High NO₃-N to NH₄-N Ratios Promote Growth and Flowering of a Hybrid *Phalaenopsis* Grown in Two Root Substrates

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Abstract. Young, bare-root plants (three leaves, 15 cm in leaf spread) from a vegetatively propagated clone of *Phalaenopsis* Blume × Taisuco Kochdian were imported in late May and planted in a mix consisting of three parts medium-grade Douglas fir bark and one part each of perlite and coarse peat (by volume) or in pure Chilean sphagnum moss. All plants were given 221 N, 124 P, 515 K, 100 Ca, and 50 Mg (all in mg·L⁻¹) when being irrigated. The total N varied from 0%, 25%, 50%, 75%, to 100% NO₃-N with the balance being NH₄-N. Plants were fertigated when the substrate became dry. For both substrates, as the percentage of NO₃-N increased, plants produced slightly fewer leaves. Regardless of the NO₃-N to NH₄-N ratio, plants grown in moss produced one extra leaf than those planted in the bark mix during an 8-month period. There was a tendency of increasing top leaf length and width as well as the whole-plant leaf spread as NO₃-N increased from 0% to 100% in either substrate. Plants receiving 50% or more NO₃-N in either substrate spiked and flowered 2 weeks earlier than those given 25% or 0% NO₃-N. When grown in the bark mix, flower count, flower diameter, and inflorescence length all increased as NO₃-N increased from 0% to 75%. Flower stem (inflorescence, 5 cm from the base) became progressively thicker as NO₃-N increased from 0% to 100%. Only two among the 24 plants grown in moss and receiving 100% NH₄-N bloomed. These results suggest that *Phalaenopsis* does not grow well with 100% NH₄-N and must be provided with NO₃-N at no less than 50%, preferably 75%, of the total N for improved growth and flowering.

Differential growth responses to N sources have been reported for many crops. Although *Rhododendrum obtusum* (Lindl.) Planch ‘Hexe’ (azalea) prefers NH₄-N (Colgrave and Roberts, 1956), *Viburnum plicatum* Miq. *tomentosum* Thunb. had improved growth with NO₃-N over NH₄-N at low pH but not at high pH (Dirr, 1975). Plant species have different sensitivities to NH₄-N. *Spinacea oleracea* L. is highly sensitive to NH₄-N and requires NO₃-N to grow well, whereas *Pisum sativum* L. is tolerant to NH₄-N (Lisa et al., 2001).

Growth of the tropical foliage species *Maranta leuconeura* did not respond to N being 5% to 75% as NH₄-N (Strojny, 1999). *Brassia actinophylla* Endl., *Calathea*

makoyama E. Morr., and *Philodendrum selloum* C. Koch had best growth and quality with NH₄-N or urea than with NO₃-N (Conover and Poole, 1982). Similarly, growth and grade of *Aglaonema* Schott. × Silver Queen and *Philodendrum scadens oxycardium* (Schott) Bunt. were improved when the N they received contained 25% NH₄-N or 100% urea as opposed to NO₃-N (Conover and Poole, 1986). However, *Dieffenbachia maculata* (Lodd.) G. Don. ‘Camille’ and *Nephrolepis exaltata* (L.) Schott. grew equally well regardless of their N sources. There exists a wide diversity in plants’ responses to N sources, and how one species responds to various N sources or ratio of N sources cannot be used to predict how another species would respond.

Hybrids of *Phalaenopsis* Blume. have become an economically important pot orchid on all continents and its production is fast increasing (Wang, 2004). This orchid requires high fertility for optimum growth and flowering (Wang, 1994, 1996; Yoneda et al., 2000). Although high N is required, there have been no efforts to examine how NO₃-N and NH₄-N regulate the performance of this important crop under greenhouse production conditions. A recent study showed that *Phalaenopsis* had good vegetative

growth under K-deficient conditions, but plants started dying after they became reproductive (Wang, 2007). Therefore, it is critical to study how nutrients affect plant growth in both phases.

The objective of this study was to characterize how a hybrid *Phalaenopsis* responded to several NO₃-N to NH₄-N ratios during vegetative growth and flowering in each of two root substrates that differed in their physical and chemical properties.

Materials and Methods

Bare-root, vegetatively propagated plants (averaged 15 cm in leaf spread) of a white-flowered *Phalaenopsis* Blume × Taisuco Kochdian clone were imported in late May. Plants were potted in 11.4-cm round plastic pots (600-mL volume) filled with a mix consisting of three parts medium-grade ground Douglas fir [Pseudotsuga menziesii (Mirb.) Franco] bark and one part each of perlite and coarse Canadian sphagnum peat (by vol.) or in 10.2-cm pots (450 mL vol.) filled with pure Chilean sphagnum moss (*Sphagnum magellanicum* Brid.). The uppermost leaf on each plant was marked for determining the number of new leaves to be produced.

The greenhouse had transparent polycarbonate sheets on the roof and sides. A layer of black polypropylene shade fabric was installed inside the greenhouse allowing for the transmission of 18% to 20% of full sunlight. Maximum photosynthetic photon flux at solar noon was 420 μmol·m⁻²·s⁻¹ in June and 260 μmol·m⁻²·s⁻¹ in December. Average temperatures were 30 day/25 night °C in the summer and 25 day/17 night °C during the winter.

Fertilizer solutions were made from 11N–3.2P–14.9K–7Ca–1.6Mg–0S (NO₃-N) or 11N–3.2P–14.9K–0Ca–1.6Mg–16S (NH₄-N) (Jack Peters, personal gifts) to provide 100%, 75%, 50%, 24%, and 0% nitrate-N. All fertilizer solutions contained, in mg·L⁻¹, 221N, 124P, 515K, 140Ca, and 54Mg. CaCl₂ was used to balance Ca in all solutions. The solutions containing 100%, 75%, 50%, 25%, and 0% NO₃-N had 32, 88, 176, 264, and 352 mg·L⁻¹ S, respectively. MgSO₄·7H₂O was added to the 100% nitrate solution to provide 32 mg·L⁻¹ S. All other macroelement cations were balanced among the nutrient solutions. Pots were fertigated only when the substrate had become dry. Plants in the bark mix were given 100 mL nutrient solution at each fertigation and those planted in moss were provided with 300 mL of a fertilizer solution to avoid salt accumulation. No supplemental micronutrients were used.

The date on which the flower stem emerged from the base of a leaf (mostly the third acropetal leaf) was recorded as the spiking date. Flowering data were collected on plants grown in the bark mix only. When the first flower bud on a plant opened, that date was recorded as the flowering date (anthesis). Flower count, the natural horizontal spread of the first flower on a plant, the

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internodal length between the first and second flowers, the length of the flower stem between the base and the first flowering node, and the distance between the first flowering node and the tip of that inflorescence were recorded after all flowers had opened. The thickness of the flowering stem was measured at ≈ 5 cm from the base with an electronic digital caliper (MAX-CAL; Fowler, Brownwood, TX). The number of new leaves and their combined lengths were determined. The length and width of the uppermost mature leaf were measured and recorded.

Treatments were arranged in a randomized complete block design. One plant in a pot represented an experimental unit that was replicated 24 times. Linear and quadratic regression analyses were performed with SAS programming (SAS Institute, Cary, NC) using the percentage nitrate-N as the independent variable.

Results

For both substrates, as the percentage of $\text{NO}_3\text{-N}$ increased, plants produced slightly fewer leaves (Fig. 1A); However, the differences were small for plants grown in the bark mix, i.e., 3.5 leaves at 100% $\text{NH}_4\text{-N}$ and 3.1 at 100% $\text{NO}_3\text{-N}$ (Fig. 1A). Regardless of the $\text{NO}_3\text{-N}$ to $\text{NH}_4\text{-N}$ ratio, plants grown in moss produced one extra leaf than those planted in the bark mix. Whole-plant leaf spread increased as $\text{NO}_3\text{-N}$ increased from 0% to 100% in both substrate (Figs. 1B and 1C). The top mature leaves on plants receiving 100% $\text{NO}_3\text{-N}$ and planted in bark mix were approximately two-thirds larger in area than those receiving 100% $\text{NH}_4\text{-N}$. In both media, the combined length of the new leaves on a plant increased as $\text{NO}_3\text{-N}$ increased from 0% to 75% and then declined slightly at 100% $\text{NO}_3\text{-N}$ (Fig. 1D). Leaf span became larger as $\text{NO}_3\text{-N}$ increased from 0% to 100% (Figs. 2 and 3A).

In both substrates, plants spiked 2 weeks earlier (Fig. 3B) when $\text{NO}_3\text{-N}$ increased from 0% to 50% with no additional change as $\text{NO}_3\text{-N}$ increased to 100%. In bark mix, plants flowered 3 weeks earlier when given 50% to 100% $\text{NO}_3\text{-N}$ (Fig. 4A). Flower count increased from 4.5 to 7.0 as $\text{NO}_3\text{-N}$ increased from 0% to 75% (Fig. 4B). Flower diameter was 16% wider and the area of a flower was 38% larger when plants were given 75% $\text{NO}_3\text{-N}$ compared with those receiving 100% $\text{NH}_4\text{-N}$ (Fig. 4C).

The length of the flower stem between the base and the first flower increased with increasing $\text{NO}_3\text{-N}$ to 50% (Fig. 4D), whereas the length between the first flower and the tip increased with increasing percentage of $\text{NO}_3\text{-N}$ to 75% (Fig. 5A). As a result, the total inflorescence length was longest at 75% $\text{NO}_3\text{-N}$ (Fig. 5B). The length of the internode between the first two flowers increased with increasing $\text{NO}_3\text{-N}$ to 100% (Fig. 5C). Flower stem diameter at 5 cm above the base was 22% larger when provided with 50% or higher $\text{NO}_3\text{-N}$ (Fig. 5D).

Fig. 1. Effect of $\text{NO}_3\text{-N}$ to $\text{NH}_4\text{-N}$ ratio on vegetative growth of a *Phalaenopsis* Blume $\times$ Taisuco Kochdian clone grown in pure sphagnum moss or a bark mix substrate. (A) New leaves; (B) top leaf length; (C) top leaf width; (D) total leaf length. The vertical bars represent SE of the mean. L and Q = linear and quadratic response. *, **, and ***, significance at $P = 0.05$, 0.01 , and 0.001 , respectively.

Fig. 2. Appearance of plants grown in a bark mix (top) or pure sphagnum moss substrate (bottom).

Fig. 3. Effect of $\text{NO}_3\text{-N}$ to $\text{NH}_4\text{-N}$ ratio on leaf span and spiking date of a *Phalaenopsis* Blume $\times$ Taisuco Kochdian clone grown in pure sphagnum moss or a bark mix substrate. (A) Leaf span; (B) days to spiking. The vertical bars represent SE of the mean. L and Q = linear and quadratic response. *, **, and ***, significance at $P = 0.05$, 0.01 , and 0.001 , respectively.

Fig. 4. Effect of NO₃-N to NH₄-N ratio on flowering characteristics of a *Phalaenopsis* Blume × Taisuco Kochdian clone grown in a bark mix substrate. (A) Days to flowering; (B) flower count; (C) flower diameter; (D) spike length, base to first flower. The vertical bars represent SE of the mean. L and Q = linear and quadratic response. *, **, and ***, significance at $P = 0.05, 0.01, \text{ and } 0.001$, respectively.

Discussion

In some previous studies that determined the effects of N sources or pH on plant growth, the concentrations of other major elements were not balanced among the nutrient solutions used or not reported (Andrews

and Hammer, 2006; Bernstein et al., 2005; Conover and Poole, 1986; Ganmore-Neumann and Hagiladi, 1990; Hanne and Schuch, 2006). Although authors described treatment effects, it was not clear if it was the treatments or the varying concentrations of other macroelements that resulted in the differ-

ences in plant responses. In this current study, the solutions containing 100%, 75%, 50%, 25%, and 0% NO₃-N had 32, 88, 176, 264, and 352 mg·L⁻¹ S, respectively. It was reported that 32 mg·L⁻¹ S is far more than adequate to avoid S deficiency and for good growth in *Euphorbia pulcherrima* Willd. (Dale et al., 1990) and *Dendrothema grandiflora* (Huang et al., 1997). S at 900 mg·L⁻¹ did not cause phytotoxicity to *Pelargonium xhortorum* L. H. Bailey 'Red Elite' (Compton, 2006). Therefore, it is very likely the differences that were observed at various NO₃-N and NH₄-N ratios were truly the result of treatment effects (Lisa et al., 2001).

Alder and Wilcox (1995) showed that, in muskmelon (*Cucumis melo* L.), NH₄-N completely inhibited K absorption. In mineral soils, NH₄⁺ may fix K so that K uptake by plants is lowered as a result of reduced availability (Barker, 1967; Maynard et al., 1968). The absorption of all macronutrients by *Phalaenopsis* young seedlings in vitro (Kubota et al., 2000) and by *Colocasia esculanta* L. Schott cv. Bun Long (taro; Osorio et al., 2003) was reduced as percentage of NH₄-N increased. However, symptoms of K deficiency such as lower leaf yellowing, bronze coloration, necrosis, and leaf death (Wang, 2007) were not observed on *Phalaenopsis* plants in either substrate that received 100% NH₄-N. This suggests that the absorption of K was likely not severely reduced by applying 100% NH₄-N to *Phalaenopsis*.

Phalaenopsis is tropical in origin and was grown under relatively high temperature during this study. Roots of plants supplied with only NH₄-N have high demands for carbon skeletons for ammonium assimilation (Arnozis et al., 1988) and high O₂ consumption (Matsumoto and Tamura, 1981), resulting in low sugar concentration in the roots and poor plant growth compared with NO₃-N-fed plants. This may have resulted in smaller plants when given high percentages of NH₄-N. Spiking (the emergence of the potential flower stem) is associated with high sugar concentration in leaves after being exposed to inductive temperatures (Lee and Lee, 1996). It may be possible that the delayed spiking in plants receiving 75% or 100% NH₄-N was the result of low sugar concentration in the foliage.

In another monocot species *Colocasia esculanta*, 75% or higher N in the nitrate form promoted growth (Osorio et al., 2003). Plants that were provided with NH₄-rich nutrient solutions had retarded growth and small leaf area. Kubota et al. (2000) reported that *Phalaenopsis* seedlings being propagated in vitro preferred 80% or higher of the total nitrogen being in the nitrate form for highest leaf number, largest leaf area, and more and longer roots. There was little or no difference in the growth of *Zea mays* plants resulting from various proportions of NO₃- and NH₄-N at low N concentrations (Xu et al., 1992). However, at higher N concentration, plant growth increased as NO₃-N increased from 0% to 75% and then declined. That was similar to the results found in this

Fig. 5. Effect of NO₃-N to NH₄-N ratio on flower stem of a *Phalaenopsis* Blume × Taisuco Kochdian clone grown in a bark mix substrate. (A) Spike length, first flower to tip; (B) total inflorescence length; (C) flower stem diameter; (D) flower internode length. The vertical bars represent SE of the mean. L and Q = linear and quadratic response. *, **, and ***, significance at $P = 0.05, 0.01, \text{ and } 0.001$, respectively.

study at a high total N concentration of 221 mg·L⁻¹, which was previously reported to result in optimum growth and flowering (Wang, 1994, 1996).

When high fertility is provided to *Phalaenopsis*, whether grown in pure sphagnum moss or in a bark mix, the data suggest that a minimum of equal proportion of NO₃-N and NH₄-N must be provided. Providing 75% NO₃-N and 25% NH₄-N further improves vegetative growth and flowering of *Phalaenopsis*.

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