied at recommended rates as needed throughout the growing period.

Plants were grown in a greenhouse at lat. 30°37'40"N and long. 96°20'3"E with glass sides and a polycarbonate roof until the time of full flower. From February to Dec. 2005, temperature set points in the greenhouse were 24 °C day/18 °C night. From February to Apr. 2005, when two new shoots emerged from the base of an old pseudobulb, the second emerging shoot was removed to maintain one shoot per plant. From March to May, flower buds that formed on some of the old pseudobulbs were removed as needed to keep plants vegetative. Starting 15 Dec. 2005, temperature set points were dropped to 18 °C day/15 °C night to promote flower initiation. On 17 Jan. 2006 after flower initiation, temperature set points in the greenhouse were raised to 22 °C day/17 °C night to promote flowering. Data loggers (HOBO H8; Onset Computer Corp., Bourne, ME) were used to measure and record the actual greenhouse temperature. Greenhouse light levels were monitored at plant canopy level using line quantum sensors (LQS 50-3; Apogee Instruments, Logan, UT). Average monthly temperature ranged from a daytime high of 28 °C in August to a nighttime low of 14 °C in December (Fig. 1), and the maximum daily light integral ranged from a high of 7.5 mol·m⁻²·d⁻¹ in July to a low of 4.2 mol·m⁻²·d⁻¹ in December (Fig. 1).

Data on plant height, pseudobulb (stem) node number, pseudobulb width and thickness, and number of leaves remaining were taken in December after all pseudobulbs had matured. Pseudobulb maturation was defined as the time when the uppermost leaf had fully expanded, the pseudobulb had fully swollen, and the top of the pseudobulb became rounded. Height was measured from the base to the top of the pseudobulb. Pseudobulb width and thickness measurements were taken with a digital caliper (Model 06-664-

16; Control Company, Friendswood, TX). Several locations on the pseudobulb were measured and the thickest/widest portion of the pseudobulb was recorded.

In February and Mar. 2006, total flower number, apical nonflowering node number (i.e., the number of nodes above the last flowering node at the top of the pseudobulb), flower diameter, and days to anthesis were collected. Reporting the number of apical nonflowering nodes is important because flowers to the top of the pseudobulb are more aesthetically desirable. Flower diameter was measured from one flower per plant at the middle flowering node. Days to anthesis were the days from planting to the day the petals of the first flower were observed to separate on each plant.

In the extended N application experiment, plants were fertilized at each watering with the same 100 mg·L⁻¹ N fertilizer solution as in the previous N experiment, while P and K were held constant at 200 and 250 mg·L⁻¹, respectively. Calcium (CaCl₂·2H₂O) was supplied at 100 mg·L⁻¹ and Mg (MgSO₄·7H₂O) was supplied at 50 mg·L⁻¹. At each fertilizer termination time, N was removed from the nutrient solution but P, K, Ca, and Mg continued until the time of full flower. Control plants (FT-C) received all fertilizer elements until termination of the experiment. This experiment differs from the N experiment, where all nutrients were ended at each fertilizer termination time. There were four termination times: 1 Sept., 1 Oct., 1 Nov., and 1 Dec. Other cultural parameters were as described above. There were 10 single-plant replications per treatment arranged in a randomized complete block design, for a total of 50 plants. Data were analyzed using analysis of variance and least squared difference (LSD) test by SAS program (SAS 8.01; SAS Institute, Cary, NC)

Results

Nitrogen. For the vegetative parameters measured at pseudobulb maturity, there were no interactions between the N rate and fertilizer termination time with the exception of number of leaves remaining. In the absence of N, five to six leaves remained on plants when the fertilizer application was ended at FT-1 (1 Sept. 2005) than when it was applied for an additional 30 or 60 days (two leaves; Fig. 2). Plants had a similar

Table 1. The amount of chemicals used in g·L⁻¹ to prepare nutrient solutions of various N, P, and K concentrations.

Experiment	Concn (mg·L ⁻¹)	KH ₂ PO ₄	KNO ₃	NH ₄ NO ₃	NH ₄ H ₂ PO ₄
(N)	0	8.42	0	0	0
	50	8.42	0	1.37	0
	100	8.42	0	2.75	0
	200	8.42	0	5.48	0
	400	8.42	0	10.97	0
(P)	0	0	6.20	0.30	0
	25	1.06	5.42	0.60	0
	50	2.11	4.64	0.89	0
	100	4.21	3.07	1.54	0
	200	8.44	0	2.75	0
(K)	0	0	0	0.30	7.12
	50	1.67	0	0.77	5.70
	100	3.35	0	1.26	4.27
	200	6.69	0	2.24	1.46
	400	6.69	4.97	0	1.46

Fig. 1. Average day and night temperatures and average daily light integral per month in the greenhouse at canopy level of *Dendrobium* cv Red Emperor 'Prince' measured from Feb. 2005 to Mar. 2006.

Fig. 2. Effect of nitrogen rate and fertilizer termination time on the number of leaves remaining counted at pseudobulb maturity for *Dendrobium* cv Red Emperor 'Prince'. FT-1 = first fertilizer termination time, 1 Sept. 2005. FT-2 = second fertilizer termination time, 1 Oct. 2005. FT-3 = third fertilizer termination time, 1 Nov. 2005. Bars indicate $\pm$ SE of the mean.

number of leaves remaining at each of the N rates from 50 to 400 mg·L⁻¹ regardless of N termination times (Fig. 2). Fertilizer termination time had no effect on node number (data not shown).

For all termination times, plants became taller and had more nodes as the N rate increased from 0 to 50 mg·L⁻¹ (Table 2), reaching a peak at 100 and 200 mg·L⁻¹ N, and were shorter when N increased to 400 mg·L⁻¹. Nitrogen rates did not result in any difference in pseudobulb width or thickness, except at 400 mg·L⁻¹ N, which resulted in smaller pseudobulb width and thickness. Pseudobulbs were wider (data not shown) and thicker when fertilization was ended at FT-1 compared with FT-2 and FT-3, with no differences between the latter two (Fig. 3A).

As the N rate increased from 0 to 50 mg·L⁻¹, total flower number increased for all fertilizer termination times and continued to increase for FT-2 to 100 mg·L⁻¹ N (Figs. 4A and 5A). When fertilization was ended at FT-1 and FT-2, plants given 200 mg·L⁻¹ N had flower numbers similar to that at 100 mg·L⁻¹ N. When fertilization was ended at FT-3, total flower number decreased from 21 flowers at 200 mg·L⁻¹ N to 12 flowers at 400 mg·L⁻¹ N.

At 0 mg·L⁻¹ N, FT-1 plants had larger flowers (6 cm) than those when N was ended at FT-2 or FT-3 (5 cm). Nitrogen rates from 50 to 200 mg·L⁻¹ resulted in plants with similar flower diameter (7 cm) for all fertilizer termination times.

Regardless of N rate, days to anthesis were similar for both FT-1 and FT-2 fertilizer

termination times (Fig. 6A). At FT-3, 200 and 400 mg·L⁻¹ N caused a delay to reach anthesis.

Phosphorus. The P rate and fertilizer termination time affected vegetative growth. The P rate at 25 mg·L⁻¹ caused plants to be taller with more nodes than 0 mg·L⁻¹ (Table 3). However, a further increase of P up to 200 mg·L⁻¹ did not result in any additional increase in node number. Leaf number remaining was largest at P rates between 25 and 100 mg·L⁻¹, with an average of 19 leaves. Pseudobulbs were widest at 100 mg·L⁻¹ P and were least at 0 mg·L⁻¹ P. Pseudobulb thickness was similar at 25 to 200 mg·L⁻¹ P, but was thinner at 0 mg·L⁻¹ P (Table 3).

There were effects of fertilizer termination time on plant height, leaves remaining, and pseudobulb width, but the differences were small and not commercially meaningful (data not shown). Pseudobulb thicknesses were similar for FT-1 and FT-2, but were thinner at FT-3 (Fig. 3B).

Total flower number per plant was affected by the P rate and fertilizer termination time. Plants supplied with 25 to 200 mg·L⁻¹ P produced an average of 29 flowers per plant (Figs. 4B and 5B). Plants produced the most flowers (30) when fertilization was ended at FT-2 (Fig. 4B). The least number of apical nonflowering nodes was produced at 0 mg·L⁻¹ P (three nodes) compared with rates of 25 to 200 mg·L⁻¹ P (four to five nodes).

Days to anthesis was the only variable showing an interaction between the P rate and fertilizer termination time (Fig. 6B). For all three termination times, plants that were not supplied with P flowered later than those receiving P.

Potassium. For all fertilizer termination times, pseudobulb thickness increased as K increased from 0 to 200 mg·L⁻¹ and then decreased at 400 mg·L⁻¹ (data not shown). Pseudobulb thickness at any given fertilizer termination time was similar at all K rates (Fig. 3C).

Plant height and pseudobulb node number increased as the K rate increased from 0 to 100 mg·L⁻¹, but remained similar from 100 to 400 mg·L⁻¹ K (Table 4). As the K rate increased from 0 to 200 mg·L⁻¹, leaves remaining increased but did not increase further at 400 mg·L⁻¹. When supplied with 0 or 50 mg·L⁻¹ K, there was severe leaf loss, and only 34% and 62%, respectively, of the leaves remained on plants. Plants supplied with 100 mg·L⁻¹ or higher K had 72% to 80% leaf retention. Pseudobulb width was similar

Fig. 3. Effect of nitrogen (A), phosphorus (B), and potassium (C) termination time on pseudobulb thickness measured at time of pseudobulb maturity for *Dendrobium* cv Red Emperor 'Prince'.

Fig. 4. Effect of the nitrogen (A), phosphorus (B), and potassium (C) rate and fertilizer termination time on total flower number measured at time of full flower for *Dendrobium* cv Red Emperor 'Prince'. FT-1 = 1 Sept. 2005, FT-2 = 1 Oct. 2005, FT-3 = 1 Nov. 2005. Bars indicate $\pm$ SE of the mean.

Table 2. Effect of the N rate regardless of fertilizer termination time on vegetative parameters measured at pseudobulb maturity for *Dendrobium* cv Red Emperor 'Prince'.

N rate (mg·L ⁻¹)	Plant height (cm)	Pseudobulb		
		Node no.	Width (mm)	Thickness (mm)
0	36.1 c ^z	11.8 d	26.5 a	20.6 a
50	56.2 b	18.7 c	26.1 a	20.4 a
100	64.1 a	21.8 a	26.2 a	20.9 a
200	63.3 a	21.2 a	25.8 a	20.4 a
400	57.9 b	19.7 b	23.5 b	18.6 b
Significance	***	***	***	***

^zMean separation within columns by LSD at $P \leq 0.05$.

Fig. 5. Effects of the nitrogen (A), phosphorus (B), and potassium (C) rates (in $\text{mg}\cdot\text{L}^{-1}$) on flowering for *Dendrobium* cv Red Emperor 'Prince'.

and greater at rates above $0\text{ mg}\cdot\text{L}^{-1}$, while thickness was greater at 0, similar and intermediate at 50 to 200, and thinner at $400\text{ mg}\cdot\text{L}^{-1}\text{ K}$ (Table 4).

Total flower number (Figs. 4C and 5C) was the lowest at $0\text{ mg}\cdot\text{L}^{-1}\text{ K}$, but remained similar from 50 to $400\text{ mg}\cdot\text{L}^{-1}\text{ K}$. When supplied with 0 or $50\text{ mg}\cdot\text{L}^{-1}\text{ K}$, plants took the fewest number of days to reach anthesis, whereas 1 to 3 d more were needed for all other K rates (Fig. 6C).

Extended N application. In this experiment, the duration of N application did not affect vegetative or flowering characteristics. Plants in all treatments averaged 57.1 cm in height and had 20 nodes and 17 leaves on pseudobulbs. Pseudobulb width and thickness was 28.6 and 22.1 mm, respectively. There was an average of 28 flowers per plant, and flower diameter averaged 6.6 cm. On average, plants required 388 d to reach anthesis. There were no aerial shoots formed on plants in this experiment.

Discussion

Cultivar Red Emperor 'Prince' and other *D. nobile* hybrids have the potential for increased production and to become a popu-

Fig. 6. Effect of the nitrogen (A), phosphorus (B), and potassium (C) rate and fertilizer termination time on days to anthesis measured at time of full flower for *Dendrobium* cv Red Emperor 'Prince'. FT-1 = 1 Sept. 2005, FT-2 = 1 Oct. 2005, FT-3 = 1 Nov. 2005. Bars indicate $\pm\text{SE}$ of the mean.

lar orchid sold on the mass market. They have long-lasting flowers that come in many colors that appeal to the customer. They have several attributes, including the ability to closely space them in the greenhouse, that give them a high value per unit of bench area. Applying optimum amounts of nutrients for the correct length of time can help commercial producers increase the quality of this orchid and grow it more efficiently.

Nitrogen. Today, consumers prefer that leaves remain on nobile dendrobium potted plants when in full flower. This study showed that no or inadequate N application caused severe leaf loss (Fig. 2), giving plants a less appealing appearance. One of the typical signs of N deficiency in plants is the abscission of older leaves (Marschner, 1995).

A leaf, and potentially flowers, can be produced at every node. Node number is an indication of how many flowers may be produced (Rotor, 1952). Plants were taller and had more nodes when they were supplied

with 100 or $200\text{ mg}\cdot\text{L}^{-1}\text{ N}$ compared with lower and higher rates. Wang (1996) used rates of 100 and $200\text{ mg}\cdot\text{L}^{-1}\text{ N}$ of each of six fertilizers containing varying percentages of N, P, and K, as well as different sources of N, and reported that *Phalaenopsis* grown in a medium of 70% fine grade fir bark and 30% peat produced larger leaves that were wider when N was applied at the higher rate. In this study, similar numbers of leaves were produced when plants were supplied with 100 to $400\text{ mg}\cdot\text{L}^{-1}\text{ N}$ at all three fertilizer termination times. Because these plants were taller and had a greater pseudobulb node number, they also produced more flowers, except for those receiving 200 or $400\text{ mg}\cdot\text{L}^{-1}\text{ N}$ until FT-3.

Pseudobulbs of the nobile dendrobium swell and become thicker only after the top leaf has unfolded and shoot elongation has ceased. Because FT-1 plants had thicker pseudobulbs, they may have matured earlier. When plants were fertilized until FT-2 or FT-3, they might not have matured as early, and were thinner and narrower. When pseudobulbs mature earlier, they can be forced to produce flowers and sold at earlier market dates.

Excess N application has been considered a common cause of poor flowering (Yamamoto Dendrobiums, 2006). Again, this is probably because of the prolonged vegetative state and delayed pseudobulb maturation as a result of prolonged fertilizer application. Flowering characteristics were similar for FT-1 and FT-2 termination times. Therefore, to reduce fertilizer inputs and assure flowering, fertilizer could be ended at the FT-1 with similar results.

From the results of this experiment, $100\text{ mg}\cdot\text{L}^{-1}\text{ N}$ is recommended for *Dendrobium* cv Red Emperor 'Prince'. This rate provides the amount of nutrients the plant can use efficiently for excellent vegetative growth and reproductive development with the least fertilizer input. Application of $100\text{ mg}\cdot\text{L}^{-1}\text{ N}$ to plants resulted in similar or greater plant height, pseudobulb width and thickness, as well as similar flowering characteristics compared with plants receiving higher rates. This is comparable to Poole and Seeley's (1978) findings for *Phalaenopsis* and *Cymbidium* grown in nutrient culture. Of the rates they used (50, 100, and $200\text{ mg}\cdot\text{L}^{-1}\text{ N}$), $100\text{ mg}\cdot\text{L}^{-1}\text{ N}$ was recommended because it resulted in greater leaf and root dry weights and larger leaves, and it increased plant height. However, each species of orchid has a different N

Table 3. Effect of the P rate regardless of fertilizer termination time on vegetative parameters measured at pseudobulb maturity for *Dendrobium* cv Red Emperor 'Prince'.

P rate ($\text{mg}\cdot\text{L}^{-1}$)	Plant height (cm)	Pseudobulb node (no.)	Leaf remaining (no.)	Pseudobulb	
				Width (mm)	Thickness (mm)
0	55.3 c ^z	18.4 b	16.8 b	24.2 c	19.4 b
25	60.1 b	19.8 a	18.4 a	24.7 bc	20.5 a
50	62.3 ab	20.2 a	19.0 a	26.0 ab	21.1 a
100	63.6 a	20.8 a	19.2 a	26.7 a	20.9 a
200	62.6 a	20.6 a	17.1 b	25.9 ab	20.8 a
Significance	***	***	***	**	***

^zMean separation within columns by LSD at $P \leq 0.05$.

Table 4. Effect of the K rate regardless of fertilizer termination time on vegetative parameters measured at pseudobulb maturity for *Dendrobium* cv Red Emperor 'Prince'.

K rate (mg·L ⁻¹)	Plant height (cm)	Pseudobulb node no.	Leaf remaining (no.)	Pseudobulb	
				Width (mm)	Thickness (mm)
0	41.0 c ²	14.6 c	4.8 d	23.0 b	27.4 a
50	54.6 b	18.3 b	11.8 c	27.1 a	21.7 b
100	59.0 a	20.1 a	14.4 b	27.6 a	21.4 b
200	60.2 a	20.5 a	16.2 a	27.7 a	21.3 b
400	59.1 a	20.0 a	16.3 a	27.8 a	19.0 c
Significance	***	***	***	***	***

²Mean separation within columns by LSD at $P \leq 0.05$.

requirement for optimal growth in different media. Poole and Seeley (1978) also reported that *Cattleya* grown under the same conditions and rates had larger leaves and greater dry weights of leaves and roots when supplied with 50 mg·L⁻¹ N. These are much lower optimal N rates than the optimal 1000 mg·L⁻¹ N observed by Miwa and Ozaki (1975).

Phosphorus. Of the three macronutrients tested, P is not required in high concentrations (above 25 mg·L⁻¹) by *Dendrobium* cv Red Emperor 'Prince'. Plants receiving P at rates greater than 0 mg·L⁻¹ had similar vegetative characteristics such as plant height, pseudobulb node number, and pseudobulb thickness. Plant height, node number, and leaf number remaining were greater at the FT-2 fertilizer termination time. When fertilizer was ended at FT-3, pseudobulbs were thinner, possibly indicating that the prolonged vegetative growth resulted in the pseudobulb not maturing like plants whose fertilizer was ended at an earlier time. Our results confirmed the findings of Miwa and Ozaki (1975) that flowering was delayed when no P was applied.

Plants had two more nodes once P was applied, regardless of the rate. However, application of P increased total flower count, indicating that P is needed for initiating more flower primordia. The number of apical non-flowering nodes increased as P rate increased, which may be considered a negative effect on the appearance of a plant in full flower. These results suggest that the P requirement for *Dendrobium* cv Red Emperor 'Prince' is low for reproductive development. Each plant produced over 20 flowers, even when no P was applied.

Wang (2000) found that for *Phalaenopsis* grown in a mix consisting of Douglas Fir bark and sphagnum peat, 50 mg·L⁻¹ P was adequate for good vegetative growth and reproductive development. Similar to these findings, the P rate recommended for *Dendrobium* cv Red Emperor 'Prince' based on this experiment would be 25 mg·L⁻¹ ended at FT-2 for the best vegetative growth and reproductive development.

Potassium. Potassium is the other macronutrient that is needed at higher rates for optimal vegetative growth of *Dendrobium* cv Red Emperor 'Prince'. Plants were taller and had higher pseudobulb node numbers with the application of 100 mg·L⁻¹ K or higher.

Applying adequate levels of K increased leaf retention. When supplied with 0 or 50 mg·L⁻¹ K, there was severe leaf loss, suggesting that K greater than 50 mg·L⁻¹ is necessary for adequate leaf retention. Bhattacharjee (1981) reported that there were beneficial effects on pseudobulbs of *D. moschatum* cv 'Wall' grown in hard wood charcoal when supplied with 500 mg·L⁻¹ K, but no further benefits resulted from the application of 1000 mg·L⁻¹ K. Both 500 and 1000 mg·L⁻¹ K levels resulted in plants that had more leaves than plants receiving 0 mg·L⁻¹ K (Bhattacharjee, 1981). In contrast, Poole and Seeley (1978) reported *Cymbidium* plants had fewer leaves when supplied with 200 mg·L⁻¹ K than plants receiving 50 or 100 mg·L⁻¹. They also determined that the K levels tested had no effect on growth of *Phalaenopsis*, *Cattleya*, and *Cymbidium* and therefore concluded that 50 mg·L⁻¹ K was sufficient.

Potassium fertilizer termination time had no effect on vegetative characteristics. Fertilizer termination at FT-2 resulted in similar or increased reproductive characteristics and therefore is recommended.

Vegetative and reproductive characteristics were similar or greater at 100 mg·L⁻¹ K, with the exception of greater leaf number remaining and pseudobulb thickness, and larger flowers when plants were supplied 200 mg·L⁻¹ K. Therefore, 100 mg·L⁻¹ K is the recommended rate to produce quality plants and minimize the amount of fertilizer input. On the contrary, Miwa and Ozaki (1975) reported K to have no effect on flowering.

Extended N application. There was comparatively no difference among the N termination times in this experiment. Both vegetative growth and reproductive development measurements were very similar to those recorded in the N experiment. Because NH₄NO₃ was used to provide N, the molar concentration of NO₃⁻ and NH₄⁺ in the fertilizer solution was equal. The ratio of NO₃-N and NH₄-N can affect plant growth, and a mixed supply of NO₃-N and NH₄-N usually results in good plant growth (Marschner, 1995). Control plants that continued to receive N and other nutrients until full flower were similar to plants whose N was ended at earlier times but continued to receive all other nutrients. When nutrient application in *Phalaenopsis* was ended at four different dates (1 Sept., 29 Sept., 27 Oct., or 24 Nov.)

or was continuously fed, there was no difference in flower diameter; however, continuously fed plants produced more flowers than plants whose fertilizer was ended on the three earlier dates (Wang, 2000).

The average height of the plant was shorter, but overall vegetative characteristics were similar for plants in the N experiment that received 100 mg·L⁻¹ N and those in the extended N application experiment. Differences between the two experiments were that in the N experiment, when all fertilizer was ended at FT-2, a greater number of flowers were produced. Times needed to reach anthesis were similar among the control plants and the termination times of the extended N application experiment. They were also similar to those plants supplied 100 mg·L⁻¹ N in the N experiment at all termination times. Therefore, eliminating N only at each termination time had similar effects as eliminating all fertilizer at each of the termination times except for flower number, which reinforces that N should be ended early for best flowering.

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