DETERMINING THE NUTRITIONAL REQUIREMENTS FOR OPTIMIZING FLOWERING OF THE NOBILE DENDROBIUM AS A POTTED ORCHID

A Thesis

by

REBECCA GAYLE BICHSEL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

December 2006

Major Subject: Floriculture

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Approved by:

Co-Chairs of Committee,	Terri W. Starman
	Yin-Tung Wang
Committee Member,	Tom Cothren
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ABSTRACT

Determining the Nutritional Requirements for Optimizing Flowering of the Nobile Dendrobium as a Potted Orchid. (December 2006)

Rebecca Gayle Bichsel, B.S., University of Missouri-Columbia

Co-Chairs of Advisory Committee: Dr. Terri Starman
Dr. Yin-Tung Wang

Five experiments were conducted to determine how nitrogen (N), phosphorus (P), and potassium (K) rate and fertilizer termination time, duration of N application, and cold duration and light intensity affect growth and flowering of *Dendrobium nobile* Red Emperor 'Prince'. The N, P, and K experiments were a factorial combination of five nutrient rates and three termination dates (1 Sept., 1 Oct., and 1 Nov. 2005). N 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}. For all nutrients, terminating fertilization on 1 Oct. or 1 Nov. resulted in thinner pseudobulbs. Pseudobulbs grew taller as N rate increased, peaking at 100 and 200 mg•L^{-1}. There were interactions between N rate and fertilizer termination time on all reproductive characteristics. For all fertilizer termination times, flower number increased once N was applied. When terminated on 1 Nov., 200 and 400 mg•L^{-1} N caused a delay for the first flower to reach anthesis. Plants required more days to full flower when supplied with 200 mg•L^{-1} N until 1 Oct. All P rates resulted in taller plants with equally more nodes compared to 0 mg•L^{-1}. For all three termination times, plants that were not supplied with P bloomed later than those receiving P. Plants produced the most flowers when P fertilization was terminated on 1 Oct. Plants required fewer days to reach full flower at the 1 Sept. P termination time. As K rate increased from 0 to 100 mg•L^{-1}, height increased, with no further increase at higher rates. Total flower number and flowering node number were the lowest at 0 mg•L^{-1} K. Leaf number increased as N and K rates increased up to 200 mg•L^{-1}. Nitrogen application did not affect vegetative or flowering characteristics when one rate was applied at four termination dates. In the last

experiment, plants cooled at 10 °C for 2, 4, or 6 weeks with light or 4 weeks in darkness produced similar higher number of flowers per plant than those cooled in darkness for 2 or 4 weeks or those that remained in a greenhouse.

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CHAPTER I

INTRODUCTION AND REVIEW OF KEY LITERATURE

Orchidaceae is the largest family in the plant kingdom containing approximately 750 genera and more than 25,000 species. Orchids are divided into two groups: epiphytic and terrestrial. In their natural habitat, epiphytic orchids absorb nutrients from rain water as it passes over their roots. Other sources of water include dew, fine droplets from mist or fog, and water vapor. Roots of orchids have a velamen, a layer outside of the exodermis, which wraps around them and acts like a sponge to absorb water. Orchid species that grow in dry habitats have more velamen layers and cell walls that are thicker and more lignified (Pridgeon, 1987). Some epiphytic orchids have enlarged stem-like structures called pseudobulbs that are storage organs (Hew and Yong, 2004).

Although there are several characteristics that vary among the flowers of various orchids, all orchid flowers have some common characteristics including three sepals and three petals. A lip, or labellum, is formed by the modified lower petal that is usually differentiated from other petals by their size, shape or color. Another characteristic of most Orchidaceae plants is their elongated leaves with parallel veins, which have varying shapes and sizes and are considered either thin or thick-leaved (Hew and Yong, 2004).

In the past decade, orchid sales have been rapidly increasing in the United States and around the world. Because of the much increased production of the *Phalaeanopsis* Bl. orchid, which is recognized as one of the easiest orchids to grow in a home environment, popularity of orchids as a flowering potted plant has increased significantly (Griesbach, 2000; Wang, 2004). They have a low light requirement and

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can flower up to four months and often longer, which makes them a very desirable plant that gives the consumer great satisfaction.

Phalaenopsis are now being produced on a large scale in many countries including China, Japan, Germany, the Netherlands, Taiwan, and the United States (Griesbach, 2000; Wang, 2004). Roughly 75% of the potted orchids produced today are *Phalaenopsis* and they can be purchased in a wide selection of flower colors and shapes (Frownie, 2006). Celebrities, retailers and e-commerce companies have helped to promote the sales for potted orchids in the United States (Britt, 2000), and today they can be purchased at supermarkets and mass-market outlets at varying prices (Laws, 2004).

There has been increased supply of orchids due to greater advances in propagation techniques. Young plant production is dominated by Taiwan and Thailand, while finished production is concentrated in Japan, the Netherlands, and the United States (Laws, 2004). Orchids are now recognized as a profitable crop by commercial growers (Britt, 2000). In 2005, the USDA estimated the wholesale value of potted orchids in the United States to be $144 million, with *Phalaenopsis* having the largest percentage of this value. Orchids continue to be the only potted flowering plants to increase in wholesale value while the production of *Euphorbia pulcherrima* Willd. ex Klotzsch (poinsettia), the number one flowering potted plant, has been on the decline in recent years (USDA, 2006).

Phalaenopsis orchids have been a main focus for commercial growers for the past few years; therefore, most of the research has been directed toward them and their growing requirements have been studied in detail (Sakanishi et at., 1980; Wang, 1998, 2000; Wang and Konow, 2002). Other orchid hybrids which are economically important such as *Aranda* (*Arachnis* x*Vanda*), *Oncidium* Sw., *Mokara* (*Arachnis* x*Ascocentrum* x*Vanda*), and *Dendrobium* need to be researched to learn their requirements for flowering (Hew and Yong, 2004).

Although *Phalaenopsis* remain the most popular potted orchid sold, the types of orchids on the market are becoming more diversified. Potted, blooming *Dendrobiums*

Sw. are being cultivated at an ever increasing rate. There have been more than 15 seed-propagated dendrobium hybrids introduced for pot plant production by the University of Hawaii (Leonhardt, 2000). Hybrids made from *Dendrobium nobile* Lindl. orchid have the potential to become very popular in the flowering potted plant market because as tastes of the consumer change, the demand for the types of orchids that are produced will also change. The main use for *Dendrobium nobile* orchids is the attainment of commercial hybrids (Dematte and Graziano, 2000), but they are also used as flowering potted plants, cut flowers, and corsages (Yamamoto Dendrobiums, 2006).

Dendrobium is a widely distributed genus that can be found in Australia, East Indies, Far East, India, the Philippines, and South Pacific Islands (Fennel, Jr., 1965). *Dendrobium nobile* is native to Burma, India, Indochina, and Thailand (Yamamoto Dendrobiums, 2006). Of the *Dendrobium* species, *Dendrobium nobile* is one of the most cultivated because of its potential to flower abundantly when grown under optimal conditions (Baker and Baker, 1996). In their natural habitats, *Dendrobium nobile* is epiphytic and usually grows on trees. Their growth habit is sympodial (Hew and Yong, 2004). Between December and January of each year, vegetative growth begins by activating a vegetative bud at the base of the old pseudobulb, leading to producing a new pseudobulb. Leaves are alternate and flower buds are formed in the leaf axis. The pseudobulbs mature by November and December of the next year. After one year of growth, the pseudobulb begins to produce flowers in February and March of the following year, following adequate cooling. Up to three flowers can be formed at each node (Rotor, Jr., 1952), which can be fragrant and last from 3 to 6 weeks or longer if conditions are favorable (Baker and Baker, 1996).

The pseudobulbs of well-grown *Dendrobium nobile* ultimately reach a height of 61 cm or taller. Pseudobulbs start to mature once the terminal leaf has fully unfolded (Nash, 1996). In *Dendrobium* Snowflake 'Red Star' and *Dendrobium* Malones 'Fantasy' (both being the nobile type), the terminal leaf is formed early and shorter pseudobulbs are produced when there is a difference between day and night temperatures, e.g. 27/17 °C day/night, but with an average temperature, e.g. 22 °C

(Ichihashi, 1997). Terminal leaf formation is affected by night temperatures, but cultivars vary in their requirements for night temperature. Acceleration of terminal leaf formation occurs at 15 to 20 °C for *Dendrobium* Snowflake 'Red Star' and at 20 °C for *Dendrobium* Malones 'Fantasy'. High temperatures of 30-35 °C are not desirable because pseudobulb diameter can be small and temperatures below 15 °C can prevent pseudobulb growth (Ichihashi, 1997). It is recommended that fertilizer be terminated once the terminal leaf appears (Nash, 1996).

Nobile dendrobiums may be deciduous and lose leaves from the previous year once they have been subjected to cold air for a period of time. It is believed that deciduous dendrobiums need to go through a resting period in order to form flower buds and that during this resting period, only sufficient amounts of water to prevent loss of turgidity are given to plants and temperature is reduced to 10 °C. There is no scientific evidence that a resting period is necessary. This belief may be due to the cold temperatures keeping plants from flowering. Once flower buds have formed, irrigation and temperature are increased to aid in flower development (Pring, 1967). It is not uncommon for smaller inflorescences to develop at the upper and basal parts of the pseudobulb as compared to inflorescences with a larger diameter on the remainder of the pseudobulb (Rotor Jr., 1952). Vegetative buds (keikis) are formed in the place of flower buds if no resting period is allowed (Pring, 1967).

It has also been determined that fertilization with a complete fertilizer is not always as important for growth as the potting mixture and its ability to retain water and nutrients (Wang, 1996). Wang and Konow (2002) grew *Phalaenopsis* Atien Kaala [*Phalaenopsis (Snow Swallow* x*Hisa Nasu*)] in either Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) bark only or a bark-peat mix and supplied them with one of four complete fertilizer formulations. Regardless of fertilizer applied, the bark-peat medium was found to hold and make available to the plant more nutrients, had a lower pH, and resulted in larger plants than those grown in the bark only. Fir bark alone does not hold much water initially, which can pose problems to newly planted orchids. Once it starts to hold more water, bark used as the lone medium component can decompose

quickly and can tie up nutrients posing problems to plants. Medium containing a mixture of bark and peat has a better water and nutrient holding capacity than bark alone. The carbon dioxide uptake through photosynthesis is reduced if water is withheld; therefore, medium should never become completely dry (Wang et al., 2005).

Today, most commercial growers mix their own growing media. Most of the mixes still contain bark, but they also have one or more other materials such as perlite, sphagnum peat, sphagnum moss, and coconut husk chips, etc. that absorb water (Wang et al., 2005).

Mineral Nutrition of Orchids

Availability. In their native habitat, the ecosystem surrounding epiphytic orchids supplies nutrients to the plants. Humus, tree bark, and the velamen can all absorb and retain water. Usually the host tree provides much needed nutrients as rain water washes over the leaves, as well as organic matter that collect in tree crevices. Water droplets containing nutrients then spread over the surface of the roots due to the small hairs on the root itself. Plant growth is at an optimum when the availability of water is constant. Other factors that affect nutrition include plant age, medium, and decomposition rate of the medium (Poole and Sheehan, 1982).

The major chemical macronutrients contained in rain running down tree trunks are nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg), but phosphorus (P) is a minor component because it is not easily leached from leaves (Pridgeon, 1987). Nitrogen, P, and K are the three macronutrients focused upon when forming a fertilizer for application because they makeup most of the plants' composition. Nitrogen is of the greatest importance in research due to its abundance in the plant. However, N is dependent on other nutrients for its effectiveness (Hew and Yong, 2004). For example, K is required to activate and synthesize nitrate reductase (Marschner, 2003).

Deficiency. Although orchids require similar nutrition to that of other plants, symptoms, depending upon the orchid species, are slow to appear due to their ability to translocate certain nutrients from older leaves and pseudobulbs to growing tissues (Hew

and Yong, 2004). This phenomenon is mainly observed in the orchids of epiphytic origin where supply of nutrients is more limited and irregular in their natural habitat. Nitrogen deficiencies took up to three weeks to become noticeable, while P and K took more than three months for symptoms of deficiency to appear in *Vanilla* Mill. grown in gravel culture (Hew and Yong, 2004). Fresh and dry weights, leaf size, and stem diameter were all reduced by N deficiency in *Vanilla*, but details on rates were not reported. When grown in gravel culture with N levels of 0, 10, or 81 $mg \cdot L^{-1}$ and K levels of 0, 7, or 40 $mg \cdot L^{-1}$, the highest N and K levels resulted in increased vine growth (Poole and Sheehan, 1982). Nitrogen also resulted in darker green leaves in vanilla, whereas K had no effect on color.

Deficiencies of both N and P can affect photosynthesis. Nitrogen is required for the formation of chloroplasts. Up to 75% of total organic N can be found in the chloroplasts of green leaf cells (Marschner, 2003). A deficiency of N can lead to decreased photosynthetic efficiency. This is also true for P, where carbohydrates accumulate in leaves and roots of P deficient plants and the feedback inhibition reduces the photosynthetic efficiency of source leaves (Marschner, 2003).

Nitrogen. For optimal growth, the N content in plants is between 2 and 5% of the plants dry weight. This is dependant on factors such as the plant species, stage of development, and the organ in which it is found.

During the past, most orchid production research in the U.S. has been focused on *Phalaenopsis* to help growers produce them more efficiently. Earlier studies performed by Poole and Seeley (1978) used a hybrid *Phalaenopsis* in nutrient culture grown in ceramic pots and supported with glass spheres. Nitrogen was supplied at 50, 100, or 200 $mg \cdot L^{-1}$. It was found that with nutrients applied three times per day, 100 $mg \cdot L^{-1}$ nitrogen (N) resulted in the best growth. Nitrogen concentration at 200 $mg \cdot L^{-1}$ decreased height, leaf number and root dry weight. In contrast, Wang (1996) grew a hybrid *Phalaenopsis* in containers with a medium of 70% Douglass fir bark and 30% peat moss and determined that high fertility was required. Six complete fertilizers were applied to provide either 100 or 200 $mg \cdot L^{-1}$ N. Plants that were supplied with 200 $mg \cdot L^{-}$

[1] N had more and larger leaves and a greater shoot fresh weight than those supplied with 100 mg•L^{-1} N. Nitrogen supplied at 200 mg•L^{-1} can benefit young plants by allowing them to grow more rapidly (Wang, 1996). Increased nutrient levels resulted in plants that produced more leaves that were both larger and darker green, leading to better flowering (Wang and Gregg, 1994). Generally, when an orchid is large before being forced to flower, it will produce more flower buds or inflorescences (Runkel et al, 2005). In contrast to *Phalaenopsis*, the production requirements for *Dendrobium nobile* remain largely undocumented in the recent scientific literature.

Dendrobium nobile plants grown in sphagnum moss (*Sphagnum magellanicum* Brid.) or hemlock (*Conium maculatum* L.) bark were given 10 different combinations of 0, 250, 500, and 1000 mg•L^{-1} N, P, and K over a period of 2 years (Miwa and Ozaki, 1975). Pseudobulb number, pseudobulb length and width, and leaf number were all highest at 1000 mg•L^{-1} N. With the exception of one nutrient combination containing 500 mg•L^{-1} N, 1000 mg•L^{-1} N produced the least flowering nodes and resulted in the greatest number of aerial shoots (keikis). Nutrient combinations containing no P decreased the pseudobulb number, pseudobulb length and width, and leaf number. Flowering node number and number of flowers per node decreased and flowering was delayed. Potassium was not shown to have effects on plants at any level. Due to its water and nutrient holding capacity, plants potted in sphagnum moss resulted in increased vegetative and reproductive growth compared to those grown in hemlock bark (Miwa and Ozaki, 1975).

It has also been found that other greenhouse grown crops also have decreased growth when supplied with highest levels of N. Smith et al. (1998) grew *Alstroemeria* ‘Parigo Pink’ in pots in a medium of sphagnum moss peat, polystyrene beads, and vermiculite. Plants were supplied with N concentration levels of 0, 3.5, 7, 14, 28.5, or 57 mmol•L^{-1}. The number of vegetative stems and flower production increased with fertilizer solutions up to 28.5 mmol•L^{-1} and then decreased at 57 mmol•L^{-1} N. Fertilizer supplied at 28.5 mmol•L^{-1} was determined to be optimum for production of plants that

produced more flowers of higher quality than plants supplied with the lower or higher rates of N.

Crops in general have higher yields when N is supplied as a combination of ammonium (NH_4^+) and nitrate (NO_3^-), but their optimal proportion is dependent upon total N supply, content of N in soil, and plant species (Marschner, 2003). There is generally a lower rate of NH_4^+ and NO_3^- uptake in orchids compared to those of other plant types (Hew and Yong, 2004). It was found that fertilizing *Cattleya* plants weekly with NH_4^+ resulted in increased fresh weight, dry weight of roots, and leaf area than those that received NO_3^- fertilizer (Poole and Sheehan, 1982). However, plants that were fertilized with either the NH_4^+ or NO_3^- at intervals of two or three weeks showed no differences in growth. Plants that received the NH_4^+ demonstrated more leaf chlorosis after ten months (Poole and Sheehan, 1982).

The use of NO_3-N versus ammonium nitrate (NH_4NO_3) was tested on orchid embryos at a constant pH level. For both *Cymbidium* Sw. and *Cattleya* Lindl., NH_4NO_3 was superior to NO_3^- (Poole and Sheehan, 1982). When grown in liquid culture media, there was a preferential uptake of NH_4^+ over NO_3^- by *Dendrobium* tissues. Once NH_4^+ had been depleted, the tissues started to take up NO_3^-. The uptake of NH_4^+ generally hindered the uptake of NO_3^-. There is a relationship between the uptake of NH_4^+ and NO_3^- by orchids and the pH level in the media. While orchid tissues are taking up NH_4^+, there is a decrease in pH, which is due to the efflux of protons. Once ammonium ions have been exhausted, NO_3^- is used and the pH level begins to increase due to efflux of hydroxyl ions (Hew and Yong, 2004).

Hew et al. (1993) compared N uptake of two terrestrial orchids, *Bromheadia finlaysonia* Lindl. and *Cymbidium sinese* (Jackson) Willd. with the epiphytic orchid *Dendrobium* White Fairy (*Dendrobium* Singapore White x*Dendrobium* Walter Omaze). Plants were grown hydroponically with various N sources. The *Dendrobium* was found to have the highest NO_3^- uptake rate of the three. When grown in a nutrient solution with NO_3^- (10 m?) as the nitrogen source, *Dendrobium* and *Cymbidium* demonstrated a linear rate of NO_3^- uptake over a period of 40 days of 0.94 and 0.33 µmol/g/fw/hr,

respectively. When *Cymbidium sinense* was supplied NH_4NO_3 as a N source for 30, 60, 90 and 100 days, it had faster root and leaf growth as well as higher photosynthetic rate when compared to the use of NO_3^- or NH_4^+ as the only nitrogen source. The highest chlorophyll concentration resulted from NH_4^+ at all treatment days. As the rate of NH_4NO_3 increased, the flower number also increased in *Cattleya* Trimos G when grown on tree bark (Hew and Yong, 2004).

Phosphorus. Most healthy plant vegetative tissues contain 0.3 -0.5% of P in dry matter (Marschner, 2003); however, P toxicity in more sensitive plants may occur at these level. Phosphorus concentration above 1% in dry matter may cause toxicity. Phosphorus deficiencies can cause a decrease in leaf number, leaf size, and leaf surface area. Root and shoot growth may decrease, and cause a reduction in shoot-root dry weight ratio (Marschner, 2003).

Wang (2000), found that there was a decrease in flower number when *Phalaenopsis* was grown in a mixture of 80% Douglas fir bark and 20% sphagnum peat were switched to low N (30 mg•L^{-1}) and high P (390 mg•L^{-1}) and K (506 mg•L^{-1}) levels at the beginning of being induced to spike, and concluded that adequate N levels were more essential to flowering than high P levels. The control was a high N soluble fertilizer containing 100, 43, and 83 mg•L^{-1} of N, P, and K, respectively, used at every irrigation. High P and low N rates also resulted in fewer new leaves and increased lower leaf abscission. Growth and flowering of *Phalaenopsis* were not affected by varying rates of P. For *Phalaenopsis*, 25-50 mg•L^{-1} P were adequate to produce a good crop (Wang et al, 2005).

Research to determine how growth and flowering were affected by 27 treatment combinations of 0, 500 and 1000 mg•L^{-1} N, P and K was performed on *Dendrobium moschatum* (Buch.-Ham.) Sw. 'Wall'. Plants were grown in pots with a media of hard wood charcoal. There was an increase in vegetative growth and flowering with the addition of 500 mg•L^{-1} P, without further increase in growth at 1000 mg•L^{-1} P. When analyzed together, the interaction of N and P made a significant difference on leaf number and flower longevity. Leaf number increased as higher or increased levels of N

and P were applied, while flower longevity decreased at 0 mg•L^{-1} P combined with both higher levels of N. Phosphorus and K interacted to increase flower size and flower longevity with combinations of P and K above 0 mg•L^{-1} (Bhattacharjee, 1981).

Whitcher et al. (2005) also found that lower levels of P were needed for vegetative growth and flower number of two greenhouse grown crops, New Guinea impatiens (*Impatiens hawkeri* Bull.) 'Paradise Violet' and vinca (*Catharanthus roseus* (L.) G. Don) 'Pacifica Red', when grown in a soilless media in recirculating subirrigation in a greenhouse. Phosphorus rates were applied at 0, 0.1, 0.25, 0.5, 1, 2, 4, 16, 32, or 64 mM. A quadratic-linear segmented model analysis showed that for New Guinea impatiens, a P rate between 0.1 and 0.96 mM was best for dry shoot weight and flower number. A P range of 0.45 to 1.25 mM was optimum when the same parameters were measured for vinca. Zhang et al. (2004) found similar results when they grew *Scaevola aemula* R. Br. 'New Wonder' in pots with Pro-Mix BX in a greenhouse. Plants were supplied with P concentrations of 0, 14.5, 29.0, 43.5, 58.0, 72.5, or 87.0 mg•L^{-1}. When supplied with P concentrations greater than 14.5 mg•L^{-1}, there was a decrease in shoot dry weight, length, and number and leaf size, with a severe decrease at rates higher than 43.5 mg•L^{-1} P. It is obvious that P is not needed in high concentration for optimal plant growth.

Potassium. Potassium should be found in the range of 2-5% of plant dry weight of vegetative tissues, tubers, and fleshy fruits for optimal plant growth (Marschner, 2003). When K is in excess, it can hinder the uptake and physiological accessibility of Ca and Mg (Marschner, 2003). On the other hand, K deficiencies can retard growth and K in mature leaves and stems can be moved to new tissues causing them to become chlorotic or necrotic under severe deficiency conditions (Marschner, 2003).

Poole and Seeley (1978) conducted research on *Phalaenopsis*, *Cymbidium*, and *Cattleya* orchids to determine the N, K, and Mg effects on growth and mineral composition of orchids. *Phalaenopsis* were supplied with 100, 200, or 300 mg•L^{-1} K and *Cattleya* and *Cymbidium* with 50, 100, or 200 mg•L^{-1} K in a nutrient culture setting in ceramic pots in a greenhouse. They found that for all three orchid genera, 50 mg•L^{-1}

K was sufficient for orchid growth and higher levels had no further affects except in *Cattleya* at 200 mg•L^{-1} K, which resulted in fewer leaves. The amount of Ca and Mg in orchid leaves decreased when K increased for all three genera at all three nutrient solution levels, except for Mg concentration in *Cattleya* (Poole and Seeley, 1978).

Contrasting results have been reported for research performed on other greenhouse grown crops. Woodson and Boodley (1982) grew 'Forever Yours' roses (Rosa Hybrid Tea) in the greenhouse in recirculating nutrient solutions. Potassium was supplied at 0.25, 2.5, 5.0, or 10.0 meq/liter. As the supply of K increased from 0.25 to 10.0 meq/liter, flower number and stem length increased, suggesting that high levels of K are required for this rose when grown in a recirculating nutrient solution. Also, the K concentration from 0.25 to 10 meq/liter did not decrease Ca and Mg levels in 'Forever Yours' roses. In opposition, Haley and Reed (2004) reported that New Guinea impatiens, vinca, and petunia (*Petunia xhybrida* Hort. Vilm.-Andr.) grown in a recirculating subirrigation system and supplied with K concentrations of 0, 0.5, 1.0, 1.5, 2.0, 3.0, 6.0, 9.0, or12.0 mM had maximum growth at levels ranging from 1.0 to 6.0 mM. Plants supplied with higher amounts resulted in decreased height, shoot dry weight, and leaf number.

Photoassimilates and Carbon Availability

Leaves are the main contributor of photoassimilates for most plants. Assimilates are usually imported to young, expanding leaves from other sources. Other organs, such as pseudobulbs, may produce some assimilate. Pseudobulbs are sinks during early development, but later become sources of assimilates. Assimilate movement throughout orchids follows a different pattern than other higher plants. Research performed on two thick-leaved sympodial orchids, *Dendrobium* Rong Rong and *Dendrobium* Jashika Pink suggests that when flowers are present they compete for assimilates from the pseudobulbs, stem internodes, roots, and when present, the vegetative basal shoot (Hew and Yong, 2004). The method used for proving the competition for assimilates was not mentioned. Orchid flowers have the ability to obtain assimilates from leaves both

nearby and distant. Therefore, there is minimal vascular restriction on movement of assimilates to the flower.

Dendrobiums are considered to have crassulacean acid metabolism (CAM) and take up CO_2 at night (Hew and Yong, 2004) which enables them to use water more efficiently in dry environments (Taiz and Zeiger, 2002). Typically, the epiphytic orchids have more environmental stress in their natural habitats compared to when grown under controlled environments and are known to be slow growing. The slow growth may be accredited to the way these plants acquire carbon. Supplying CAM plants with a foliar fertilizer at night was found effective when stomata were open (Hew and Yong, 2004). However, dendrobiums are thick-leaved and must be sprayed from the under surface where stomata are present making this method economically difficult for commercial growers (Hew and Yong, 2004).

Flower Initiation and Flower Development

Genetic, environmental, and physiological factors including juvenility, photoperiod, and temperature all influence orchid flower bud initiation. After flower bud initiation, the buds of epiphytic orchids rely on photassimilates from leaves, pseudobulbs, and roots in order to continue developing (Hew and Yong, 2004). Knowledge of flowering seasonality and the factors that affect flowering are necessary to program plants to flower for specific market dates. Over a period of five years, Hew and Yong (2004) investigated the control of flowering in *Dendrobium* Jaquelyn Thomas. As plants matured, there was an increase in inflorescences (exact numbers not reported) that reached a maximum at three to four years. During the first year, flowering peaked in the summer. During the five-year evaluation period, flowering seasonality fluctuated.

It is not uncommon for dendrobiums to flower more than once per year. The average juvenile phase for most orchids is two to three years; however, some can remain juvenile for up to 13 years. Orchids chosen for commercial production usually have a juvenile stage of 12-36 months (Hew and Yong, 2004). Once the juvenile stage is over there is a period of maturation, which differs depending on the cultivar. At the

beginning of the maturation process, the terminal leaf forms, however the length of time needed between terminal leaf formation and pseudobulb maturity is unclear. In *Dendrobium* Snowflake 'Red Star', a longer period for maturation and flower bud development is needed if the terminal leaf is formed early (i.e. June and July) (Ichihashi, 1997). Pseudobulbs can mature in two weeks after the terminal leaf has formed if the temperature is kept below a maximum of 15 °C (Ichihashi, 1997). In contrast, it can take more than a month for pseudobulbs to mature when grown below a maximum winter temperature of 25 °C (Ichihashi, 1997).

If pseudobulbs are not fully mature, they will not respond to low temperatures and therefore will not initiate flower buds. Ichihashi (1997) reported that under 25 °C day/15 °C night conditions, *Dendrobium* Hinode 'Toutenkou' (*Dendrobium* (Winter Star x Snowflake)) had fewer flowers on the upper nodes and *Dendrobium* Snowflake 'Red Star' produced aerial shoots. Both clones required temperatures above 25 °C day/15 °C night in order for pseudobulbs to mature timely for flower induction.

Many species in Orchidaceae need a period of vernalization after maturation to induce flowering. This is also true for tropical orchids (Hew and Yong, 2004). In commercial production of *Phalaenopsis*, day/night temperatures of 25/20 °C are used to promote flowering. Spiking of *Phalaenopsis* hybrids is triggered by air temperatures of 26 °C or lower (Sakanishi et al., 1980).

The effect of temperature on *Dendrobium nobile* is critical during both vegetative growth and flower initiation. During the spring and summer in both Hawaii and Japan, nobile dendrobiums are grown in lower elevations where the pseudobulbs can mature completely in a warmer climate before being taken to higher elevations where flower initiation can begin under cooler conditions (Nash, 1996). The initiation of flower buds is best at day/night temperatures of 25/10 °C for *Dendrobium* Snowflake 'Red Star' (Ichihashi, 1997). Flower bud differentiation improved in both *Dendrobium* Snowflake 'Red Star' and *Dendrobium* Hinode 'Toutenkou' with day temperatures of 25 °C and below and night temperatures of 10-13 °C (Ichihashi, 1997). In *Dendrobium* Malones 'Fantasy', flower bud initiation was optimal at night temperatures between 7.5 and10 °C.

The number of flower buds decreased and flowering was delayed with night temperatures of 15 °C or higher (Suto et al., 1984). The cooler temperatures (10 to 15 °C) together with the termination of fertilizer after pseudobulb maturity produces the best flower display of *Dendrobium nobile* (Nash, 1996). For all cultivars, flower bud initiation is inhibited by day temperatures above 25 °C (Ichihashi, 1997).

Temperature can also be used to manipulate timing of flower bud initiation and flowering. Raising or lowering the air temperature in the greenhouse can be used to manipulate the flowering date once spiking has taken place (Wang, 1998). Wang (1997) reported that spiking can be delayed by maintaining temperatures above 28 °C all day. Flowering of a first generation *Phalaenopsis pulcherrima* hybrid is delayed by cool day temperatures of 25 °C and warm night temperatures of 30 °C (Wang, 2007). Cool day temperature of 20 °C and warm night of 25 °C induced flowering, whereas warm day of 25 °C and cool night of 20°C inhibit flowering. Flower induction begins as temperatures fall below 26 °C for four to five weeks. *Phalaenopsis* plants with a young inflorescence can become an aerial shoot known as a keiki, in place of a flower bud when temperatures remain at 28 °C or higher (Lopez et al., 2005).

After a low temperature treatment of 10 °C for 16 hours daily over a period of 30-40 days, flower initiation of nobile dendrobiums was accelerated when there was an increase of night temperature from 10 °C to 25 °C (Sinoda et al., 1988). Lopez and Runkle (2004) reported a decrease in time from visible inflorescence to flower opening in *Zygopetalum* Hook. (*Zygopetalum Redvale* 'Fire Kiss') when there was an increase in temperature (14 °C to 26 °C). The average number of flowers was not notably affected by temperature. For *Dendrobium nobile*, despite photoperiod, 13 °C (details were not given as to whether this temperature was constant or average), was found to trigger flower bud initiation. *Dendrobium nobile* usually begins flowering in February or March, which can be too early for the Easter holiday. Plants grown at 18 °C for up to 4 months had delayed flowering until the preferred blooming date (Rotor Jr., 1952).

Photoperiodic response is important in controlling flowering in many plant species. Orchids, like other plants, can be classified into three groups: Short day (SD),

long day (LD), and day neutral (DN). Those with origin close to the Equator are believed to be more affected by changes in daylength than those found in more temperate areas. Rotor, Jr. (1952) found that *Phalaenopsis amabilis* (L.) Bl. grown in an 18 °C (comparisons to other temperatures were not reported) greenhouse supplied with uninterrupted short days encouraged flowering and inflorescence stalks and old stalks to produce lateral flowering branches throughout the year. Long days gave the plants a specific once-a-year flowering period, but did not hinder flowering. Some of the dendrobium hybrids are considered day neutral and not affected by daylength for flowering (Hew and Yong, 2004).

In addition to the photoperiod needed for flowering, some orchids also require certain light intensity for best growth and flowering. If plants are subjected to low light or darkness, spiking of *Phalaenopsis* does not occur even under optimum temperature conditions (Wang, 1995). To obtain 100 percent flowering of *Phalaenopsis* a light level of 250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ or higher is necessary (Wang, 1997). In order for *Dendrobium nobile* to reach their full flowering potential, they must have reached maturity under high-light conditions before the cooling period (Nash, 1996). A study suggests the photosynthetic capacity of *Dendrobium* Jaquelyn Thomas can be increased by increasing irradiance (decreasing % shade in the greenhouse) on their leaves, thus increasing flower number (Hew and Yong, 2004). For *Dendrobium* Nodoka and *Dendrobium* Snowflake 'Red Star' (both the nobile type), high light is not necessary during flower bud initiation. However, exposure to low light (an exact light amount was not stated) during this time can result in leaf chlorosis and defoliation (Ichihashi, 1997). Cymbidiums need a combination of low temperatures and a certain light intensity in order to flower. A period of full sunlight was needed for *Vanda* Miss Joaquim and *Arachnis* Maggie Oei to flower, while high light intensities (above 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$) reduced flowering of *Oncidium* Goldiana (Hew and Yong, 2004).

Light can be used to manipulate the timing of flowering. Wang (1998) performed five experiments giving *Phalaenopsis* TAM Butterfly various cycles of darkness and light. Cycles were, 1 day darkness/1 day light; 4 days darkness/3 day light;

7 days darkness/7 days light, and the control (natural photoperiod). The greenhouse was provided with shade and the maximum *PPF* was 360 µmol•m^{-2}•s^{-1}. Results showed that plants subjected to four days of darkness followed by three days of light for three months suspended spiking for three months without a decrease in flower number when plants were finally brought to flowering.

CHAPTER II

FERTILIZER RATE AND DURATION EFFECT ON GROWTH AND FLOWERING OF *Dendrobium* RED EMPEROR 'PRINCE'

Introduction

There has been increased supply of orchids due to greater advances in propagation techniques. Young plant production is dominated by Taiwan and Thailand, while finished production is concentrated in Japan, the Netherlands, and the United States (Laws, 2004). Orchids are now recognized as a profitable crop by commercial growers (Britt, 2000). In 2005, the USDA estimated the wholesale value of orchids in the United States to be $144 million, with *Phalaenopsis* having the largest percentage of this value. Orchids continue to be the only potted flowering plants to increase in wholesale value while the production of *Euphorbia pulcherrima* Willd. ex Klotzsch (poinsettia), the number one potted flowering plant, has been on the decline in recent years (USDA, 2006).

Dendrobium is a widely distributed genus that can be found in Australia, East Indies, Far East, India, the Philippines, and South Pacific Islands (Fennel, Jr., 1965). *Dendrobium nobile* is native to Burma, India, Indochina, and Thailand (Yamamoto Dendrobiums, 2006). Of the *Dendrobium* species, *Dendrobium nobile* is one of the most frequently cultivated because of its potential to flower abundantly when grown under optimal conditions (Baker and Baker, 1996). Uses for *Dendrobiums*, in general, include cut flowers and potted plants (Dole and Wilkins, 2005).

Although *Phalaenopsis* remain the most popular potted orchid sold, the types of orchids on the market are becoming more diversified. Potted, blooming *Dendrobiums* Sw. are being cultivated at an ever increasing rate. There have been more than 15 seed-propagated dendrobium hybrids introduced for potted plant production by the University of Hawaii (Leonhardt, 2000). Hybrids made from *Dendrobium nobile* Lindl. (*Dendrobium nobile*) orchids have the potential to become very popular in the flowering

potted plant market because, as tastes of the consumer change, the demand for the types of orchids that are produced will also change. Orchid hybrids which are economically important such as *Aranda* (*Arachnis* x*Vanda*), *Oncidium* Sw., *Mokara* (*Arachnis* x*Ascocentrum* x*Vanda*), and *Dendrobium* need to be researched to develop their requirements for flowering (Hew and Yong, 2004).

During the past, most orchid production research in the U.S. has been focused on *Phalaenopsis* to help growers produce them more efficiently. In contrast to *Phalaenopsis*, the production requirements for *Dendrobium nobile* remain largely undocumented in the recent scientific literature. In one study, *Dendrobium nobile* plants grown in sphagnum moss (*Sphagnum magellanicum* Brid.) or hemlock (*Conium maculatum* L.) bark were given 10 different combinations of 0, 250, 500, and 1000 $mg \cdot L^{-1}$ N, P, and K over a period of 2 years (Miwa and Ozaki, 1975). Pseudobulb number, pseudobulb length and width, and leaf number were all highest at 1000 $mg \cdot L^{-1}$ N. With the exception of one nutrient combination containing 500 $mg \cdot L^{-1}$ N, 1000 $mg \cdot L^{-1}$ N, plants produced the least flowering nodes and resulted in the greatest number of aerial shoots (keikis). Nutrient combinations containing no P decreased the pseudobulb number, pseudobulb length and width, and leaf number. Flowering node number and number of flowers per node decreased with no P and flowering was delayed. Potassium at any level was shown to not have effects on plants. Due to its water holding capacity, *Dendrobium nobile* plants potted in sphagnum moss resulted in increased vegetative and reproductive growth compared to those grown in bark (Miwa and Ozaki, 1975). The requirements for nutrition, temperature, and light of the more modern dendrobium cultivars need to be investigated.

The overall objective of the first three experiments was to determine how various rates of nitrogen (N) (Expt. 1), phosphorus (P) (Expt. 2), and potassium (K) (Expt. 3) and nutrient termination times would affect growth and flowering of *Dendrobium nobile* Red Emperor 'Prince'. The objective of the fourth experiment was to determine optimum N termination time, while still applying all other nutrients, for vegetative and reproductive growth.

Materials and Methods

One-year-old *Dendrobium nobile* Red Emperor 'Prince' liners, each having a single pseudobulb, were received from Yamamoto Dendrobiums, Mountain View, Hawaii, on 3 Feb. 2005. The young plants had been propagated from single-node stem cuttings in 72-cell plug trays filled with sphagnum moss as the root substrate. After arrival, pseudobulbs were potted on 4 Feb. 2005 in a root substrate of 2 coarse peat : 1 perlite (no. 3) : 1 diatomite (no. 3) (90% silicon dioxide, 10% elemental minerals) (Diatomite USA, Elma, N.Y.) (by volume) with 0.5 g•L^{-1} Micromax, (a micronutrient source, The Scotts Company, Marysville, Ohio) and 5.0 g•L^{-1} powdered dolomite. Plants were potted in 10.2 cm top diameter (414 mL) standard round plastic pots.

Immediately after potting, plants were watered with reverse osmosis (RO) water containing a fungicide (Banrot 40% WP, Scotts-Sierra Crop Protection Company, Marysville, Ohio) 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.

Experiments 1-3 were factorial treatment combinations 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 all rates, Ca and Mg were held at a fixed rate. In 0 mg•L^{-1} rates, only the nutrient being tested was eliminated. The three fertilizer termination times for all experiments were 1 Sept. (FT-1, 209 DAP), 1 Oct. (FT-2, 239 DAP), and 1 Nov. (FT-3, 270 DAP) 2005. At each fertilizer termination time, all nutrients were terminated. 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 total plants in each experiment.

Each experiment was designed to allow for only N, P, or K rate to increase while all other nutrient rates were held constant. Total N stayed constant at 100 mg•L^{-1} in the P (Expt. 2) and K (Expt. 3). P was held constant at 200 mg•L^{-1} in the N (Expt. 1) and 250 mg•L^{-1} in the K (Expt. 3) experiment. K was kept constant at 250 mg•L^{-1} in the N (Expt. 1) and P (Expt. 2) experiments. All nutrient solutions had a common 100 mg•L^{-1} Ca ($CaCl_2$•$2H_2O$) and 50 mg•L^{-1} Mg ($MgSO_4$•$7H_2O$). Table 1 shows how nutrient

solutions were supplied to increase N, P, or K in each of the 3 experiments while holding all other nutrients constant.

At the beginning, fifteen pots were placed in each 29.5 x 50.5 cm molded carrying tray (4.00 AZ Transport Tray (15), Landmark Plastic Corporation, Akron, Ohio). Initially, the molded carrying trays were spaced 7.6 cm apart to simulate commercial growing conditions. To prevent lodging, plants were supported in July 2005, with 8-10 mm diameter bamboo stakes (Bamboo Stake Co., Lakeland, Fla.) 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 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 given additional support with 12-14 mm diameter bamboo stakes cut at 61 cm. Pots were spaced at 232.3 cm^2.

For all experiments, pots were watered by hand at each watering by applying 100 mL of nutrient solution per pot. As plants grew, 150 mL of nutrient solution was applied per pot. After the termination of fertilization, plants were watered with plain RO water by hand-held hose. Insecticides and fungicides were applied at recommended rates as needed throughout the growing period (Table A1).

Plants were grown in a glass and polycarbonate greenhouse until the time of full flower. From February to December 2005, temperature set points in the greenhouse were 24 °C day/18 °C night and actual average temperatures were 24 ± 11.5 °C day/20 ± 11 °C night. From February to April, if two new shoots emerged from the base of the 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 18 °C day/15 °C and actual average temperatures were 18 ± 9.5 °C day/14 ± 6 °C night to promote flower initiation. On 17 Jan. 2006 after flower initiation, temperature set points in the greenhouse were 22 °C day/17 °C night and actual average temperatures were 22 ± 6 °C day/18 ± 4.5 °C night through flower development (Fig. 1). HOBO H8 data loggers (Onset Computer Corp., Bourne, Maine) were used to measure

and record the actual greenhouse temperature (Figures A1-A5). Greenhouse light levels were monitored at plant canopy level using line quantum sensors (LQS 50-3, Apogee Instruments Inc., Logan, Utah) (Figures A1-A5). The maximum daily light level ranged from a high of 10 $mol \cdot m^{-2} \cdot d^{-1}$ in June to a low of 2 $mol \cdot m^{-2} \cdot d^{-1}$ in January.

Table 1. The amount of chemicals used to prepare nutrient solutions of various nitrogen (N), phosphorus (P), and potassium (K) concentrations.

	Rate ($g \cdot L^{-1}$)	KH_2PO_4	KNO_3	NH_4NO_3	$NH_4H_3PO_4$
Expt. 1 (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
Expt. 2 (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
Expt. 3 (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

Plant height, pseudobulb node number, pseudobulb width and thickness, leaf number, and chlorophyll readings data 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 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, Texas). Several locations on the pseudobulb were measured and the thickest/widest portion of the pseudobulb was recorded. The leaf number was the number of leaves remaining on the plant in December. The chlorophyll reading was measured using a Minolta chlorophyll meter (model SPAD-502, Spectrum Technologies, Inc., Plainfield, Ill.) for the lower, middle and upper leaves. The lower leaf was at one of the bottom three nodes, the middle leaf was midway on the pseudobulb, and the upper leaf was the upper most fully expanded leaf. All measurements were taken at the point halfway between the leaf apex and leaf base and between the side margins and the midrib at the widest point.

In February and March 2006, flowering data were collected including total flower number, flowering node number, apical non-flowering node number, flower number per node, middle flower diameter, days to anthesis, and time to full flower. Apical non-flowering node number was the number of nodes above the last flowering node at the top of the pseudobulb. This 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 of anthesis were the days from planting to the day the petals of the first flower were observed separating on each plant. Time to full flower was number of days between anthesis and the time when all flowers on the plant were fully open.

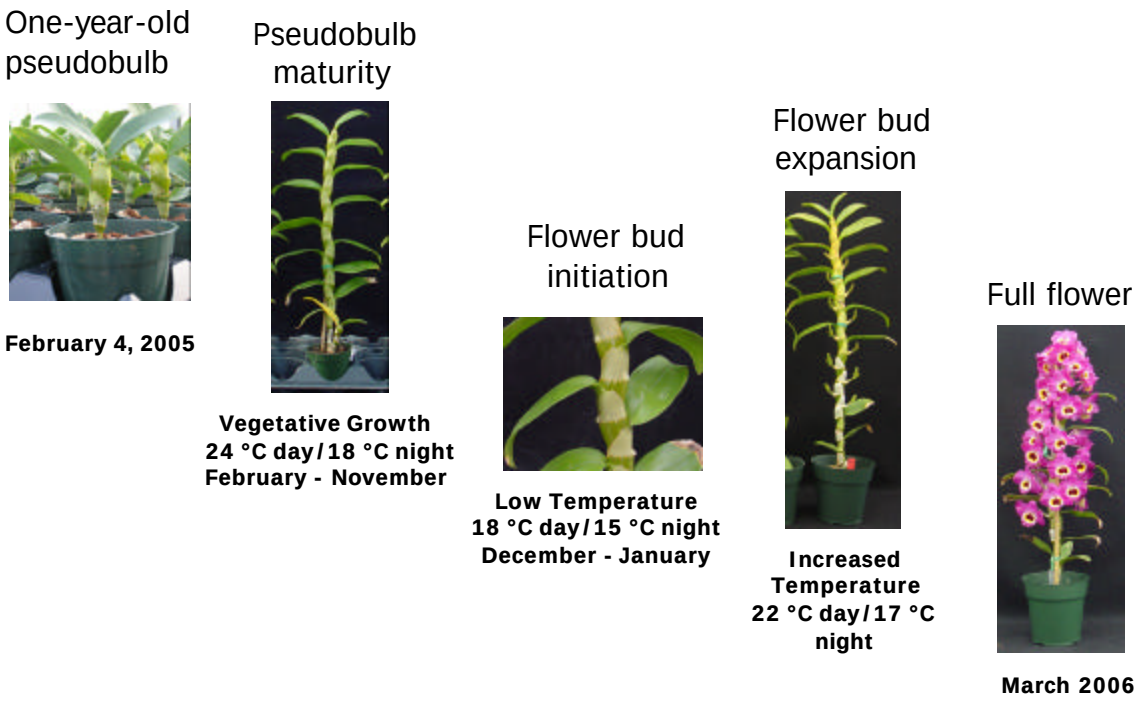


Figure 1. Timeline of growth and development for *Dendrobium* Red Emperor 'Prince'.

In Expt. 4, plants were fertilized at each watering with the same 100 mg•L^{-1} N fertilizer solution as in the previous N experiment, while P was held constant at 200 mg•L^{-1} and K at 250 mg•L^{-1}. Calcium ($CaCl_2$•$2H_2O$) was supplied at 100 mg•L^{-1} and Mg ($MgSO_4$•$7H_2O$) 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 time of full flower. There were four termination times 1 Sept., 1 Oct., 1 Nov., and 1 Dec. Control plants received continuous N (FT-C) until the time of full flower. There were 10 replications per treatment arranged in a randomized complete block design. There were a total of 50 plants.

Data were analyzed using ANOVA and least squared difference (LSD) test by SAS program (SAS 8.01; SAS Institute, Cary, N.C.).

Results: Experiment 1

The objective of experiment 1 was to determine the effect of nitrogen (N) rate and fertilizer termination time (FT) on *Dendrobium* Red Emperor 'Prince'.

For the vegetative parameters measured at pseudobulb maturity, there were no interactions between N rate and fertilizer termination time with the exception of leaf number (Table 2). For 0 mg•L^{-1} N, plants retained more leaves when fertilization was terminated at FT-1 than at FT-2 or FT-3 (Fig. 1). When absent of N, five to six leaves were present on plants when fertilizer was terminated at FT-1 (1 Sept. 2005) than when it was applied for an additional 30 or 60 more days. The second (FT-2) and third (FT-3) termination times resulted in plants having similar number of leaves at each of the N rates above 0 mg•L^{-1}. For all fertilizer termination times, plants produced similar number of leaves at N rates from 50 to 400 mg•L^{-1} (Fig. 2).

Table 2. ANOVA for the effect of nitrogen rate and fertilizer termination time on vegetative parameters measured at pseudobulb maturity of *Dendrobium* Red Emperor 'Prince'.

	Plant height (cm)	Pseudobulb node no.	Leaf no.	Pseudobulb	
				Width (mm)	Thickness (mm)
Nitrogen rate (N) (mg•L^{-1})	***	***	***	***	***
Fertilizer termination time (FT) (d)	NS	NS	NS	**	***
N × FT	NS	NS	**	NS	NS

NS, **, *** Not significant or significant at $P = 0.01$, 0.001, respectively.

For all fertilizer termination times, plants became taller as N rate increased from 0 to 50 mg•L^{-1} (Table 3), reaching the peak at 100 and 200 mg•L^{-1} N. Plants were shorter when N increased to 400 mg•L^{-1} N. Plants fertilized with N at 50 mg•L^{-1} had more pseudobulb nodes than those with 0 mg•L^{-1} N but fewer than those fertilized with

400 mg•L^{-1} N. The total pseudobulb node number was largest at 100 and 200 mg•L^{-1} N (Table 3).

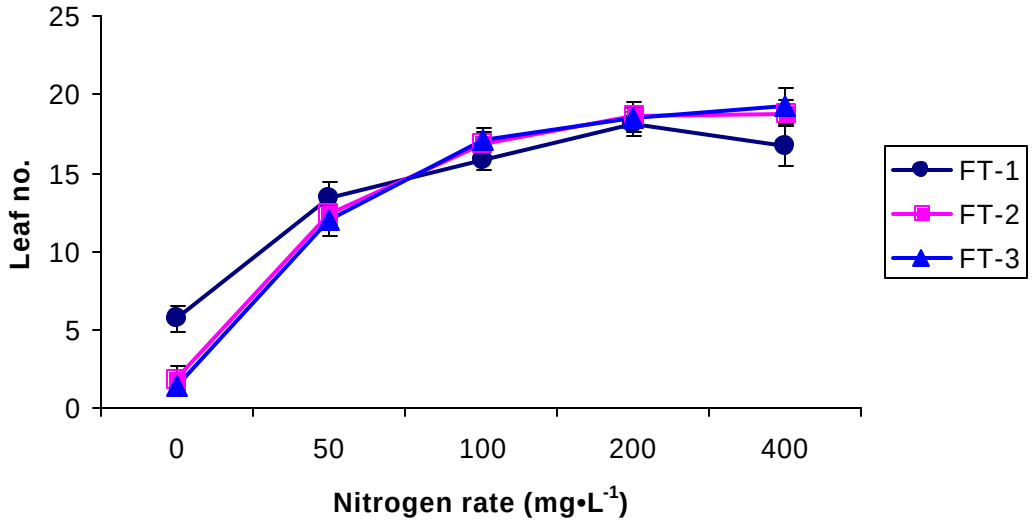


Figure 2. Effect of nitrogen rate and fertilizer termination time on leaf number measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince'.
FT-1= first fertilizer termination time, 1 Sept. 2005.
FT-2= second fertilizer termination time, 1 Oct. 2005.
FT-3= third fertilizer termination time, 1 Nov. 2005.
Bars indicate ± standard error of the mean.

Pseudobulb width and thickness were significantly affected by both N rate and fertilizer termination time (Table 2). N rates did not result in any difference in either pseudobulb width or thickness except at 400 mg•L^{-1} N which resulted in smaller pseudobulb width and thickness (Table 3). Pseudobulbs were wider and thicker when fertilization was terminated at FT-1 compared to FT-2 and FT-3, with no differences between the latter two (Fig. 3).

There were no interactions between N rate and fertilizer termination time and there was no effect of fertilizer termination time on chlorophyll readings for lower,

middle, and upper leaves, but all three were significant for N rate (Table 4). On lower leaves, chlorophyll readings were the lowest at 0 mg•L^{-1} N, while all other N rates were similar (Table 5). Chlorophyll reading of middle leaves increased from 0 to 400 mg•L^{-1} N. On the upper leaves, 50 mg•L^{-1} N caused the highest chlorophyll reading, but it was not different at 100 or 400 mg•L^{-1} N.

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

Nitrogen rate (N) (mg•L^{-1})	Plant height (cm)	Pseudobulb node no.	Pseudobulb	
			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

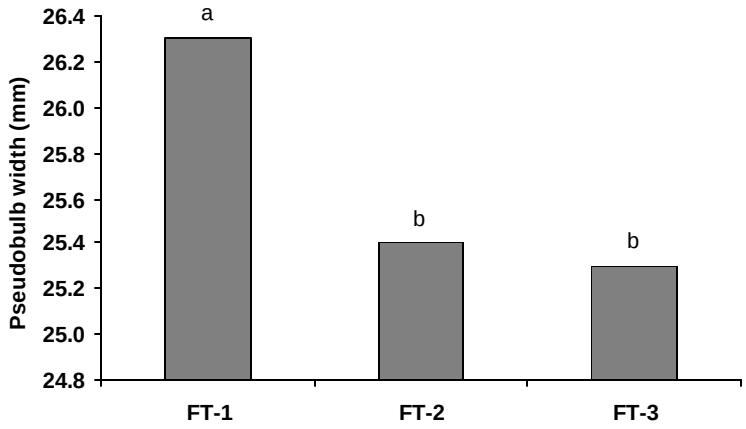
[z]Mean separation within columns by LSD at $P = 0.05$.

Table 4. ANOVA for the effect of nitrogen rate and fertilizer termination time on chlorophyll readings of lower, middle and upper leaves measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince'.

	Leaf position of chlorophyll reading		
	Lower	Middle	Upper
Nitrogen rate (N) (mg•L^{-1})	**	***	**
Fertilizer termination time (FT) (d)	NS	NS	NS
N × FT	NS	NS	NS

NS, **, *** Not significant or significant at $P = 0.01$, 0.001, respectively.

(A)



(B)

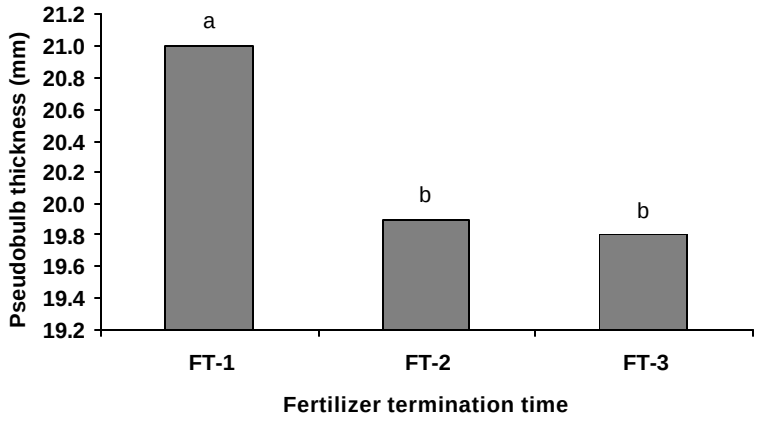


Figure 3. Effect of fertilizer termination time regardless of nitrogen rate on pseudobulb width (A) and thickness (B) measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince'.
FT-1= first fertilizer termination time, 1 Sept. 2005.
FT-2= second fertilizer termination time, 1 Oct. 2005.
FT-3= third fertilizer termination time, 1 Nov. 2005.
Mean separation by LSD at $P = 0.05$.

Table 5. Effect of nitrogen rate regardless of fertilizer termination time on chlorophyll readings of lower, middle and upper leaves measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince'.

Nitrogen rate (N) ($mg \cdot L^{-1}$)	Leaf position of chlorophyll reading		
	Lower	Middle	Upper
0	35.90 b[z]	37.23 d	41.70 bc
50	50.26 a	50.81 c	47.16 a
100	52.66 a	56.02 b	43.25 abc
200	57.20 a	57.43 b	40.71 c
400	59.19 a	64.87 a	45.87 ab

[z]Mean separation within columns by LSD at $P = 0.05$.

Table 6. ANOVA for the effect of nitrogen rate and fertilizer termination time on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

	Total flower no.	Flowering node no.	Apical non-flowering node no.	Middle flower diam (cm)	Days to anthesis	Time to full flower (d)
Nitrogen rate (N) ($mg \cdot L^{-1}$)	***	***	***	***	***	***
Fertilizer termination time (FT) (d)	***	***	***	**	***	NS
N × FT	***	**	**	*	***	**

NS, *, **, *** Not significant or significant at $P = 0.05$, 0.01, 0.001, respectively.

There were interactions between N rate and fertilizer termination time on all reproductive parameters measured at the time of full flower (Table 6). As 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 (Fig. 4A). At 200 mg•L^{1} N, FT-1 and FT-2 flower numbers were similar to that at 100 mg•L^{-1} N. When terminated at FT-3, total flower number decreased at 200 mg•L^{-1} N and 400 mg•L^{-1} N. With FT-3, the total flower number decreased from 21 flowers to 12 flowers as N rate increased from 200 mg•L^{-1} to 400 mg•L^{-1}.

When no N was applied, plants had the least number of flowering nodes for all fertilizer termination times (Fig. 4B). When fertilized with 50 or 100 mg•L^{-1} N, plants responded by producing more flowering nodes at all three fertilizer termination times. At FT-3, flowering node numbers decreased from 100 to 400 mg•L^{-1} N whereas flowering node numbers stayed unchanged when fertilizer was terminated at FT-1 and FT-2.

At 0 mg•L^{-1} N, all fertilizer termination times resulted in plants having the least number of apical non-flowering nodes. For FT-1 and FT-2, there was no difference between the numbers of apical non-flowering nodes produced at 50 to 400 mg•L^{-1} N (Fig. 4C). From 50 to 200 mg•L^{-1} N and at FT-3, the number of apical non-flowering nodes was similar, but increased from six to nine apical non-flowering nodes from 200 and 400 mg•L^{-1} N.

At 0 mg•L^{-1} N, FT-1 plants had larger flowers than those when fertilizer was terminated at FT-2 or FT-3 (Fig. 4D). Nitrogen rates from 50 to 200 mg•L^{-1} N produced plants with similar flower diameter for all fertilizer termination times. FT-1 plants had the same flower diameter at all N rates. At FT-3, plants supplied with 400 mg•L^{-1} N had decreased flower diameter, compared to 50, 100, and 200 mg•L^{-1} N, that was not different from 0 mg•L^{-1} N.

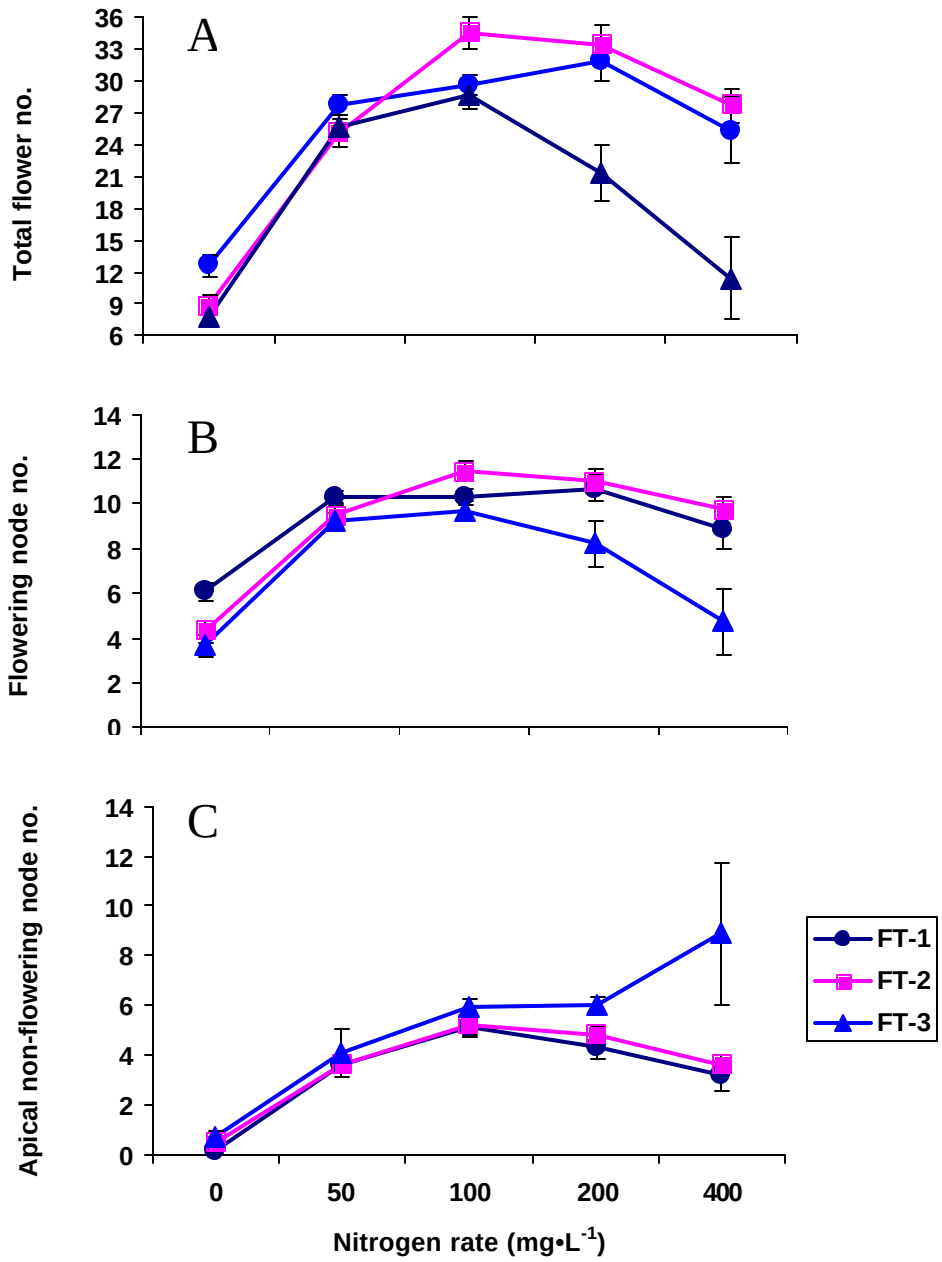


Figure 4. Effect of nitrogen rate and fertilizer termination time on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince'. FT-1 = 1 Sept. 2005, FT-2 = 1 Oct. 2005, FT-3 = 1 Nov. 2005. Bars indicate ± standard error of the mean.

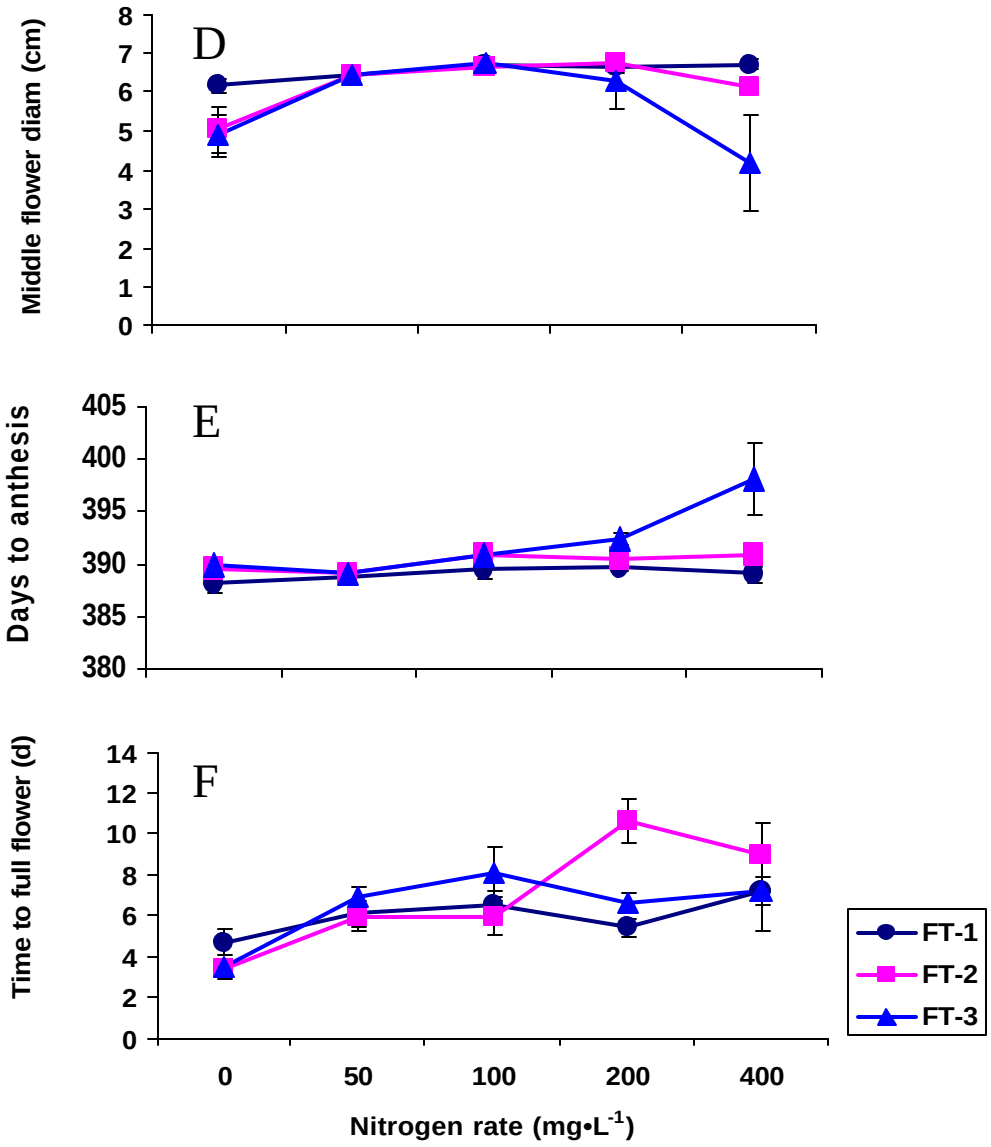


Figure 4 continued.

Regardless of N rate, days to anthesis were similar for both FT-1 and FT-2 fertilizer termination times (Fig. 4E). At FT-3, 200 and 400 mg•L^{-1} N caused a delay for the first flower to reach anthesis. The number of days to obtain full flower was similar for all N rates in FT-1 and FT-3 (Fig. 4F). When 200 mg•L^{-1} N was applied until FT-2, plants required 11 days from anthesis to full flower compared to six days to reach full flower at 100 mg•L^{-1} N. The length of time needed to reach full flower decreased to nine days for 400 mg•L^{-1} N at FT-2.

There were no interactions between N rate and fertilizer termination time for number of flowers per node (Table 7). Nitrogen rates of 100 and 200 mg•L^{-1} N produced the most nodes bearing three or four flowers (Table 8) whereas other N rates resulted in more nodes producing two flowers (Table 8). At 0 mg•L^{-1} N, most nodes produced two flowers. There was no difference in the number of nodes with one flower produced at any fertilizer rate. For plants at both FT-1 and FT-2, there were more nodes with three flowers than at FT-3 (Table 9). A greater number of nodes with two flowers were produced at FT-1, while FT-2 and FT-3 plants each had two nodes with two flowers.

Table 7. ANOVA for the effect of nitrogen rate and fertilizer termination time on number of flowers per node measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

	Flower no. per node			
	4	3	2	1
Nitrogen rate (N) (mg•L^{-1})	***	***	***	NS
Fertilizer termination time (FT) (d)	NS	***	*	NS
N × FT	NS	NS	NS	NS

NS, *, *** Not significant or significant at $P = 0.05$, 0.001, respectively.

Table 8. Effect of nitrogen rate regardless of fertilizer termination time on number of flowers per node measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Nitrogen rate (N) ($mg \cdot L^{-1}$)	Flower no. per node			
	4	3	2	1
0	0.0 c[z]	0.7 d	3.6 a	0.4 a
50	0.4 bc	6.3 b	2.6 b	0.3 a
100	1.4 a	7.5 a	1.3 c	0.3 a
200	1.3 a	6.8 ab	1.5 c	0.4 a
400	0.8 ab	4.8 c	2.0 b	0.3 a

[z]Mean separation within columns by LSD at $P = 0.05$.

Table 9. Effect of fertilizer termination time regardless of nitrogen rate on number of flowers per node measured at time to full flower for *Dendrobium* Red Emperor 'Prince'.

Fertilizer termination time (FT) (d)	Flower no. per node			
	4	3	2	1
FT-1[z]	0.7 a[y]	5.7 a	2.7 a	0.2 a
FT-2	1.1 a	5.7 a	2.0 b	0.4 a
FT-3	0.5 a	4.3 b	1.9 b	0.5 a

[z]FT-1 = 1 Sept. 2005, FT-2 = 1 Oct. 2005, FT-3 = 1 Nov. 2005.
[y]Mean separation within columns by LSD at $P = 0.05$.

Results: Experiment 2

The objective of experiment 2 was to determine the effect of phosphorus (P) rate and fertilizer termination time (FT) on *Dendrobium* Red Emperor 'Prince'.

With the exception of days to anthesis, interactions between P rate and fertilizer termination time were not significant for the vegetative (Table A2) and reproductive (Table A3) characteristics.

Both P rate and fertilizer termination time affected vegetative growth including: plant height, pseudobulb node number, leaf number, and pseudobulb thickness. Phosphorus rate at 25 mg•L-1 caused plants to be taller than 0 mg•L^{-1} (Table 10). However, further increase of P to 200 mg•L^{-1} did not result in any additional increase in plant height. Pseudobulb node number increased as P increased from 0 to 25 mg•L^{-1} and then remained unchanged as P was raised from 25 to 200 mg•L^{-1}. Leaf number was largest at P rates between 25 and 100 mg•L^{-1} with an average of 19 leaves. Pseudobulb width was widest at 100 mg•L^{-1} P and 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. There were no interactions for effects of fertilizer termination time on chlorophyll readings for lower, middle and upper leaves. For P rate, only the chlorophyll reading for the middle leaves was significant.

Table 10. Effect of phosphorus rate regardless of fertilizer termination time on vegetative parameters measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince'.

Phosphorus rate (P) (mg•L^{-1})	Plant height (cm)	Pseudobulb node no.	Leaf no.	Pseudobulb	
				Width (mm)	Thickness (mm)
0	55.3 c[z]	18.4 b	16.8 b	24.18 c	19.42 b
25	60.1 b	19.8 a	18.4 a	24.72 bc	20.50 a
50	62.3 ab	20.2 a	19.0 a	25.98 ab	21.08 a
100	63.6 a	20.8 a	19.2 a	26.69 a	20.94 a
200	62.6 a	20.6 a	17.1 b	25.89 ab	20.83 a

[z]Mean separation within columns by LSD at $P = 0.05$.

Table 11. Effect of fertilizer termination time regardless of phosphorus rate on vegetative parameters measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince'.

Fertilizer termination time(FT) (d)	Plant height (cm)	Pseudobulb node no.	Leaf no.	Pseudobulb	
				Width (mm)	Thickness (mm)
FT-1[y]	60.4 b[z]	19.8 ab	17.6 b	25.76 a	21.06 a
FT-2	62.8 a	20.7 a	18.7 a	25.88 a	20.70 a
FT-3	59.1 b	19.4 b	18.0 ab	24.83 a	19.90 b

[z]FT-1 = 1 Sept. 2005, FT-2 = 1 Oct. 2005, FT-3 = 1 Nov. 2005.
[y]Mean separation within columns by LSD at $P = 0.05$.

Plant heights were similar when fertilization was terminated at FT-1 or FT-3, but were taller at FT-2 (Table 11). Pseudobulb node number was highest at FT-2 but not different than FT-1. Leaf number was greater for FT-2, less for FT-1, and intermediate for FT-3. Regardless of fertilizer termination time, pseudobulb widths were similar. Pseudobulb thicknesses were similar for FT-1 and FT-2, but thinner at FT-3.

For flowering responses, days to anthesis was the only variable showing an interaction between P rate and fertilizer termination time (Fig. 5). For all three termination times, plants that were not supplied with P flowered later than those receiving P. At 50 mg•L^{-1} P, terminating nutrient application at FT-2 or FT-3 resulted in the least time to reach anthesis, 389 days.

Total flower number per plant and time to full flower were affected by P rate and fertilizer termination time (Table A3). Neither P rate nor fertilizer termination time had any effect on middle flower diameter. Plants supplied with 25 to 200 mg•L^{-1} P all produced an average of 29 flowers per plant (Table 12). Regardless of P rate, flowering node numbers were similar. The least number of apical non-flowering nodes was produced at 0 mg•L^{-1} P compared to rates of 25 to 200 mg•L^{-1} P. Plants that were

fertilized with 200 mg•L^{-1} P required two more days to reach full flower than plants supplied with other P rates.

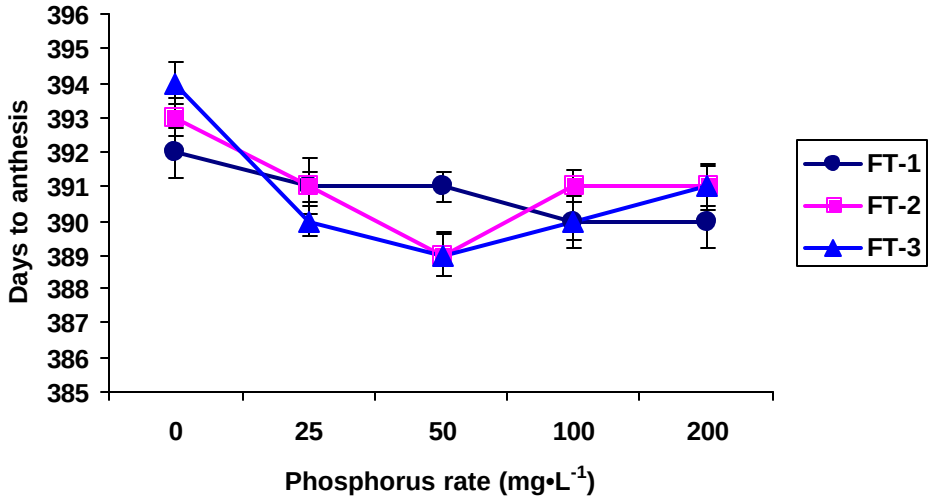


Figure 5. Effect of phosphorus rate and fertilizer termination time on days to anthesis measured at time of full flower for *Dendrobium* Red Emperor 'Prince'. FT-1 = 1 Sept. 2005, FT-2 = 1 Oct. 2005, FT-3 =1 Nov. 2005. Bars indicate ± standard error of the mean.

Table 12. Effect of phosphorus rate regardless of fertilizer termination time on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Phosphorus rate (P)(mg•L^{-1})	Total flower no.	Flowering node no.	Apical non-flowering node no.	Time to full flower (d)
0	23.0 b[z]	9.1 a	3.3 d	5 b
25	28.7 a	10.0 a	4.1 c	6 b
50	29.5 a	10.1 a	4.5 bc	6 b
100	29.2 a	9.9 a	5.0 ab	5 b
200	29.1 a	9.7 a	5.3 a	7 a

[z]Mean separation within columns by LSD at $P = 0.05$.

Table 13. Effect of fertilizer termination time regardless of phosphorus rate on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Fertilizer termination time (FT) (d)	Total flower no.	Flowering node no.	Middle flower diam (cm)	Time to full flower (d)
FT-1[z]	26.9 b[y]	9.8 ab	6.9 a	5 b
FT-2	29.8 a	10.3 a	6.9 a	6 a
FT-3	26.9 b	9.3 b	6.9 a	7 a

[z]FT1 = 1 Sept. 2005, FT-2 = 1 Oct. 2005, FT-3 = 1 Nov. 2005.
[y]Mean separation within columns by LSD at $P = 0.05$.

Plants produced the most flowers when fertilization was terminated at FT-2 (Table 13). Flowering node number was not different for FT-1 and FT-2, but were fewer at FT-3. Flower diameter was similar for all fertilizer termination times. Both FT-2 and FT-3 plants required more time to full flower than FT-1.

Nodes with four, three, two and one flowers were significant for P rate (Table A4). Plants that were supplied with 200 mg•L^{-1} P had more nodes bearing four flowers than any other rate (Table 14). However, when provided with 25 to 200 mg•L^{-1} P, plants produced the highest number of nodes with three flowers. At 0 mg•L^{-1} P, there were two more nodes with two flowers than at any other fertilizer rate. Plants supplied with 0 mg•L^{-1} P produced the most nodes with one flower. At FT-1, the greatest number of nodes with two flowers was produced (Table 15). More nodes with four flowers were produced at FT-2 and FT-3.

Table 14. The effect of phosphorus rate regardless of fertilizer termination time on number of flowers per node measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Phosphorus rate (P) ($mg \cdot L^{-1}$)	Flower no. per node			
	4	3	2	1
0	0.03 c[z]	4.83 c	3.97 a	0.43 a
25	0.90 b	7.07 ab	1.90 b	0.13 b
50	1.07 b	7.28 ab	1.66 b	0.07 b
100	0.77 b	7.87 a	1.27 b	0.03 b
200	1.73 a	6.33 b	1.53 b	0.07 b

[z]Mean separation within columns by LSD at $P = 0.05$.

Table 15. Effect of fertilizer termination time regardless of phosphorus rate on number of flowers per node measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Fertilizer termination time (FT) (d)	Flower no. per node			
	4	3	2	1
FT-1	0.5 b[z]	6.5 a	2.8 a	0.12 a
FT-2	1.2 a	7.0 a	1.8 b	0.16 a
FT-3	1.0 a	6.5 a	1.6 b	0.16 a

[z]Mean separation within columns by LSD at $P = 0.05$.

Results: Experiment 3

The objective of experiment 3 was to determine the effect of potassium (K) rate and fertilizer termination time (FT) on Dendrobium Red Emperor 'Prince'.

Except for pseudobulb thickness, no variables measured were affected by interactions between K rate and fertilizer termination time (Table A5). 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}. Pseudobulb thickness at all fertilizer termination times was similar at any given K rate (Fig. 6).

Potassium rate had no effect on lower and middle leaf chlorophyll readings or time to full flower (Tables A5 and A6). Time of fertilizer termination did not affect vegetative growth and only nodes with two and four flowers and time to full flower were affected.

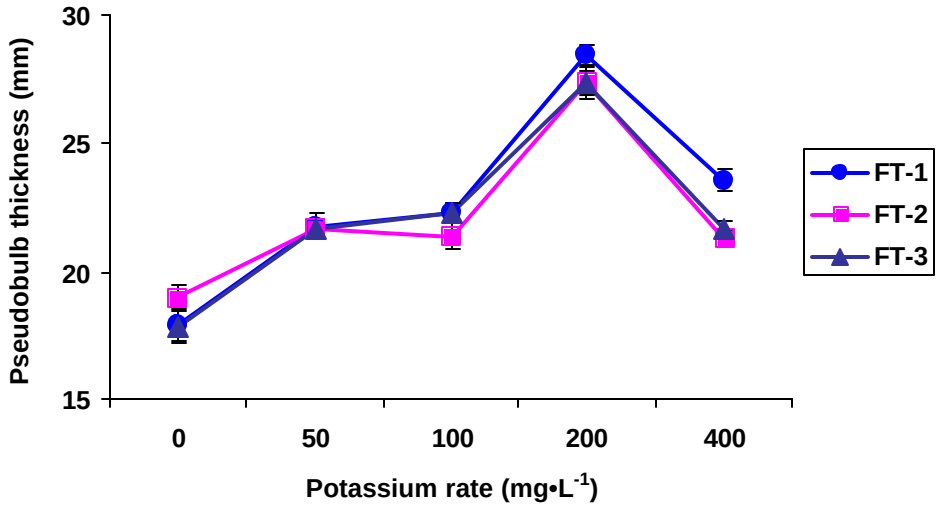


Figure 6. Effect of potassium rate and fertilizer termination time on pseudobulb thickness measured at pseudobulb maturity on *Dendrobium* Red Emperor 'Prince'. FT-1 = 1 Sept. 2005, FT-2 =1 Oct. 2005, FT-3 = 1 Nov. 2005. Bars indicate ± standard error of the mean (but are too small to be seen).

Plant height and pseudobulb node number increased as K rate increased from 0 to 100 mg•L^{-1}, but were similar from 100 to 400 mg•L^{-1} K (Table 16). As K rate increased from 0 to 200 mg•L^{-1}, leaf number increased but did not increase further at 400 mg•L^{-1}. Plants that received 0 mg•L^{-1} K had the highest chlorophyll reading in their upper leaves compared to those receiving 50 to 400 mg•L^{-1} K. Application of K resulted in wider pseudobulbs, with no difference among plants supplied with 50 to 400 mg•L^{-1} K.

Table 16. Effect of potassium rate regardless of fertilizer termination time on vegetative parameters measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince'.

Potassium rate (K) (mg•L^{-1})	Plant height (cm)	Pseudobulb node no.	Leaf no.	Upper leaf chlorophyll reading	Pseudobulb width (mm)
0	41.0 c[z]	14.6 c	4.8 d	54.5 a	23.01 b
50	54.6 b	18.3 b	11.8 c	49.6 b	27.10 a
100	59.0 a	20.1 a	14.4 b	48.3 b	27.57 a
200	60.2 a	20.5 a	16.2 a	44.9 c	27.72 a
400	59.1 a	20.0 a	16.3 a	49.3 b	27.80 a

[z]Mean separation within columns by LSD at $P = 0.05$.

Total flower number and flowering node number were the lowest at 0 mg•L^{-1} K but remained similar from 50 to 400 mg•L^{-1} K (Table 17). Apical non-flowering node number was the lowest at 50 mg•L^{-1} K and the highest at 200 mg•L^{-1} K. Flower diameter was largest at 200 mg•L^{-1} K. When supplied with 0 or 50 mg•L^{-1} K plants took

the fewest number of days to anthesis while one to three more days were needed for all other K rates.

The number of nodes with four, three, two, or one flowers was also significant for K rate. As K rate increased from 0 to 400 mg•L^{-1} K, the number of nodes with four flowers increased (Table 18). Nodes with three flowers were the greatest at 50 and 100 mg•L^{-1} K and the least at 0 mg•L^{-1} K. The greatest number of flowering nodes with two flowers and one flower was at 0 mg•L^{-1} K.

Table 17. Effect of potassium rate regardless of fertilizer termination time on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Potassium rate (K) (mg•L^{-1})	Total flower no.	Flowering node no.	Apical non-flowering node no.	Middle flower diam (cm)	Days to anthesis
0	11.0 c[z]	5.1 b	4.1 bc	6.4 c	390 cd
50	26.2 b	9.5 a	3.5 c	6.9 b	389 d
100	28.5 ab	9.8 a	5.0 ab	7.1 b	391 bc
200	29.0 a	9.4 a	5.6 a	7.4 a	393 a
400	29.8 a	9.8 a	4.4 bc	7.0 b	392 ab

[z]Mean separation within columns by LSD at $P = 0.05$.

Table 18. Effect of potassium rate regardless of fertilizer termination time on number of flowers per node measured at time of full flower on *Dendrobium* Red Emperor 'Prince'.

Potassium rate (K) ($mg \cdot L^{-1}$)	Flower no. per node			
	4	3	2	1
0	0.1 c	1.1 d	3.4 a	0.5 a
50	0.5 cb	6.4 ab	2.5 b	0.1 b
100	1.1 b	6.9 a	1.8 bc	0.1 b
200	2.4 a	5.5 c	1.3 c	0.1 b
400	2.2 a	5.9 bc	1.6 c	0.1 b

Mean separation within columns by LSD at $P = 0.05$.

Apical non-flowering node number, nodes with four flowers, nodes with two flowers and time to full flower were significant for fertilizer termination time (Table 19). The number of apical non-flowering nodes was more at FT-3. FT-2 and FT-3 resulted in the highest number of four flowers. The least number of nodes with 2 flowers was produced at FT-2 and FT-3. Flowering progressively delayed when terminating nutrient application was delayed from FT-1 to FT-3.

Time of terminating nutrient application had no effect on vegetative growth or flowering. All plants averaged 55 cm tall with 19 nodes, 13 leaves, pseudobulb width of 27 mm, and lower, middle and upper chlorophyll readings of 53, 55, and 49, respectively. Plants had an average of 25 flowers, nine flowering nodes, a middle flower diameter of 7.0 cm, five nodes with three flowers and 0.18 nodes with one flower, and took 391 days to reach anthesis.

Table 19. Effect of fertilizer termination time on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Fertilizer termination time (FT) (d)	Apical non-flowering node no.	Flower no. per node		Time to full flower (d)
		4	2	
FT-1[z]	4.0 b[y]	0.76 b	2.59 a	6 b
FT-2	4.5 ab	1.38 a	2.08 ab	7 ab
FT-3	5.0 a	1.71 a	1.63 b	8 a

[z]FT-1 = 1 Sept. 2005, FT-2 = 1 Oct. 2005, FT-3 = 1 Nov. 2005.
[y]Mean separation within columns by LSD at $P = 0.05$.

Results: Experiment 4

The objective of experiment 4 was to determine the effect of duration of nitrogen application.

In this experiment, the duration of N application did not affect vegetative (Table A7) or flowering (Table A8) characteristics. Plants in all treatments averaged 57.1 cm in height and had 20 pseudobulb nodes and 17 leaves. Pseudobulb width and thickness was 28.6 and 22.1 mm respectively. Plants had an average of two nodes with four flowers, six nodes with three flowers, one node with two flowers and no nodes with one flower. There was an average of 28 total flowers per plant and middle flower diameter was 6.6 cm. On average, plants required 388 days to reach anthesis and eight more days to full flower.

Discussion

Dendrobium Red Emperor 'Prince' and other *Dendrobium nobile* hybrids have the potential for increased production and to become a popular orchid sold on the mass market. They have several attributes including the ability to closely space them in the greenhouse giving them a high value per square foot. More importantly, they have long lasting flowers that come in many colors, which appeal to the customer. 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. A leaf, and potentially a flower, can be produced at every node. Node number may be an indication of how many flowers can be produced (Rotor, 1952). Plants were taller and had a greater number of total pseudobulb nodes when they were supplied with 100 and 200 mg•L^{-1} N compared to lower and higher rates. Wang (1996) used rates of 100 and 200 mg•L^{-1} N 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 moss, produced larger leaves that were wider when N was applied at the higher rate. A similar number of leaves were produced when plants were supplied with 100 to 400 mg•L^{-1} N at all three fertilizer termination times. Because these plants were both taller and had a greater pseudobulb node number, they also produced more flowers except for 200 mg•L^{-1} N applied until FT-3.

Today, consumers prefer that leaves remain on nobile dendrobium potted plants when in full flower. When not given N, leaf loss was greater than all other N rates, having only 38% leaf retention (Table A9). When N continued to be withheld until the second and third termination times, leaf loss was greater than FT-1. One of the typical signs of N deficiency in plants is the abscission of older leaves (Marschner, 2003).

Pseudobulb width and thickness were affected by N rate and termination time. Application of 400 mg•L^{-1} N, was the only rate which caused pseudobulb width and thickness to decrease. Because plants had thicker and wider pseudobulbs, it was determined that when fertilizer was terminated at FT-1 plants matured faster. When plants were supplied with N until FT-2 and FT-3, they did not mature and were thinner

and narrower. When pseudobulbs mature earlier, they can be forced to produce flowers and sold at earlier market dates.

Total flower number and flowering node number decreased significantly when plants were not supplied N. However, apical non-flowering nodes increased with application of N. Since plants were shorter and had fewer nodes, they were not able to produce as many flowers. Plants had an average of 10 flowers on plants receiving 0 $mg \cdot L^{-1}$ N.

When plants were supplied with 400 $mg \cdot L^{-1}$ N at FT-3, pseudobulbs remained vegetative for a longer period of time than those terminated fertilization at FT-1 or FT-2. Number of apical non-flowering nodes and days to anthesis increased, while flower number, flowering node number, and middle flower diameter decreased. Plants that were terminated fertilization earlier and given 200 or 400 $mg \cdot L^{-1}$ N, stopped vegetative growth, matured earlier, and produced more flowers after the cold duration than those receiving 400 $mg \cdot L^{-1}$ N until FT-3. The Yamamoto Dendrobium website (2006) suggests that plants not be supplied N after August when plants have already reached their final height.

When N fertilization was terminated at FT-1, plants had an average of five more flowers than plants that were terminated fertilizer at the later times. Rates of 100 to 400 $mg \cdot L^{-1}$ N produced a greater number of flowers at FT-1 and FT-2. Plants fertilized until FT-3 with 200 or 400 $mg \cdot L^{-1}$ N, had fewer flowers than those receiving lower rates of N. The addition of too much N from fertilizers is a common cause of poor flowering (Yamamoto Dendrobiums, 2006). Again, this is probably due to the prolonged vegetative state and delayed pseudobulb maturation for plants fertilized until the latest fertilizer termination time. Flowering characteristics were similar for FT-1 and FT-2 termination times. Therefore, in order to reduce inputs, fertilizer could be terminated earlier with similar results.

Before the termination of fertilizer, 13% of plants were lost in treatments receiving 400 $mg \cdot L^{-1}$ N for all termination times. These plants had severe root injury due to excess salts and died. Mineral salts can reach a toxic range that causes the growth

rate to decrease (Marschner, 2003). Plants receiving 400 mg•L^{-1} N until FT-3 also had a greater occurrence of aerial shoots in place of flower buds. Seventy percent of the plants in this treatment had aerial shoots (23 in total). When pseudobulbs are not mature, they form aerial shoots (keikis) in place of flowers if supplied with too much fertilizer and/or inadequate cooling (Ichihashi, 1997). Miwa and Ozaki (1975) grew *Dendrobium nobile* in sphagnum moss (*Sphagnum magellanicum* Brid.) or hemlock (*Conium maculatum* L.) bark and supplied them with 10 different combinations of 0, 250, 500 and 1000 mg•L^{-1} N, P, and K over a period of 2 years. At 1000 mg•L^{-1} N, the least flowering nodes were produced and resulted in the greatest number of aerial shoots (keikis). Yamamoto Dendrobiums (2006) also cautions that excessive amounts of N can cause aerial shoots to form on the upper nodes. This may be due to the prolonged vegetative state and pseudobulbs did not mature in time to differentiate flower buds while being cooled.

From the results of this experiment, 100 mg•L^{-1} N is recommended for *Dendrobium* Red Emperor 'Prince'. This rate provides the amount of nutrients the plant can use efficiently for vegetative and reproductive growth with the least fertilizer input. Application of 100 mg•L^{-1} N to plants results in similar or greater plant height, pseudobulb width and thickness, as well as similar flowering characteristics compared to plants receiving higher rates. It is also recommended that fertilizer be terminated at FT-1, which results in greater pseudobulb width and thickness. 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 mg•L^{-1} N), 100 mg•L^{-1} N was recommended because it resulted in greater leaf and root dry weights, larger leaves, and increased plant height. However, each species of orchid has a different N requirement for optimal growth. 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.

Phosphorus. In this experiment, it was found that of the three macronutrients, N, P, and K, P is not required in high concentrations (above 25 mg•L^{-1}) by *Dendrobium* 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. In their native environments, epiphytic orchids receive their nutrients from several sources, but especially from rain water. Phosphorus is the element found in the least amounts in rain water (Pridgeon, 1987). It is possible that epiphytic orchids grown in a controlled environment also need less P than N and K as do those in nature.

Plant height, node number and leaf number were greater at the FT-2 fertilizer termination time. When terminated fertilizer at FT-3, pseudobulb thickness was thinner indicating that the pseudobulb does not mature like plants being terminated fertilizer at an earlier time.

Plants had two more nodes once P was applied, regardless of rate. However, application of P increased total flower count, indicating P is needed for initiating more flower primordial. Apical non-flowering node number increased as P rate increased, which may be considered as a negative effect on the appearance of a plant in full flower. Time to full flower was delayed with application of 200 $mg \cdot L^{-1}$ P, but similar at all other rates. These results suggest that P requirement for *Dendrobium* Red Emperor 'Prince' is low for reproductive growth. The FT-2 termination time resulted in similar or increased vegetative and reproductive characteristics compared to FT-1 and FT-3 termination times.

Wang (2000) found that for *Phalaenopsis* grown in Douglas fir bark and sphagnum peat, 50 $mg \cdot L^{-1}$ P was adequate for good vegetative and reproductive growth. Similar to these findings, P rate recommendation for *Dendrobium* Red Emperor 'Prince' based on this experiment would be 25 $mg \cdot L^{-1}$ terminated at FT-2 for best vegetative and reproductive growth. This recommendation reduces the input of fertilizer, time and expense for the producer.

Potassium. Besides N, it was determined that K is the other macronutrient that is needed at higher rates for optimal vegetative growth of *Dendrobium* Red Emperor 'Prince'. Plants were taller and had higher pseudobulb node numbers with the application of 100 $mg \cdot L^{-1}$ K or more.

It is important to retain the most leaves possible so those leaves can act as sources of photoassimulates to provide for flower development. Applying adequate amounts of K to nobile dendrobiums increases leaf retention and flower size (Tables 16 and 17). When supplied with the 0 or 50 mg•L^{-1} K, there was severe leaf loss with 34 and 62% leaf retention, respectively, suggesting that K supplied in amounts greater than 50 mg•L^{-1} are necessary for adequate leaf retention (Table A9). Plants supplied with 100, 200, or 400 mg•L^{-1} K had 72, 80 and 82% leaf retention, respectively. When grown in hard wood charcoal, there were beneficial effects on pseudobulbs of *Dendrobium moschatum* 'Wall' when supplied with 500 mg•L^{-1} K, but no further benefits were 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 50 mg•L^{-1} K was sufficient.

Fertilizer termination time had no effect on vegetative characteristics, but did affect apical non-flowering node number, nodes with four and two flowers and time to full flower. Fertilizer termination at FT-2 resulted in similar or increased reproductive characteristics and therefore is the recommended fertilizer termination time.

Vegetative and reproductive characteristics were similar or greater at 100 mg•L^{-1} K, with the exception of greater leaf number 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 in order to produce quality plants and minimize the amount of fertilizer input.

Experiment 4. In Expt 4, only 100 mg•L^{-1} N was terminated at each fertilizer termination time while all other nutrients continued to be supplied until the end of the experiment. Control plants received all fertilizer elements until termination of the experiment. This experiment differs from Expt. 1, where all nutrients were terminated at each fertilizer termination time.

There was comparatively no difference among the N termination times in this experiment. Plants in this experiment received the same 100 mg•L^{-1} N solution used in Expt. 1. Both vegetative and reproductive growth measurements were very similar to those recorded in experiment one. Since NH_4NO_3 was used to provide N, the molar concentration of NO_3^- and NH_4^+ in the fertilizer solution was equal. The ratio of NO_3-N and NH_4-N can affect plant growth and usually a mixed supply of NO_3-N and NH_4-N results in good plant growth (Marschner, 2003). Control plants that continued to receive N and other nutrients until full flower were similar to plants that were terminated N at the four termination times but continued to receive all other nutrients. When *Phalaenopsis* were terminated all fertilization at four different dates (1 Sept., 29 Sept., 27 Oct., or 24 Nov.) or continuously fed, there was no difference in flower diameter, however, continuously fed plants produced more flowers than plants that had been terminated fertilizer on the three earlier dates (Wang, 2000).

The average height of the plant was shorter, but overall vegetative characteristics were similar for plants in Expt. 1 that received 100 mg•L^{-1} N and Expt. 4. Differences between the two experiments were that in Expt. 1 when all fertilizer was terminated at FT-2, a greater number of flowers and flowering nodes were produced. Times needed to reach anthesis and full flower were similar among the plants in control and the terminations times of Expt 4. They were also similar to those plants supplied 100 mg•L^{-1} N in Expt. 1 at all termination times. Therefore it can be concluded that eliminating N only at each termination time had similar effects as eliminating all fertilizer at each of the termination times except for flower number and flowering node number, which reinforces that N should be terminated early for best flowering results.

CHAPTER III

EFFECT OF COLD DURATION AND LIGHT ON FLOWER BUD INITIATION OF *Dendrobium* RED EMPEROR 'PRINCE'

Introduction

In the floriculture industry, it is important to develop production schedules to control timing of flowering in order to meet consumer demand at holidays such as Christmas, Valentine's Day, Easter and Mother's Day. For most orchids, this can usually be accomplished by controlling light intensity and temperature (Hew and Yong, 2004).

In the case of *Dendrobium nobile*, flower initiation is controlled by cold temperatures (Rotor, Jr., 1952). Day/night temperatures of 20 °C/10-12.5 °C were the optimum temperature for initiating flower buds. The effects of temperature on *Dendrobium nobile* are critical during both vegetative growth and flower initiation and development. After a low temperature treatment of 10 °C for 16 hours daily over a period of 30-40 days, flower initiation of nobile dendrobiums was increased when there was an increase of night temperature from 10 °C to 25 °C (Sinoda et al., 1988). During the period of cold treatment, aerial shoots (keikis) and flower number were reduced when the daytime temperatures reached 30 °C (Sinoda et al., 1988). Despite photoperiod, 13 °C (details were not given as to whether this temperature was constant or average), was found to trigger flower bud initiation. *Dendrobium nobile* species usually begin flowering in February or March, which can be too early for the Easter holiday. Plants grown at 18 °C for up to 4 months after maturation delayed flowering until the preferred blooming date (Rotor Jr., 1952).

In addition to the photoperiod needed for flowering, some orchids also require a certain light intensity for both growth and flowering. For *Dendrobium* Nodoka and *Dendrobium* Snowflake 'Red Star', high light is not necessary during flower bud initiation. However, exposing to low light (an exact light amount was not stated) during

this time can result in chlorosis, loss of turgidity in pseudobulbs and defoliation (Ichihashi, 1997).

The objective of this experiment was to determine cold duration with or without light on flower initiation and development of *Dendrobium* Red Emperor 'Prince'.

Materials and Methods

One-year-old *Dendrobium nobile* Red Emperor 'Prince' liners, each having a single pseudobulb, were received from Yamamoto Dendrobiums, Mountain View, Hawaii, on 3 Feb. 2005. These young plants were propagated from single-node stem cuttings in 98-cell plug trays filled with sphagnum moss as the root substrate. The pseudobulbs were potted on 4 Feb. 2005 in a root substrate of 2 coarse peat : 1 perlite (no. 3) : 1 diatomite (no. 3) (90% silicon dioxide, 10% elemental minerals) (Diatomite USA, Elma, N.Y.) (by volume) with 0.5 $g \cdot L^{-1}$ Micromax, (a micronutrient source, The Scotts Company, Marysville, Ohio) and 5.0 $g \cdot L^{-1}$ powdered dolomite. Plants were potted in 10.2 cm top diameter (414 mL) standard round plastic pots.

Immediately after potting, plants were hand irrigated with reverse osmosis (RO) water containing a fungicide (Banrot 40% WP, Scotts-Sierra Crop Protection Company, Marysville, Ohio) at a rate of 59.8 $mg \cdot L^{-1}$ to prevent root rot. Plants continued to be irrigated with RO water until 22 Feb. 2005 when treatments commenced.

This experiment was a 3x2 factorial with three cold (10 °C) treatment durations (2, 4, and 6 weeks) and two light intensity levels of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ or 0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during the cooling duration with 10 replications. Plants were fertilized with constant liquid feed Scott's 20-10-20 (20N-4.4P-16.6K) at 0.5 $g \cdot L^{-1}$ (100 $mg \cdot L^{-1}$ N). Pots were watered by hand at each watering by measuring 100 mL of nutrient solution per pot. As plants grew, 150 mL of nutrient solution was applied per pot. Fertilization was terminated on 1 Oct. 2005 and plants were irrigated with plain RO water thereafter.

At the beginning, fifteen pots were placed in each 29.5 x 50.5 cm molded carrying tray (4.00 AZ Transport Tray (15), Landmark Plastic Corporation, Akron, Ohio). Initially, the molded carrying trays were spaced 7.6 cm apart to simulate

commercial growing conditions. To prevent lodging, plants were supported in July 2005, with 8-10 mm diameter bamboo stakes (Bamboo Stake Co., Lakeland, Fla.) cut at 30.5 cm (12 in.). On 6 Aug. 2005, plants from the middle row of the carrying trays were removed and placed in additional trays to improve air circulation. In December 2005, to prepare for flowering, each of the 10.2 cm (414 mL) pots was placed inside a 14.6 cm (1.77 L) pot surrounded by pea gravel and given additional support with 12-14 mm diameter bamboo stakes cut at 61 cm. Pots were spaced at 232.3 cm^2.

Plants were grown in a glass and polycarbonate greenhouse until mature. From February to December temperature set points in the greenhouse were 24 ºC day/18 ºC night and actual average temperatures were 24 ± 11.5 ºC day/20 ± 11 ºC night. From February to April 2005, if two new shoots emerged from the base of the old pseudobulb, the second emerging shoot was removed to maintain one shoot per pseudobulb. From March to May, flower buds that formed on old pseudobulb were removed to keep plants vegetative. HOBO H8 data loggers (Onset Computer Corp., Bourne, Maine) were used to measure and record the actual greenhouse temperature (Figures A1-A5). Greenhouse light levels were monitored at plant canopy level using line quantum sensors (LQS 50-3, Apogee Instruments Inc., Logan, Utah) (Figs. A1-A5). The maximum daily light level ranged from a high of 10 $mol \cdot m^{-2} \cdot d^{-1}$ in June to a low of 2 $mol \cdot m^{-2} \cdot d^{-1}$ in January. Insecticides and fungicides were applied at recommended rates as needed throughout the growing period (Table A1).

Plants were kept in a greenhouse with temperature set points of 24 °C day/18 ºC night and actual average temperatures of 22 ± 7.5 °C day/17 ± 8 °C night (Figure A6) to prevent them from receiving flower inducing temperatures. Thirty plants each were placed in two growth chambers on 9 Dec. The growth chamber with light had temperatures of 10 ± 3.5 °C throughout the six weeks of the experiment. The growth chamber without light held a temperature of 10 ± 1 °C. Plants with light received twelve hours of light per day. While in the growth chambers, plants were irrigated with RO water as needed. Ten control plants were left in the greenhouse with the same temperature set points of 24 °C day/18 ºC night and actual average temperatures of 21 ±

8 °C day/16 ± 4.5 °C night. The last groups of plants were moved out of the chambers on 19 Jan. 2006. Once they were moved out of the chambers, plants were placed back into the greenhouse with temperature set points of 24 °C day/18 °C night and actual average temperatures of 21 ± 9.5 °C day/16 ± 3.5 °C night. There were 70 plants total.

Plant height, pseudobulb node number, pseudobulb width and thickness, leaf number, and chlorophyll content data 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 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 readings were taken with a digital caliper (Model 06-664-16, Control Company, Friendswood, Texas). Several locations on the pseudobulb were measured and the thickest/widest portion of the pseudobulb was recorded. The leaf number was the number of leaves after some loss over the course of vegetative growth. The chlorophyll reading was measured using a Minolta chlorophyll meter (mode SPAD-502, Spectrum Technologies, Inc., Plainfield, Ill.) for the lower, middle, and upper leaves. The lower leaf was at one of the bottom three nodes, the middle leaf was midway on the pseudobulb, and the upper leaf was the top most fully expanded leaf. All measurements were taken at the point halfway between the leaf apex and leaf base and between the side margins and the midrib at the widest point.

In February and March 2006, flowering data were collected including total flower number, flowering node number, apical non-flowering node number, flower number per node, middle flower diameter, days to anthesis and time to full flower. Apical non-flowering node number is the number of nodes above the last flowering node at the top of the pseudobulb. This 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 of anthesis were the days from planting to the day the petals of the first flower were observed separating on each plant. Time to full flower was number of days between anthesis and when all flowers on the plant were fully open.

Data were analyzed using ANOVA and Tukey's honest significant difference test (HSD) by SAS program (SAS 8.01; SAS Institute, Cary, N.C.). This method was used to compare plants in growth chambers to the control plants that were in the greenhouse.

Results

The objective of experiment 5 was to determine the effect of cold duration and presence of light on flower initiation.

Since the plants were all grown together until maturity, there was no difference for vegetative parameters measured of the control plants or the plants that were placed in growth chambers with or without light for two, four, or six weeks (Table A9). Plants averaged 55.1 cm in height, had 18 nodes per pseudobulb, 17 leaves, and had a pseudobulb width and thickness of 27.3 and 21.6 mm, respectively. For flowering parameters measured, only middle flower diameter was not affected by treatments (Tables A10 and A11) and averaged 6.9 cm.

The control plants produced the least number of flowers (Table 20) compared to plants receiving the 10 °C cold treatments. Plants placed in growth chambers with light at all three cold treatment durations and plants in the dark for four or six weeks all produced similar high number of flowers. When cooled in darkness, at least four weeks of cooling was needed for high flower count. Cooling for only two weeks in darkness resulted in fewer flowers similar to that of controls.

Flowering node number for control plants and plants in the dark for two, four or six weeks was similar. The largest number of flowering nodes was produced by plants that were in the growth chamber with light for two, four, or six weeks with no differences among the durations. Plants in light for six weeks of cold had the least number of apical non-flowering nodes, while plants in the dark growth chamber for six weeks had the highest number of apical non-flowering nodes. There was no difference between the control plants and plants in all other cold durations in the light and dark chambers for apical non-flowering node number. The control plants and plants that were cooled in light or darkness for two weeks required the least time to reach anthesis.

Plants in growth chambers with light or in darkness for six weeks required the most days to reach anthesis and needed 20 to 28 days more for the first flower to open than control plants and plants in light for two weeks. Control plants required 7 to 17 more days to reach full flower than all other treatments. Time to full flower was less and similar for plants in the light or dark for four or six weeks.

Table 20. Effect of light or darkness and 2, 4, or 6 weeks at 10 °C in growth chambers on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Treatments											
Light level ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Cold duration (weeks)	Total flower no.		Flowering node no.		Apical non-flowering node no.		Days to anthesis		Time to full flower (d)	
100	2	33.6	a[z]	11.1	ab	1.9	ab	380	e	9	bc
100	4	33.8	a	11.4	ab	1.3	ab	392	cd	5	c
100	6	33.9	a	12.1	a	0.9	b	402	ab	4	c
0	2	22.2	bc	8.8	c	2.6	ab	386	de	13	b
0	4	27.6	ab	8.8	c	2.4	ab	397	bc	4	c
0	6	28.3	ab	9.1	bc	2.8	a	408	a	5	c
Control[y]	0	19.1	c	8.4	c	2.2	ab	382	e	21	a

[z]Mean separation within columns by Tukey's honest range test at $P = 0.05$.
[y]Plants remained in the greenhouse.

Control plants and plants cooled for six weeks in light had the least nodes with four flowers at time of full flower (Table 21). Plants cooled in the dark for four or six weeks or in the light for two or four weeks produced a similar and greater number of nodes with four flowers. Control plants and plants in light for six weeks and in darkness

for two weeks produced a fewer number of nodes with four flowers. With exception of control plants, plants in both light and dark at all three cold durations had more nodes with three flowers than any other flower numbers. Plants receiving light for two, four or six weeks had seven or eight nodes with three flowers, while plants in the dark at the three durations had five or six nodes with three flowers. Nodes with two flowers were greatest for the control plants and similar for plants in darkness for two weeks and plants in the light for six weeks. All other light and cold duration treatments produced similar number of nodes with two flowers.

Table 21. Effect of light or darkness and 2, 4, or 6 weeks at 10 °C in growth chambers on flower number per node measured at time of full flower for *Dendrobium* Red Emperor 'Prince'.

Treatments		Flower no. per node							
Light level ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Cold duration (weeks)	4		3		2		1	
100	2	1.6	ab	8.3	a	1.1	bc	0.1	b
100	4	1.9	a	7.4	ab	1.9	bc	0.2	b
100	6	0.1	c	8.9	a	3.0	ab	0.1	b
0	2	0.2	bc	5.1	bc	2.6	abc	0.9	a
0	4	2.3	a	5.4	bc	1.1	bc	0.0	b
0	6	1.9	a	6.4	ab	0.7	c	0.1	b
Control[y]	0	0.0	c	3.3	c	4.1	a	1.0	a

[z]Mean separation within columns by Tukey's honest range test at $P = 0.05$.
[y]Plants remained in the greenhouse.

Discussion

Plants were supposed to be held in a greenhouse at 24 °C day/18 °C night as to not receive cold temperatures that would induce flower bud differentiation. However, all plants were erroneously subjected to temperatures below 15 °C in the greenhouse before going into the growth chambers. The greenhouse failed to hold the temperature set points and between 4 Nov. and 31 Jan. 2006 temperatures fell below 15 °C for thirty-two nights. Although the critical temperature for flower initiation in *Dendrobium* Red Emperor 'Prince' is not known, it was assumed that all plants were subjected to temperatures low enough to initiate flower primordia. When plants were put into growth chambers on 9 Dec. did not have buds. The lateral buds of control plants, which were left in the greenhouse for the duration of the experiment, began to swell on 19 Dec.; ten days after the other plants were placed in the growth chambers. The control plants began to develop visible flower buds in the greenhouse, whereas the other plants did not develop visible flower buds until they were returned to the greenhouse after the various durations under 10 °C in growth chambers. The 10 °C temperature effectively deferred them from producing visible flower buds in the growth chambers, but had no adverse effects on flower count once they were moved out of the chambers and flowered.

None of the plants in either the light or dark growth chambers had swollen lateral buds while given two, four, or six week of 10 °C. Regardless of the duration of the 10 °C treatment, once plants in the light chamber for two, four, or six weeks were moved back to the greenhouse at 24 ± 3.5 °C day/18 ± 3.5 °C night, the lateral buds began to swell within three days. Plants moved to the greenhouse after cold duration in darkness also had swollen lateral buds within three days of returning to the greenhouse, but buds did not increase in size as rapidly as plants that were cooled in light.

Compared to plants in other treatments, control plants required more days to reach full flower and produced the least number of flowers. Therefore it was possible that although control plants were subjected to low temperatures, it may not have been low enough for a sufficient length of time. In *Dendrobium* Malones 'Fantasy', flower bud initiation was optimal at night temperatures between 7.5 and 10 °C. The number of

flower buds decreased and flowering was delayed with night temperatures of 15 °C or higher during the period of cold treatment (Suto et al., 1984). However, it is possible that 15 °C at a longer duration could compensate for lower temperatures at shorter durations to trigger flower bud initiation. Yamamoto Dendrobiums claims on its website that exposing the nobile dendrobium for one hour of night temperature at 14 °C daily for fours weeks was able to result in good flowering. Based on our results, this claim is certainly not completely true. At least, it would not result in the highest possible flower count.

It was found that for *Dendrobium* Red Emperor 'Prince', low temperatures (10 °C) and duration of low temperatures are the factors that most effect swelling of lateral buds. Lateral bud swelling can be postponed until a later date, if plants are kept in the light or dark at 10°C for six weeks. Mainly due to the 10 °C temperature, plants that were given two weeks of cold duration in darkness or light required the least amount of time to anthesis because they were subjected to warm air earlier. Plants left in the chambers for up to six weeks in either light or dark conditions delayed flowering by three to four weeks in some cases. Rotor, Jr. (1952), grew *Dendrobium nobile* at temperatures of 13 or 18 °C to try to induce flowering. Plants grown in 18 °C remained vegetative while those given 13 °C flowered regardless of photoperiod. Perhaps if flowering needs to be postponed until a later date, plants could be kept at a higher temperature until a desirable time and then given low temperatures to initiate flowers. More research is needed to develop a technology to effectively defer flower initiation and/or flowering.

Since plants cooled for four or six weeks in darkness at 10 °C produced similar amounts of flowers as those cooled in light for two, four, or six weeks, the data suggest that longer cooling durations may substitute for light for higher flower count. Yamamoto Dendrobiums (2006) suggests that plants need approximately one month of low temperature (below 14 °C) treatment to differentiate flower buds. Since plants cooled for four or six weeks in darkness at 10 °C produced similar amounts of flowers as those cooled in light for two, four, or six weeks, the results from this current research

show that for *Dendrobium* Red Emperor 'Prince', two weeks at 10 °C in the light is just as effective as prolonging low temperatures for four or six weeks in light for total flower number. However, since it its uncertain how much cold plants experienced before the 10 °C treatment, this will have to be reinvestigated.

Although the dark growth chambers were effective in delaying flowering, the plants suffered more leaf loss than plants that received light. Several leaves were lost from plants in the dark growth chambers for six weeks, and leaf abscission continued once plants were returned to the greenhouse. The plants kept in darkness for four or six weeks each with several leaves remaining were not aesthetically acceptable once moved back to the greenhouse. These two groups of plants developed large black spots on the leaves resembling fungal infection, probably due to moisture and/or lack of light in the chamber. This is similar to the findings of Wang (1995) for *Phalaenopsis* kept in dark growth chambers at temperatures of 20°C day/15 °C night for six weeks which lost an average of one leaf per plant. *Dendrobium* Nodoka and *Dendrobium* Snowflake 'Red Star' experienced leaf chlorosis and abscission under low light conditions (Ichihashi, 1997).

Once plants reached full flowering, the only visible difference between plants in light or darkness for six weeks was the number of apical non-flowering nodes that remained above flowers. Plants kept in darkness during the cold treatment had an average of two more apical non-flowering nodes than plants that received light. As a result, plants transferred from the dark growth chamber after two weeks had 12 fewer total flowers than plants that received light for two weeks; however, the number of flowers was still adequate to be considered of good commercial quality.

The growth chamber with light failed to hold 10 °C after the first two groups (two and four week) plants had been removed. Because there was light in the growth chamber, the temperature rose two or three degrees above 10 °C during the light hours. However, on 27 Dec. when the chamber stopped holding 10 °C, temperatures began to rise between 14 and 16 °C during the light hours. Plants in the six week cold duration

with light were moved to a different growth chamber on 3 Jan. 2006 to correct this problem.

CHAPTER IV

SUMMARY OF FINDINGS

A series of five experiments were conducted on *Dendrobium nobile* Red Emperor 'Prince'. The objectives of the first three experiments were to determine the effects of N, P, and K and fertilizer termination time on the vegetative and reproductive growth. The objective of experiment four was to determine the effect of duration of nitrogen application, and the goal of the last experiment was to determine cold duration with or without light on flower initiation and development.

- For all N rates, terminating fertilization at FT-2 and FT-3 resulted in thinner pseudobulbs.
- In general application of 100 or 200 $mg \cdot L^{-1}$ N resulted in the tallest plants with the most leaves and greatest flower number.
- Plants had increasingly higher chlorophyll readings in the middle leaves with increasing N rate.
- When 400 $mg \cdot L^{-1}$ N was terminated at FT-3, flower number decreased and days to anthesis was delayed.
- Plants fertilized with 400 $mg \cdot L^{-1}$ N until FT-3 resulted in plants with the greatest number of apical non-flowering nodes.
- Nitrogen rates from 50 to 200 $mg \cdot L^{-1}$ N produced plants with similar flower diameter for all fertilizer termination times.
- Regardless of N rate, days to anthesis were similar for both FT-1 and FT-2 fertilizer termination times.
- Plants required more days to obtain full flower when supplied 200 $mg \cdot L^{-1}$ N until FT-2.
- Vegetative growth was adequate when plants received 25 to 50 $mg \cdot L^{-1}$ P.

- All P rates resulted in taller plants with equally more nodes compared to 0 mg•L^{-1} P.
- Plants that received 25 mg•L^{-1} P or higher rates resulted in similar flower numbers.
- For all three fertilizer termination times, plants that were not supplied with P bloomed later than those receiving P.
- Plants in the P experiment produced the most flowers when terminated on FT-2.
- Plants in the P experiment required fewer days to reach full flower when fertilizer application was terminated on FT-1.
- Vegetative growth was adequate when plants were supplied with 100 mg•L^{-1} K.
- Total flower number and flowering node number increased once K was applied and were similar at all rates above 0 mg•L^{-1} K.
- Pseudobulb node number and leaf number remaining increased as N and K rates increased up to 200 mg•L^{-1}.
- Deficiencies of N and K resulted in severe premature leaf abscission.
- In the K experiment, fertilizer termination time had no effect on vegetative growth.
- The duration of N application (Expt. 4) did not affect vegetative or flowering characteristics.
- For experiment 5, control plants remaining in a greenhouse produced the least number of flowers and required more days to reach full flower than all other treatments.
- Plants cooled at 10 °C for 2, 4, or 6 weeks with light and for 4 or 6 weeks in the dark produced a similar high number of flowers per plant.

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APPENDIX A

CHEMICAL TABLE, LIGHT AND TEMPERATURE DATA, AND ANOVA TABLES FOR EXPERIMENTS 1-5

Table A1. Trade and common names, target organisms, foliar spray application rates, and dates used for insect and disease control during vegetative and reproductive growth of *Dendrobium* Red Emperor 'Prince'.

Trade name	Common name	Insect/Disease	Application	
			Rate	Dates
Avid	Abamectin	Spidermites	6 mg•L^{-1}	5/25/05 and 5/31/05
Azatin	Azadirachtin	Thrips/worms	29.7 mg•L^{-1}	Multiple times between 6/17/05 and 3/2/06
Chipco	Iprodione	Fungus	1100 mg•L^{-1}	Multiple times between 7/1/05 and 9/27/05
Conserve	Spinosad	Thrips	52.2 mg•L^{-1}	5/15/05 and 3/9/06
Decathlon	Cyfluthrin	Worms/thrips	132 mg•L^{-1}	Multiple times between 6/17/05 and 3/2/06
Enstar	S-kinopene	Worms	244 mg•L^{-1}	9/13/05
Flagship	Thiamethoxam	Thrips	224.7 mg•L^{-1}	5/10/05
Heritage	Azoxystrobin	Fungus	264.2 mg•L^{-1}	10/18/05 and 11/14/05
Mavrik	Tau-fluvalinate	Worms	133.8 mg•L^{-}	9/13/05
Phyton 27	Copper sulfate pentahydrate	Fungus	480.6 mg•L^{-1}	5/18/05
Pylon	Chlorfenapyr	Spidermites	64.2 mg•L^{-1}	Multiple times between 6/5/05 and 8/15/05

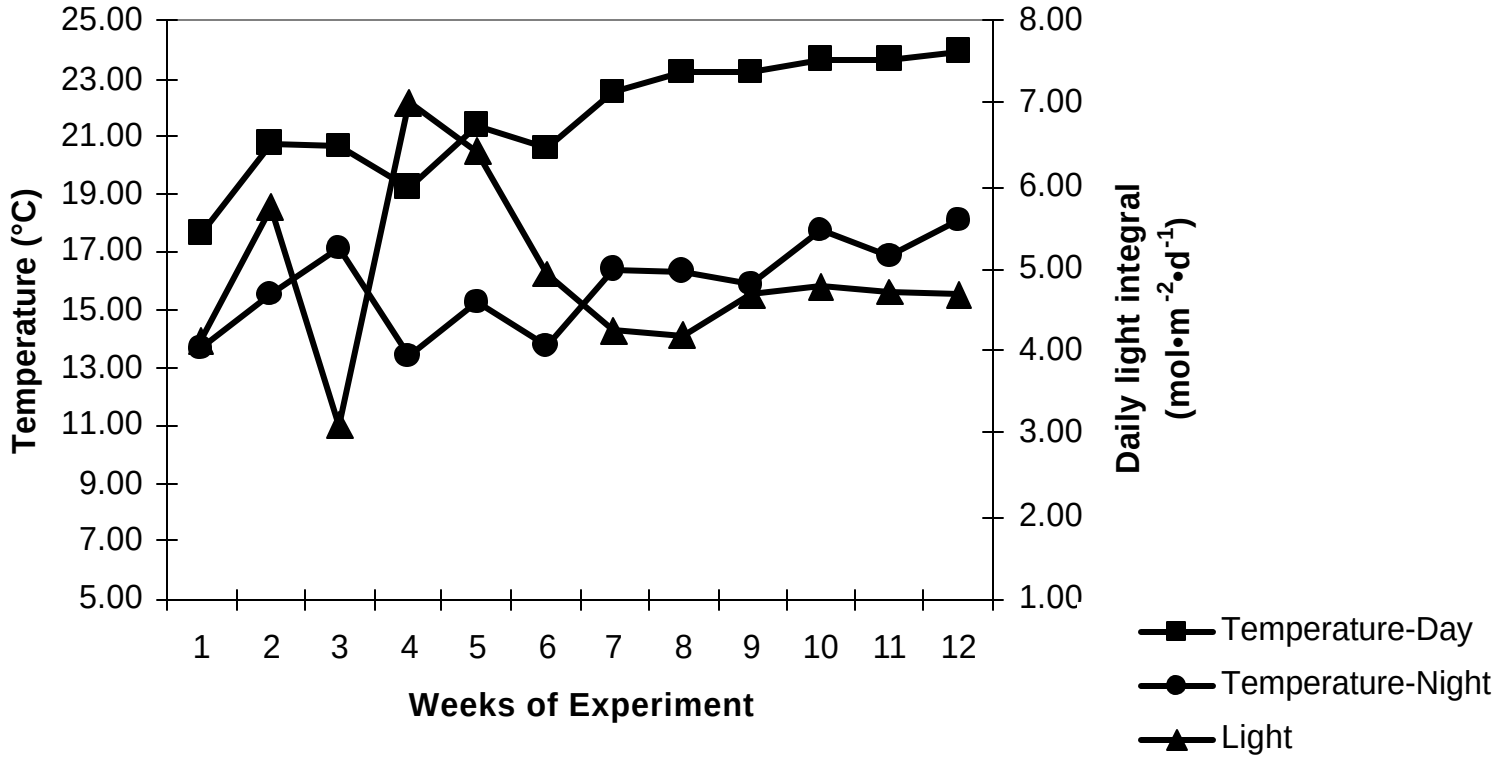


Figure A1. Average weekly day and night temperature and daily light integral in the greenhouse at canopy level (4 Feb. - 28 April 2005) (vegetative growth).

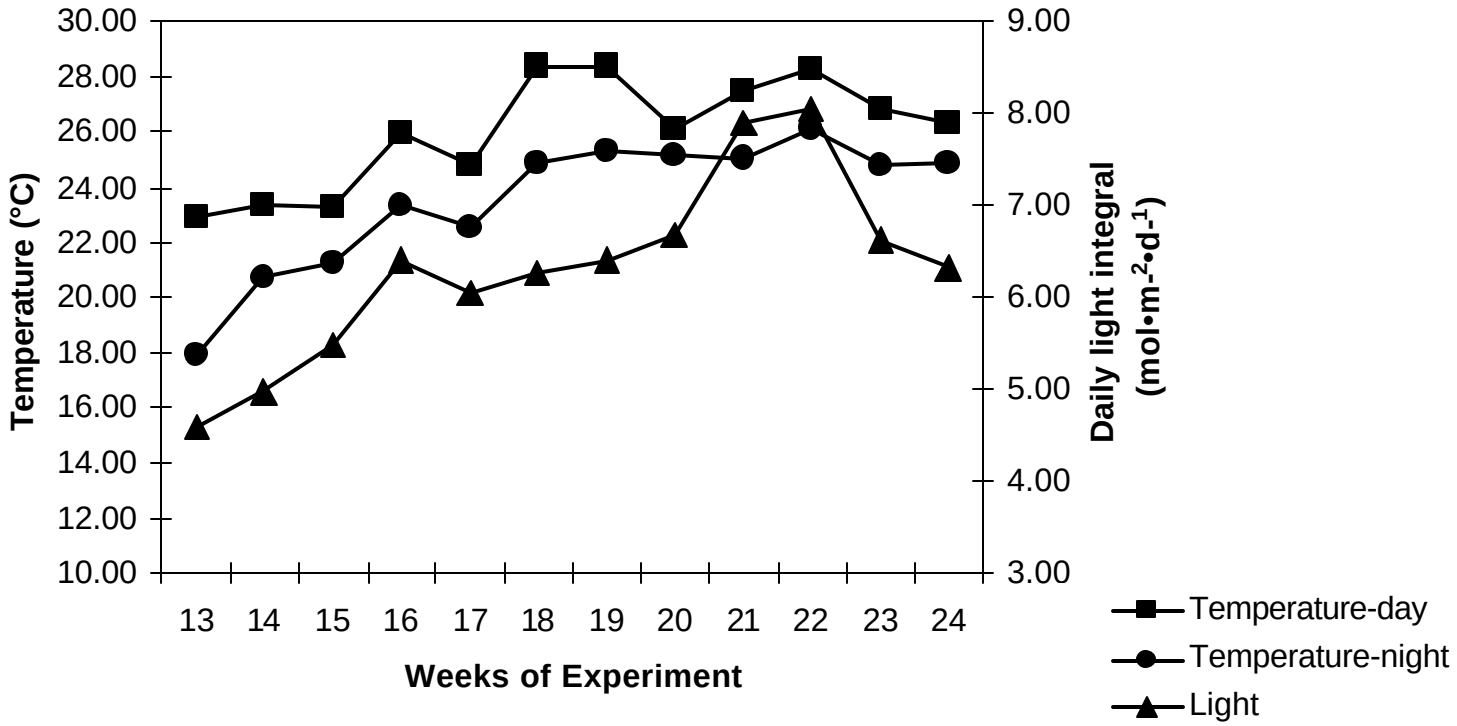


Figure A2. Average weekly day and night temperature and daily light integral in the greenhouse at canopy level (29 April - 21 June 2005) (vegetative growth).

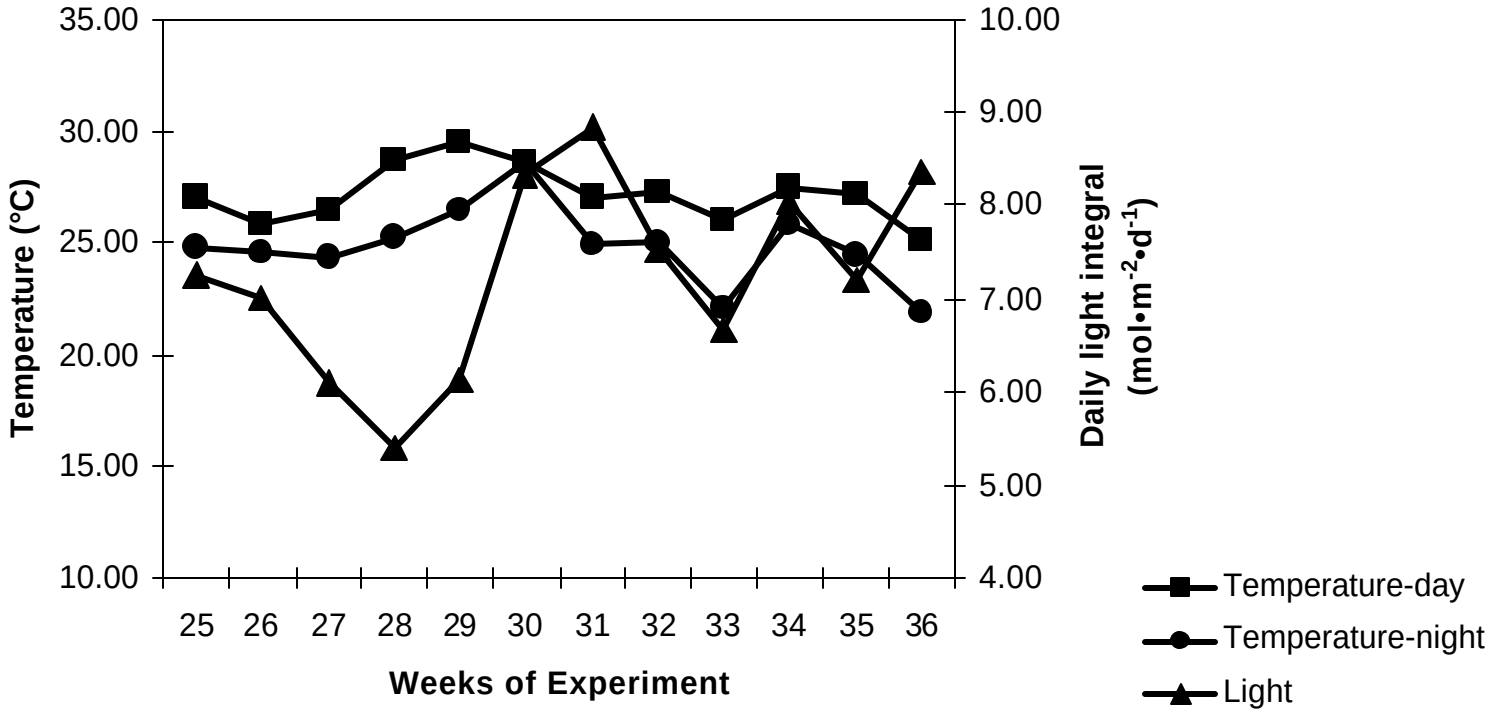


Figure A3. Average weekly day and night temperature and daily light integral in the greenhouse at canopy level (22 June - 13 Oct. 2005) (vegetative growth and maturation period).

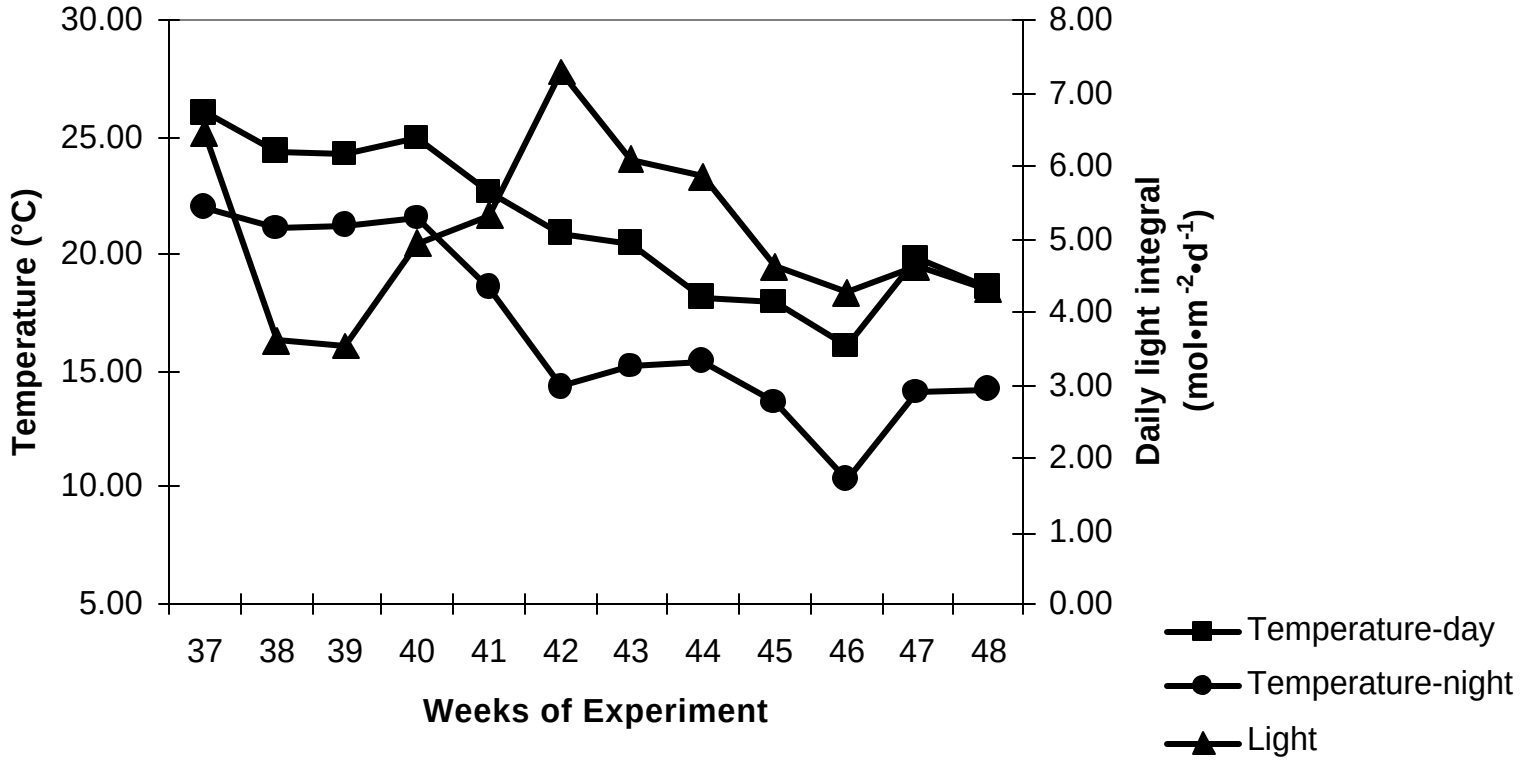


Figure A4. Average weekly day and night temperature and daily light integral in the greenhouse at canopy level (14 Oct. 2005 - 5 Jan. 2006) (maturation period and flower initiation).

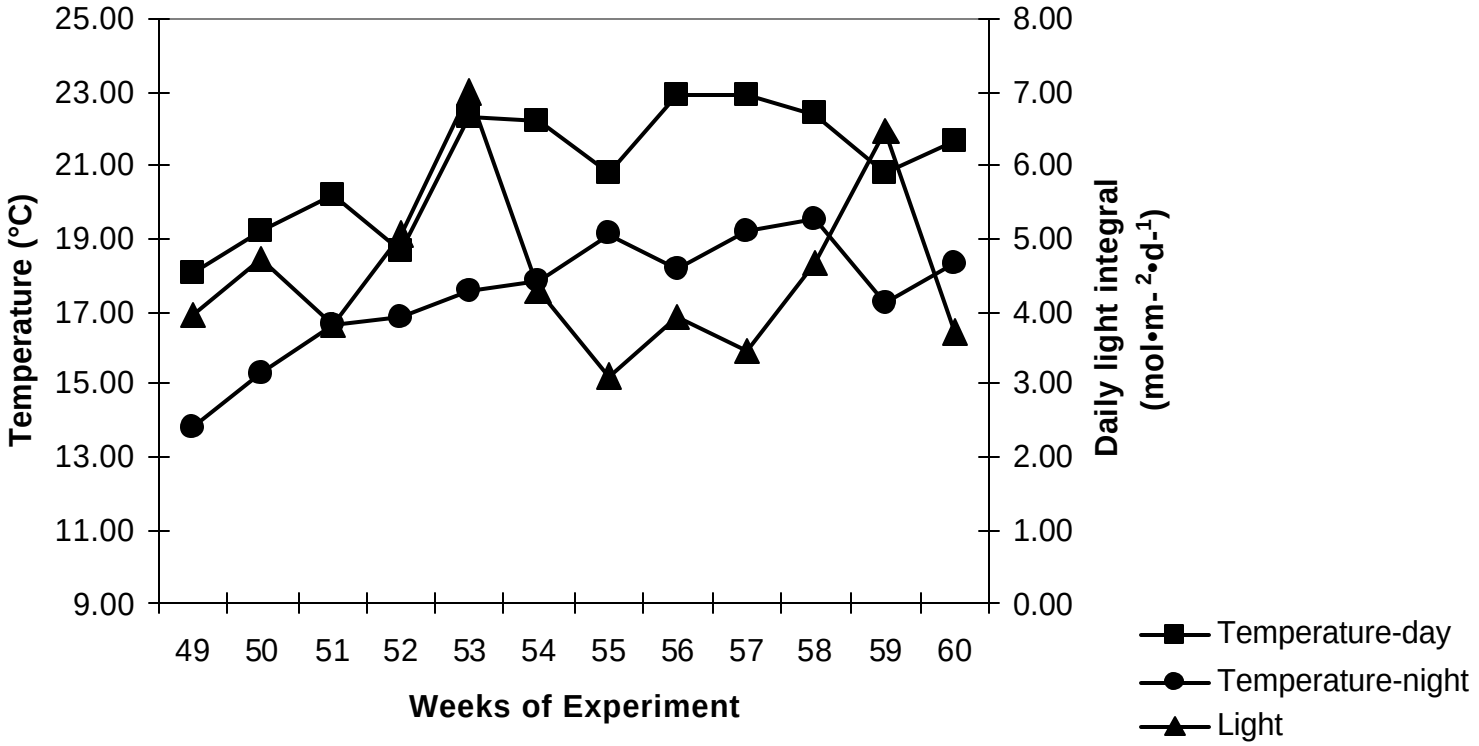


Figure A5. Average weekly day and night temperature and daily light integral in the greenhouse at canopy level (6 Jan. - 31 March 2006) (flower initiation and development).

Table A2. ANOVA for the effect of phosphorus rate and fertilizer termination time on vegetative parameters measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince' (Expt. 2).

	Plant height (cm)	Pseudobulb node no.	Leaf no.	Position of chlorophyll leaf readings			Pseudobulb	
				Lower	Middle	Upper	Width (mm)	Thickness (mm)
Phosphorus rate (P) ($mg \cdot L^{-1}$)	***	***	***	NS	*	NS	**	***
Fertilizer termination time (FT) (d)	***	*	*	NS	NS	NS	NS	***
P ×FT	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, **, *** Not significant or significant at $P = 0.05$, 0.01, 0.001, respectively.

Table A3. ANOVA for the effect of phosphorus rate and fertilizer termination time on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince' (Expt. 2).

	Total flower no.	Flowering node no.	Apical non-flowering node no.	Middle flower diam (cm)	Days to anthesis	Time to full flower (d)
Phosphorus rate (P) ($mg \cdot L^{-1}$)	***	NS	***	NS	***	**
Fertilizer termination time (FT) (d)	**	**	NS	NS	NS	***
P × FT	NS	NS	NS	NS	*	NS

NS, *, **, *** Not significant or significant at $P = 0.05$, 0.01, 0.001, respectively.

Table A4. ANOVA for the effect of phosphorus rate and fertilizer termination time on flower number per node measured at time of full flower for *Dendrobium* Red Emperor 'Prince' (Expt. 2).

	Flower no. per node			
	4	3	2	1
Phosphorus rate (P) ($mg \cdot L^{-1}$)	***	***	***	***
Fertilizer termination time (FT) (d)	**	NS	**	NS
P × FT	NS	NS	NS	NS

NS, **, *** Not significant or significant at $P = 0.01$, 0.001, respectively.

Table A5. ANOVA the effect of potassium rate and fertilizer termination on vegetative parameters measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince' (Expt. 3).

	Plant height (cm)	Pseudobulb node no.	Leaf no.	Leaf position for chlorophyll readings			Pseudobulb	
				Lower	Middle	Upper	Width (mm)	Thickness (mm)
Potassium rate (K) ($mg \cdot L^{-1}$)	***	***	***	NS	NS	***	***	***
Fertilizer termination time (FT) (d)	NS	NS	NS	NS	NS	NS	NS	*
K × FT	NS	NS	NS	NS	NS	NS	NS	*

NS, *, *** Not significant or significant at $P = 0.05$, 0.001, respectively.

Table A6. ANOVA for the effect of potassium rate and fertilizer termination time on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince' (Expt. 3).

	Total flower no.	Flowering node no.	Apical non-flowering node no.	Flower no. per node				Middle flower diam (cm)	Days to anthesis (d)	Time to full flower (d)
				4	3	2	1			
Potassium rate (K) ($mg \cdot L^{-1}$)	***	***	***	***	***	***	**	***	***	NS
Fertilizer termination time (FT) (days)	NS	NS	*	**	NS	**	NS	NS	NS	*
K × FT	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS,*,**,*** Not significant or significant at $P = 0.05, 0.01, 0.001$, respectively.

Table A7. ANOVA for the effect of fertilizer termination time on vegetative parameters measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince' (Expt. 4).

	Plant height (cm)	Pseudobulb node no.	Leaf no.	Pseudobulb	
				Width (mm)	Thickness (mm)
Fertilizer termination time (FT)	NS	NS	NS	NS	NS

NS = Not significant.

Table A8. ANOVA for the effect of fertilizer termination time on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince' (Expt. 4).

	Total flower no.	Flowering node no.	Flower no. per node				Middle flower diameter (cm)	Days to anthesis	Time to full flower (d)
			4	3	2	1			
Fertilizer termination time (FT)	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS =Not Significant.

Table A9. Leaf number, leaf node number and leaf retention percentage for nitrogen (N) (Expt. 1) and potassium (K) (Expt. 3) measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince'.

Fertilizer Rate($mg \cdot L^{-1}$)	Leaf no.	Leaf node no.	% Retention
Nitrogen (N)			
0	4.3	11.7	38
50	12.6	18.7	67
100	16.6	21.8	76
200	18.4	21.2	87
400	18.2	19.7	84
Potassium (K)			
0	5.0	14.6	34
50	11.8	18.3	62
100	14.4	20.1	72
200	16.2	20.2	80
400	16.3	20.0	82

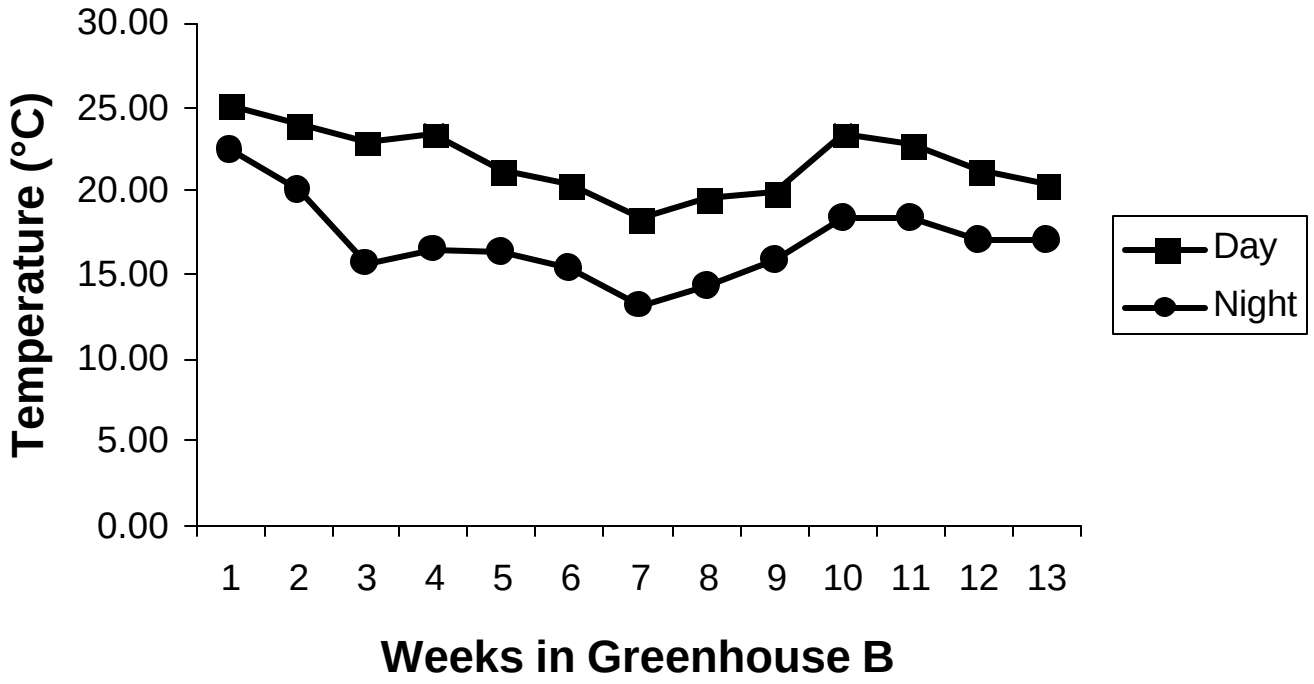


Figure A6. Average weekly day and night temperature in the greenhouse B at canopy level (4 Nov. 2005 - 31 Jan. 2006).

Table A10. ANOVA for the effect of cold duration and light or no light on vegetative parameters measured at pseudobulb maturity for *Dendrobium* Red Emperor 'Prince' (Expt. 5).

				Pseudobulb	
	Plant height (cm)	Pseudobulb node no.	Leaf no.	Width (mm)	Thickness (mm)
Significance	NS	NS	NS	NS	NS

[NS]=Not significant.

Table A11. ANOVA for the effect of cold duration and light or no light on reproductive parameters measured at time of full flower for *Dendrobium* Red Emperor 'Prince' (Expt. 5).

	Total flower no.	Flowering node no.	Apical non-flowering node no.	Middle flower diam (cm)	Days to anthesis	Time to full flower (d)
Significance	***	***	*	NS	***	***

NS, *, *** Not significant or significant at $P = 0.05$ and 0.001, respectively.

Table A12. ANOVA for the effect of cold duration and light or no light on flower number per node measured at time of full flower for Dendrobium Red Emperor 'Prince' (Expt. 5).

	Flower no. per node			
	4	3	2	1
Significance	***	***	***	***

*** = significant at $P = 0.001$.

APPENDIX B

NO_3 VS NH_4 PERCENTAGES

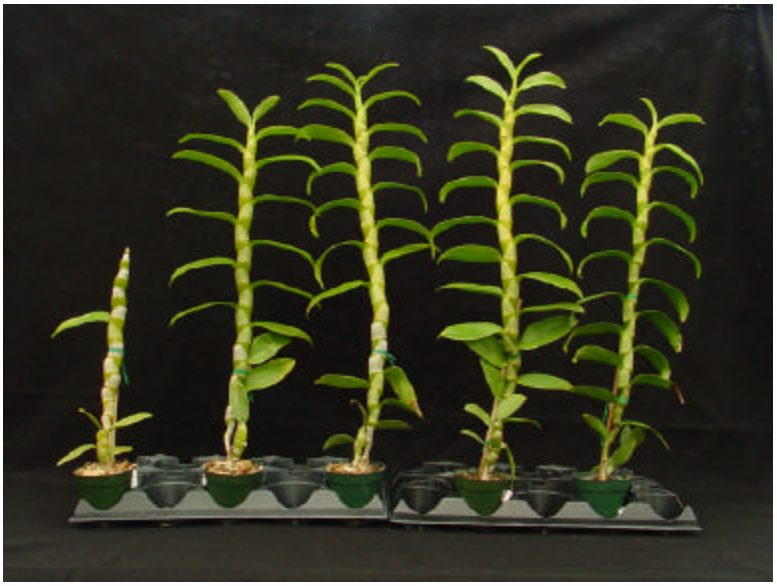
Table B1. Total ammonium (NH_4), nitrate (NO_3) and percentage of NH_4 and NO_3 in nitrogen (N), phosphorus (P), and potassium (K) treatments applied to *Dendrobium* Red Emperor 'Prince'.

	Total NH_4 (mM)	Total NO_3 (mM)	% NH_4	% NO_3
N rate ($mg \cdot L^{-1}$)				
0	0	0	---	---
50	1.79	1.79	50	50
100	3.57	3.57	50	50
200	7.13	7.13	50	50
400	14.28	14.28	50	50
P rate ($mg \cdot L^{-1}$)				
0	.387	6.78	5	95
25	.787	6.38	11	89
50	1.16	5.94	16	84
100	2.00	5.17	28	72
200	3.57	3.57	50	50
K rate ($mg \cdot L^{-1}$)				
0	6.81	.362	95	5
50	6.60	.999	87	13
100	5.51	1.64	77	23
200	4.23	2.91	60	40
400	1.32	5.13	20	80

APPENDIX C

VEGETATIVE AND REPRODUCTIVE GROWTH (EXPTS 1-3)

Appendix C1. Expt. 1 Nitrogen (N) vegetative (A) (14 Nov. 2005) and reproductive (B) (10 Mar. 2006) growth of *Dendrobium* Red Emperor 'Prince'.



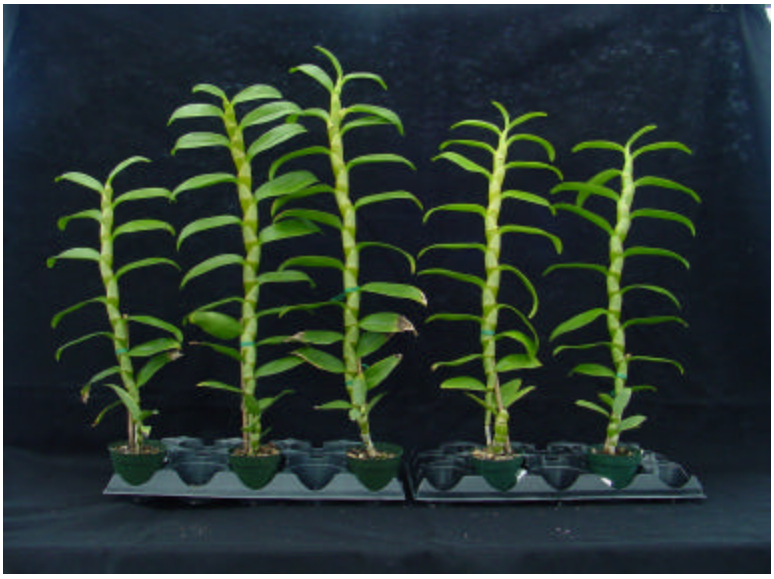
(A)

0 50 100 200 400 mg•L^{-1} N

(B)

0 50 100 200 400 mg•L^{-1} N

Appendix C2. Expt. 2 Phosphorus (P) vegetative (A) (14 Nov. 2005) and reproductive (B) (10 Mar. 2006) growth of *Dendrobium* Red Emperor 'Prince'.



(A)

0 50 100 200 400 mg•L^{-1} P

(B)

0 50 100 200 400 mg•L^{-1} P

Appendix C3. Expt. 3 Potassium (K) vegetative (A) (14 Nov. 2005) and reproductive (B) (10 Mar. 2006) growth of *Dendrobium* Red Emperor 'Prince'.

(A)

0 50 100 200 400 mg•L^{-1} K

(B)

0 50 100 200 400 mg•L^{-1} K

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