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Potassium Nutrition Affects *Phalaenopsis* Growth and Flowering

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***Abstract*. Bare-root, vegetatively propagated plants (average 15-cm leaf spread) of a white-flowered *Phalaenopsis* Taisuco Kochdian clone were imported in late May and planted either in a mix consisting of three parts medium-grade douglas fir bark and one part each of perlite and coarse canadian sphagnum peat (by volume) or in chilean sphagnum moss. All plants were given 200 mg·L^{-1} each of nitrogen and phosphorus, 100 mg·L^{-1} calcium, and 50 mg·L^{-1} magnesium at each irrigation with 0, 50, 100, 200, 300, 400, or 500 mg·L^{-1} potassium (K). After 8 months, K concentration did not alter the number of new leaves on plants in either medium. Plants grown in moss produced four to five leaves, whereas those planted in the bark mix produced only two to three leaves. K concentration did not affect the length of the uppermost mature leaves when grown in the bark mix. However, in moss, plants had increasingly longer and wider top leaves as K concentration increased. The lower leaves on plants in the bark mix lacking or receiving 50 mg·L^{-1} K showed symptoms of yellowing, irregular purple spots, and necrosis after spiking and flowering, respectively. Yellowing and necrosis started from the leaf tip or margin and progressed basipetally. Symptoms became more severe during flower stem development and flowering. All of the plants lacking K were dead by the end of flowering. Leaf death originated from the lowest leaf and advanced to the upper leaves. K at 50 mg·L^{-1} greatly reduced and 100 mg·L^{-1} completely alleviated the symptoms of K deficiency at the time of flowering. However, by the end of flowering, plants receiving 50 or 100 mg·L^{-1} K had yellowing on one or two lower leaves. Plants grown in moss and lacking K showed limited signs of K deficiency. All plants in the bark mix bloomed, whereas none in sphagnum moss receiving 0 mg·L^{-1} K produced flowers. For both media, as K concentration increased, flower count and diameter increased. Flower stems on plants in either medium became longer and thicker with increasing K concentration. To obtain top-quality *Phalaenopsis* with the greatest leaf length, highest flower count, largest flowers, and longest inflorescences, it is recommended that 300 mg·L^{-1} K be applied under high N and high P conditions regardless of the medium.**

Compared with fruit and vegetable crops, the effects of potassium (K) on growth and performance of ornamental and floral crops have not been studied as extensively. K deficiency is a widespread disorder on many palm species worldwide (Chase and Broschat, 1991) that can lead to the death of the plant if supplemental K is not applied (Broschat, 1990).

In field studies, flower production of *Anthurium andraeanum* Linden. (Higaki et al., 1992) and *Gerbera jamesonii* H. Bolus ex Hook.f. (Dufault et al., 1990) increased when K was at 375 and 110 to 220 kg·ha^{-1}, respectively, compared with lower rates. In a greenhouse study, increasing K concentration from 0.25 to 10 meq·L^{-1} (10 to 390 mg·L^{-1}) in the recirculating nutrient solution resulted in more flowers, longer stem, and whole-plant fresh weight of *Rosa hybrida* 'Forever Yours' (Woodson and Boodley, 1982). Shoot dry weight and leaf area of *Salvia splendens* F. Sellow 'Bonnfire' increased as K concentration increased from 25 to 300 mg·L^{-1} (Eakes et al., 1991). The tropical foliage species *Aglaonema commutatum* Schott, however, did not respond to increased K from 80 to 320 mg per 15-cm pot per month (Poole and Conover, 1977).

Phalaenopsis Blume. hybrids are the most popular pot orchids on the market around the world. Individual flowers of these orchids often last 3 to 4 months (Wang, 1997, 2000). Their relatively rapid growth and short juvenile period (Lee, 1991) are advantageous for breeders to improve this crop by crossbreeding and cloning. Several studies found that *Phalaenopsis* plants require high nutrient concentrations for optimal growth under warm environmental conditions (Lee and Lin, 1988; Wang, 1996; Wang and Gregg, 1994).

Leaves of healthy *Phalaenopsis* plants may remain on the plant for 2 or more years and contain 3% to 8% K on a dry-weight basis (Lee, 1988; Wang, 1998; Wang and Konow, 2002). In recent years, a physiological disorder has been observed on *Phalaenopsis* leaves. The affected plants had irregular yellowish areas on the second or third basipetal leaves (Chen, 2001; Lee, 2001; Lee and Lee, 2000). Symptoms of this disorder became much more severe after vegetative plants have been induced to initiate the flowering process by exposing them to cool air. The yellowed leaf tissues were found to have extremely low levels of K (0.40% to 0.64%) (Lee, 2001). No controlled studies have been conducted to quantify *Phalaenopsis* K requirements and to characterize the specific symptoms of K deficiency.

As a result of the long production time from seed, millions of *Phalaenopsis* plants of varying sizes are imported to the United States each year from overseas suppliers. Although nearly all overseas *Phalaenopsis* suppliers grow this crop in straight sphagnum moss (moss), most growers in the United States produce this orchid in media largely made of ground douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] bark. Because it is obvious that these two materials have markedly diverse water retention characteristics, *Phalaenopsis* grown in these media may have different requirements for K concentration in the nutrient solution being applied.

The objectives of this study were 1) to determine the growth and flowering of *Phalaenopsis* in response to a wide range of K concentrations when grown in two media drastically different in water and nutrient retention characteristics and 2) to characterize the K deficiency symptoms.

Materials and Methods

Bare-root, vegetatively propagated small plants (average 15-cm leaf spread) of a white-flowered *Phalaenopsis* 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 douglas fir [*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco] bark (Rexius Forest By-Products, Eugene, OR) and one part each of No. 3 perlite and coarse canadian peat (by volume) or in 10.2-cm round pots (450-mL volume) filled with chilean sphagnum moss (*Sphagnum magellanicum* Brid.). Plants were irrigated with water from a reverse osmosis machine when needed. The uppermost leaf on each plant was marked for determining the number of new leaves produced after planting. Plants were grown in a greenhouse with polycarbonate panels 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 ambient light. 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

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day/night temperatures were 30/25 °C in the summer and 25/17 °C during the winter.

Treatments were initiated on 1 July. Nutrient solutions were made from KH_2PO_4, KNO_3, $NH_4H_2PO_4$, NH_4NO_3, $CaCl_2{\cdot}2H_2O$, and $MgSO_4{\cdot}7H_2O$ to provide (in mg·L^{-1}) 200 nitrogen (N), 200 phosphorus (P), 100 calcium (Ca), and 50 magnesium (Mg), with K concentrations at 0, 50, 100, 200, 300, 400, or 500 mg·L^{-1}. Fertigation was applied only when the medium was nearly dry as determined by the light color and weight. At each fertigation, plants in the bark mix were given 100 mL, whereas those in moss were given 600 mL in two applications of the needed nutrient solution. This larger volume of nutrient solution was given to plants in the moss to leach the medium and avoid the accumulation of salts. Nutrient solutions were poured from a beaker directly onto the medium, avoiding contact with the plant and possible leaching of K from the leaves.

The date a flower stem emerged from the base of a leaf was recorded as the spiking date. When the first flower bud on a plant opened, that date was recorded as the flowering date. Flower count, the natural horizontal spread of the first flower on a plant, the 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 diameter of the flower stem (now the inflorescence) was measured at the middle of the second basipetal internode with an electronic digital caliper (MAX-CAL; Fred V. Fowler Co., Newton, MA). The number of new leaves and their combined lengths were determined. The length and width of the uppermost mature leaf were measured and recorded for each plant.

A single plant in a pot represented an experimental unit. Within each medium, treatments were replicated 12 times in a randomized complete block design. Standard error bars are presented in Figures 1 through 6 and linear and quadratic regression analyses were performed and presented.

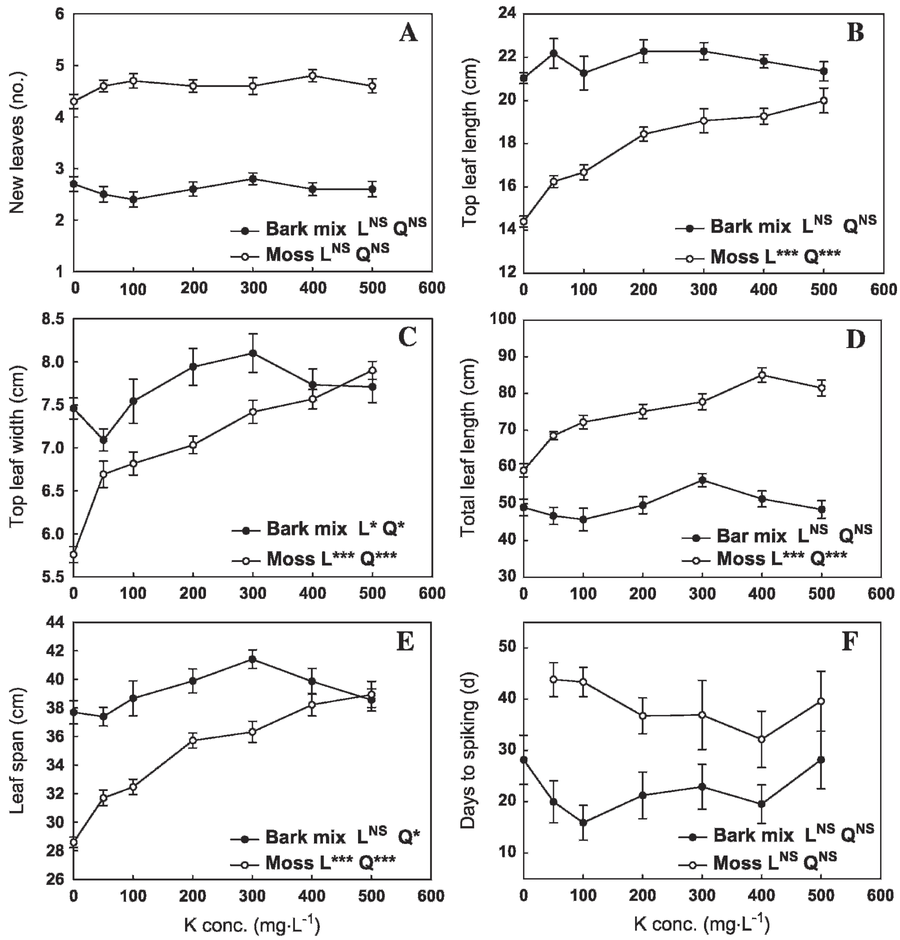

Fig. 1. (**A**) The number of new leaves, (**B**) top leaf length, (**C**) top leaf width, (**D**) total leaf length, (**E**) leaf span, and (**F**) time of spiking of a *Phalaenopsis* Taisuco Kochdian clone in response to increasing potassium concentration. Vertical bars indicate SE of the mean. n = 12. L, linear; Q, quadratic responses.

Results

The number of new leaves produced by plants in either medium was unaffected by K concentration (Fig. 1A). Plants grown in moss produced four to five leaves, whereas those planted in the bark mix produced only two to three leaves. The length of the youngest mature leaf was unaffected by K concentration in the nutrient solution when grown in the bark mix; however, leaf length increased with increasing K concentration when grown in moss (Fig. 1B). These top leaves became wider as K concentration increased, reaching a maximum width at 300 mg·L^{-1} and 500 mg·L^{-1} K for plants grown in the bark mix and moss, respectively (Fig. 1C).

Total leaf length was unaffected by K when grown in the bark mix but increased with K concentration for plants in moss (Fig. 1D). Leaf span as a function of K concentration followed the pattern of top leaf width in both media with maximum leaf span occurring at 300 mg·L^{-1} and 500 mg·L^{-1} K for plants grown in the bark mix and moss, respectively (Fig. 1E).

All plants in the bark mix flowered, whereas none of the plants grown in moss and lacking K became reproductive at the termination of this experiment. Dates of spiking (Fig. 1F) and flowering (Fig. 2A) were unaffected by K concentration in either medium. There was a considerable range in spiking date among plants at any given K concentration. At low K concentrations (50 and 100 mg·L^{-1} K), although no statistical comparison between the two media was attempted, it was apparent that plants in the bark mix flowered earlier than those in moss (Fig. 2A). Flower count (Fig. 2B) and flower diameter (Fig. 2C) on plants in both media increased with increasing K concentration, reaching their peaks at 300 mg·L^{-1} K in the bark mix and 400 mg·L^{-1} K in moss.

The length of the flower stem (inflorescence), either from the base to the first flowering node (Fig. 2D) or from the first flower to the tip (Fig. 2E), internodal length between the first two flowers (Fig. 2F), and flower stem diameter (Fig. 3) all increased with increasing K concentrations, reaching their peaks at 400 mg·L^{-1} K, regardless of the medium they were planted in.

The first one or two basipetal leaves on plants grown in the bark mix and lacking K began to exhibit yellowing and necrosis on their distal ends or edges in mid-December (Fig. 4) as flower stems were developing. Symptoms of severe K deficiency included yellowing, rusty or bronze patches, and necrosis (Fig. 4). This leaf yellowing and necrosis became more severe and leaves started to die acropetally as the flower stem continued to develop and particularly after anthesis. All plants grown in the bark mix and lacking K were dead by the end of May. Some plants in moss and receiving 0 mg·L^{-1} K only exhibited rusty coloration on lower leaves or necrotic leaf tips at the end of this study, but none of these plants bloomed or died. Plants in the bark mix that received 50 mg·L^{-1} K appeared healthy initially (Fig. 5) but lost one or two leaves during flowering, and those receiving 100 mg·L^{-1} K had light yellowish basipetal leaves by the end of the flowering period (Fig. 6).

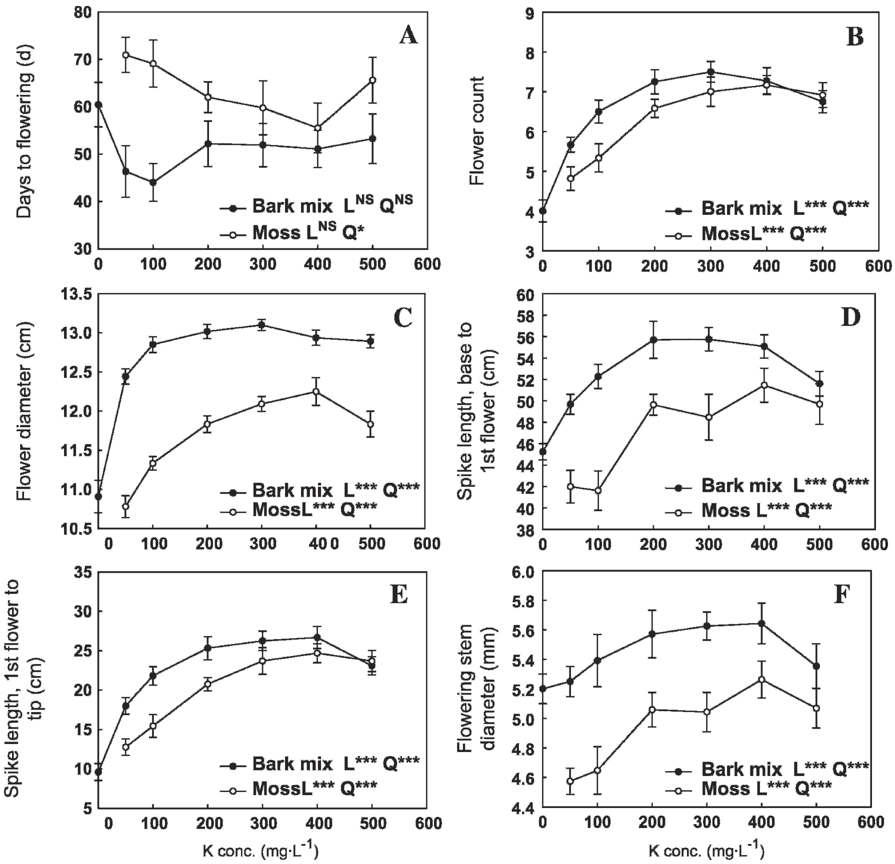

Fig. 2. (**A**) Time to anthesis, (**B**) flower count, (**C**) flower diameter, (**D**) length of the flowering stem from the base to the lowest flowering node, (**E**) of the flowering stem from the lowest flowering node to the tip, and (**F**) flower stem diameter in a *Phalaenopsis* Taisuco Kochdian clone as a function of potassium concentration. Fewer days means earlier spiking (day 1 = 1 Nov. 2005) and flowering (day 1 = 1 Jan. 2006). Vertical bars indicate SE of the mean. n = 12. L, linear; Q, quadratic responses.

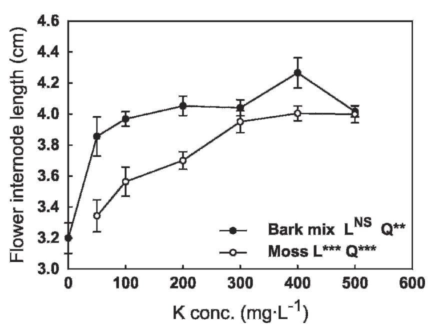

Fig. 3. Length of the internode between the first and second flowers as a function of increasing potassium concentration. Vertical bars indicate SE of the mean. n = 12. L, linear; Q, quadratic responses.

Discussion

K in leaves is highly mobile and easily redistributed within plants (Mengel and Kirby, 1982). K deficiency symptoms are always first displayed in the older leaves and are less severe in younger leaves. K in the lower leaves of *Phoenix roebelenii* is translocated out of the dying leaves (Broschat, 1994). When growing under K-deficient conditions, the K pool in the older, dying leaves becomes an important K source for the young, growing leaves. Early removal of this important K source accelerates plant decline from K deficiency. Widders and Lorenz (1979) reported that certain determinant tomato cultivars compensate under K-deficient conditions by translocating K out of leaves and stems into fruits. These plants also partition a high percentage of absorbed K into fruit rather than supporting continued vegetative growth. They also found that K concentration in shoots of these tomato cultivars declined from 4% to 2% after fruit set, resulting in K deficiency symptoms.

These findings are consistent with those observed in this study with *Phalaenopsis* in which K deficiency symptoms started to appear after plants in the bark mix had become reproductive in November. Death of lower leaves on K-deficient plants began in late December when the flowering stem had reached one-third to one-half of their final lengths. It is possible that, similar to tomato under K-deficient conditions, K in the lower leaves of *Phalaenopsis* was removed and redistributed to the developing flower stem and later to flower buds. This may explain the development of yellowed lower leaves initially and gradual yellowing and death of progressively upper leaves and eventually the death of the entire plants when grown with 0 mg·L^{-1} K. Severe K deficiency was reported to result in leaf withering and death of affected palms (Broschat, 1989, 1990). Therefore, it is extremely important that adequate K be applied during the months before flower induction to guarantee leaf retention during and after flowering. It is not understood how plants deficient of K during vegetative growth would perform after being provided with proper levels of K after flower induction.

Lower leaf yellowing was reported to be a serious problem in certain hybrids of *Phalaenopsis*. As flower stems started to emerge in late fall, the second and third basipetal leaves became chlorotic (Lee, 2001; Lee and Lee, 2000). These yellowish leaves were found to have extremely low levels of K (Lee, 2001). Similarly, in *Brassica napus* L. (Pissarek, 1973), K deficiency symptoms were first seen in the second and third basipetal leaves, never the oldest. Application of 15K–4.3P–16.8K or full-strength Johnson's solution reduced the incidence of lower leaf yellowing in *Phalaenopsis* (Chen, 2001). The results of the current study suggest that the lower leaf yellowing observed by Lee and Lee (2000) was likely symptoms of K deficiency. However, in this study, leaf yellowing and leaf death all started from the lowest, oldest leaf on a plant and the symptoms progressed acropetally.

The reason for the limited or lack of K deficiency symptoms on plants in sphagnum moss receiving K or under low K concentrations is not known. It could be the result of the higher volumes of fertilizer given to the moss, the higher cation exchange capacity (CEC) of the moss, K released by the moss, and so on. Because moss retains more water and hence renders higher nutrient concentrations while the medium dries, it is expected that plants grown in moss may require lower K concentration than those planted in the bark mix resulting in similar flowering quality. However, this is not the case (Figs. 1D and 2B–C). It is important in the future to study the properties of various media as well as reflect on the differences in nutrient availability among the media resulting from medium properties as well as the differences in fertilizer application amounts and nutrient retention by these media.

In a previous study, plants of *Phalaenopsis* TAM Butterfly were fertilized with N, P, and K at 100, 44, and 83 mg·L^{-1}, respectively, during vegetative growth and then fertilization was withheld for over 6 months. It only resulted in the abscission of one leaf at the end of flowering (Wang, 2000). In this study, plants receiving 50 mg·L^{-1} K initially appeared healthy (Fig. 5) but began showing symptoms of K deficiency after anthesis (Fig. 6). There was light yellowing on some leaves, whereas others had numerous rusty or bronze spots on one or two of the lower leaves. Some of the yellowish leaves eventually abscised. These suggest that although applying 50 mg·L^{-1} K may be adequate for vegetative growth, it was not high enough for producing quality flowering plants. It is possible that the amount of K required also

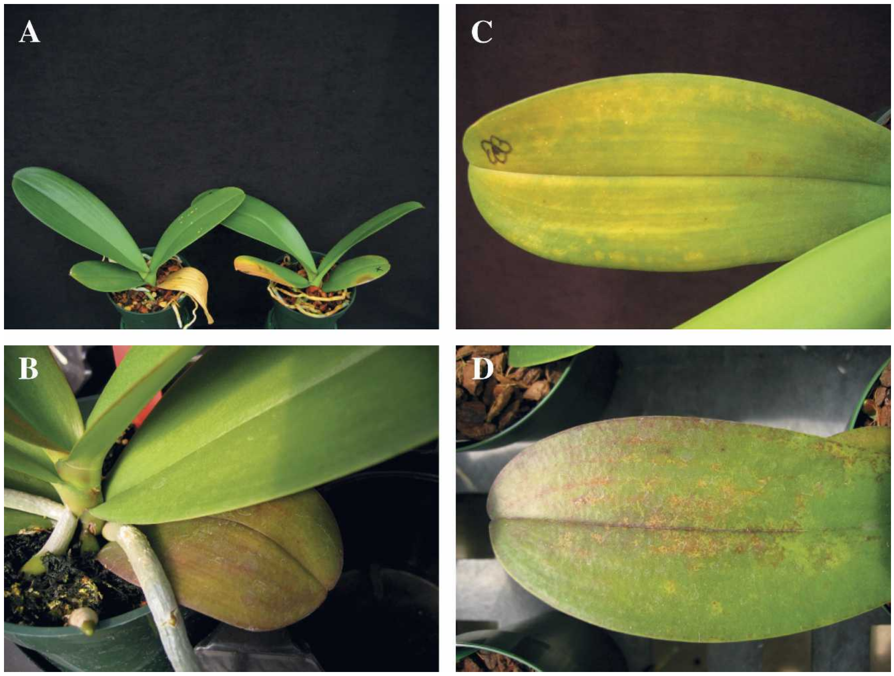

Fig. 4. Symptoms of potassium (K) deficiency on *Phalaenopsis* Taisuco Kochdian plants in a (**A**) fir bark mix or (**B**) sphagnum moss. (**C**) Leaf yellowing and (**D**) bronze lesions on plants receiving 100 or 50 mg·L^{-1} K, respectively.

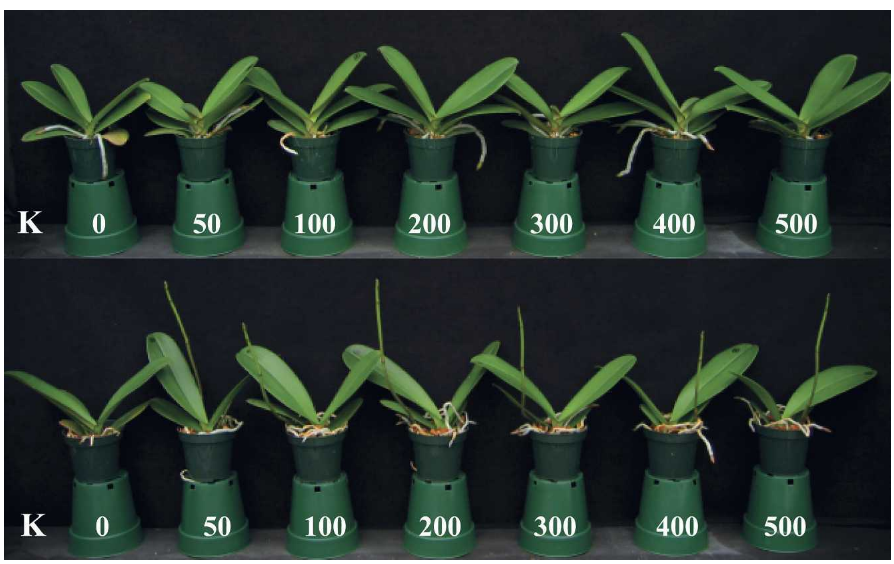

Fig. 5. *Phalaenopsis* Taisuco Kochdian plants in sphagnum moss (upper) or a bark mix (lower) with various potassium concentrations (in mg·L^{-1}) 12 Dec. 2005.

depends on N availability. The differences between these results and Wang (2000) may have to do with the concentration of N given to the plants (two times greater in the current study and a drop in the N:K ratio). Increased N availability may have increased K demand (i.e., more N, larger plants, more demand for K).

Plants grown in sphagnum moss and receiving no K produced an identical number of new leaves with similar total length as plants receiving 50 to 500 mg·L^{-1} K, but no spiking and flowering occurred in these plants. Visual symptoms of K deficiency were minimal on these plants. It is not understood why these plants did not become reproductive. This may explain grower complaints that sometimes the bare-root plants, previously produced in moss, received by growers in the United States did not spike, regardless of the favorable environmental conditions in the greenhouse for flowering. Studies need to be conducted to learn whether plants that received less than optimal K during production would perform well when adequate K is applied after bare-root plants have been shipped internationally, potted, and induced to flower.

A crop's response to K largely depends on the level of N being applied (Gartner, 1969). Higher N results in a greater yield response resulting from an increase in K. Plants used in this study received 200 mg·L^{-1} each of N and P, which have been reported to promote fast growth and to produce high-quality *Phalaenopsis* (Wang, 1996, 1998; Wang and Gregg, 1994). Therefore, the responses to K in vegetative growth and flowering in either medium were likely the true responses to K concentrations. Plants are able to use Na to substitute for K under K-deficient conditions to lessen the deficiency symptoms (Figdore et al., 1989; Sharma and Singh, 1990). Reverse osmosis water and nutrient salts used in this study contained no Na and that may have contributed to the severe symptoms and death of K-deficient *Phalaenopsis*. Na released from the bark mix may be too little to save these plants from severe K deficiency.

Consistent with increased flower size and inflorescence length in *Phalaenopsis* found in this study, Higaki et al. (1992) reported larger flowers on a longer flower stem in *Anthurium andreaeanum* when K rate increased from 0 to 448 kg·ha^{-1} per year. Yoneda et al. (1999) reported that increasing K concentration in the nutrient solution did not result in significant changes in the number of leaves produced by *Odontioda* Lovely Morning 'Sayaka', which is in agreement with that observed on *Phalaenopsis* in this study. *Phalaenopsis* responded to increasing K concentration by producing longer flower stalks (Figs. 2D–E) with higher flower counts (Fig. 2B), thereby increasing the quality of the finished product. In *Odontioda*, flower stem length increased, but its diameter decreased with increasing K concentration. In *Phalaenopsis*, both the length and the diameter of the flower stem increased with K concentration, improving structural support of the flowers. Increasing K concentration resulted in larger flowers in both *Odontioda* and *Phalaenopsis*. In commercial operations, some growers follow a single fertilizer application with one or several applications of plain water with minimal or no leaching when irrigations are needed. It is not understood how K concentration would affect *Phalaenopsis* performance under such production practices or under conditions of low N or P.

Conclusions

Similar to *Spathiphyllum* 'Sensation' (Yeh et al., 2000), *Phalaenopsis* plants initially grew normally under K-deficient conditions with a perfect healthy appearance. Symptoms of K deficiency began to appear after plants had become reproductive. When grown in a bark mix, 50 or 100 mg·L^{-1} K resulted in vegetative plants that appear healthy but developed some degrees of leaf yellowing or leaf abscission during flowering. Although applying 200 mg·L^{-1} K completely eliminated K deficiency symptoms and resulted in good growth and flowering in this study, to obtain top-quality *Phalaenopsis* with the greatest leaf length, highest flower count, largest flowers, and longest inflorescences, it is recommended that 300 mg·L^{-1} K

Fig. 6. *Phalaenopsis* Taisuco Kochdian plants in a bark mix that received various concentrations of potassium (in mg·L^{-1}).

be applied regardless of the medium. How *Phalaenopsis* would respond to various K concentrations under less than optimal N and P levels remains to be determined.

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