Abstract

GIBSON, JAMES LLOYD. Influence of Mineral Nutrition on Stock Plant Yield and Subsequent Rooting of Stem Cuttings of Scaevola, New Guinea Impatiens, and Vegetative Strawflower. (Under the direction of Brian E. Whipker and Paul V. Nelson).

Mineral nutrition is a key factor in successful rooting of vegetatively-propagated floriculture crops. Cutting yield and rooting performance influenced by stock plant fertilization and how mineral nutrients play a role in the development of adventitious roots are new frontiers in floriculture research. Propagation specialists desire a fertilization program that maximizes yield of stem cuttings, yet achieves the highest degree of quality. This research project therefore provides propagators with proper fertilization strategies for stock plants to successfully propagate cuttings. There were three experiments in the study.

Experiment 1. Effects of N and K concentration on yield, cutting quality, and adventitious rooting were investigated to establish a scientifically based program for light and moderate to heavy nutrient requiring stock plants. Stock plants of New Guinea impatiens (*Impatiens* x *hawkeri* Bull.) 'Grenada' (light) and scaevola (*Scaevola aemula* R. Br.) 'Purple Fan' (moderate to heavy) were fertigated with a factorial arrangement of N and K at concentrations of 100, 200, or 300 $mg \cdot L^{-1}$. Stock plants should be fertilized with N at 300 $mg \cdot L^{-1}$ because yield and rooting performance were maximized, while K at 100 $mg \cdot L^{-1}$ resulted in decreased leaching of K and improved rooting of stem cuttings of

New Guinea impatiens. No improvement occurred in cutting production and rooting of scaevola at K concentrations over 100 $mg \cdot L^{-1}$.

Experiment 2. Elemental deficiencies of N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, or B were induced in stock plants of 'Florabella Pink' strawflower [*Bracteantha bracteata* (Vent.) A.A. Anderberg]. Stem cuttings were harvested when initial foliar symptoms were first expressed and later under moderate deficiency symptoms. A sub-set of cuttings were analyzed for mineral nutrient levels and the remainder rooted in perlite for 3 weeks and evaluated for root quality and root and shoot dry weight. Nutrients at an incipient or moderate stage of deficiency that affected rooting quality negatively were P, Ca, and Zn. Low K tissue levels near 1.5% affected rooting positively. Calcium and B should be applied to stock plants at recommended concentrations because cuttings will develop shoot tip necrosis under high humidity environments. Although Cu, Fe, Mg, Mn, N, and S deficiencies did not affect rooting of cuttings at an incipient stage, they produced cuttings with foliar symptoms not desired by propagators.

Experiment 3. Yield and subsequent rooting of stem cuttings of stock plants of strawflower [*Bracteantha bracteata* (Vent.) A.A. Anderberg] were recorded when fertilized with K at 0, 29, 59, 117, or 234 $mg \cdot L^{-1}$. Cutting height was also evaluated because previous research had shown that lower concentrations of K produced compact shoots with commercially acceptable roots. While a threshold level of K at 32 $mg \cdot L^{-1}$ achieved the highest number of cuttings, rooting was not different with cuttings from stock plants fertilized with K at 59 to 234 $mg \cdot L^{-1}$. Deficiency symptoms appeared on

stock plants fertilized with K at 59 $mg \cdot L^{-1}$ and less with necrosis on mature leaf tips and interveinal chlorosis on recently mature leaves. The minimum stock plant recently mature leaf K concentration necessary to avert unacceptable deficiency symptoms during subsequent rooting of cuttings was found to be between 4.7% and 6.6% K. Stock plants of strawflower can be fertilized at 1N:1.1K (N at 217 $mg \cdot L^{-1}$ and K at 234 $mg \cdot L^{-1}$) or 2N:1K (N at 217 $mg \cdot L^{-1}$ and K at 117 $mg \cdot L^{-1}$) ratios because upper cutting foliage did not exhibit deficiency symptoms and optimal cutting yield and rooting occurred.

Influence of Mineral Nutrition on Stock Plant Yield and Subsequent Rooting of Stem Cuttings of Scaevola, New Guinea Impatiens, and Vegetative Strawflower

by

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Dedication

This dissertation is dedicated to my great-grandfather, Dr. J.B.S. Norton. He served as a professor of botany and plant pathology at the University of Maryland and as a state plant pathologist from 1901 to 1942. He also organized the Botanical Society of Washington and the Hyattsville Horticulture Society. After retirement, he enjoyed the remaining years of his life developing new hybrids of daylilies. His love for horticulture has been passed down through the generations and I shall continue to share our deep interest for ornamental plants with family, friends, and students.

Biography

James Lloyd Gibson was born in Washington, D.C. to Terence N. Gibson and Mary Ellen Gibson on 28 December 1974. He grew up with his younger brother Nelson in Calvert County, Southern Maryland, nestled between the Patuxent River and the Chesapeake Bay. He graduated from Calvert High School, Prince Frederick, Maryland in May 1992. Jamie graduated with a B.S. degree in Agriculture at West Virginia University, Morgantown in December 1996. Following graduation he was employed by Windmere Nursery, Lothian, Maryland, as an Assistant Grower from December 1996 until June 1998. In August 1998, he began graduate studies in the Department of Horticultural Science at North Carolina State University, Raleigh, under the direction of Dr. Brian E. Whipker. He completed all requirements for the M.S. degree in the floriculture program in June 2000 and remained at North Carolina State University to pursue a Ph.D. degree. Currently, Jamie is completing the requirements for Ph.D. degree in the floriculture program under the direction of Drs. Brian E. Whipker and Paul V. Nelson. In October 2003 Jamie will begin an academic career as an Assistant Professor at the West Florida Research and Education Center, University of Florida- Milton Campus.

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Chapter 1

Introduction

Propagation of floriculture crops is a dynamic business in the horticultural industry. Because of intensive breeding efforts and competition among propagation firms, new cultivars with unique characteristics are appearing on the market at a rapid rate (John Gaydos, personal communication). Vegetative propagation of these cultivars allows propagators to maintain true to type individuals with the same genotype as the mother plant (Hartmann et al., 2002). Stock plant establishment and large-scale propagation must be successful to increase market share and profitability (Debbie Hamrick, personal communication). Thus, the primary objective of propagation firms is to maximize cutting quality and quantity.

Many factors can influence asexual propagation: cultural practices, plant growth regulator applications, genotype, temperature, light (photoperiod, irradiance, and quality), and mineral nutrition (Read et al., 1985). Mineral nutrition has been investigated by propagators and researchers to improve cutting quality and yield, as well as the root regeneration of cuttings taken from stock plants. One nutrient in particular, nitrogen (N), has been determined to influence rooting response, but research has also shown that adventitious root formation is affected by both initial N levels and carbohydrate status (Blazich, 1988). Krause and Kraybill (1918) demonstrated that a high carbon (C) to N ratio (C:N) increased rooting of stem cuttings of tomato (*Lycopersicon esculentum* Mill.). Although a high C:N ratio in cuttings promotes rooting, rooting response has not been

linked directly to individual carbohydrates responsible for root initiation in primordial cells (Veirskov, 1988). Research in Germany found that rooting stem cuttings of chrysanthemum (*Dendranthema* x *grandiflorum* Kitam.) under natural light conditions was positively correlated with low N concentration, and not low sugar concentrations (Druege et al., 1998).

Controversy still remains in determining the exact relationship between carbohydrates and adventitious root formation. Therefore, this review will focus on the effects of mineral nutrition on cutting quality and quantity in floricultural crops. In some cases irradiance, cultural systems, and cultural practices will be mentioned, but an effort will be made to address mineral nutrition as the main effect on cutting size (e.g. caliper, length, and leaf area), productivity, and rooting response.

Specific Nutrient Effects on Stock Plant Productivity and Rooting Response

Nitrogen

Nitrogen is important for nucleic acid and protein synthesis in plant tissue (Hartmann et al., 2002). Levels of N in cuttings excised from stock plants have a direct influence on rooting performance. Stock plant fertilization and rooting performance have been investigated in chrysanthemum. Roeber and Reuther (1982) provided N concentrations of 56, 112, or 168 $mg \cdot L^{-1}$ to stock plants grown in nutrient solution. In this hydroponic setting, supplying N at 168 $mg \cdot L^{-1}$ surpassed the level necessary for maximum stock plant growth and resulted in fewer harvested cuttings. There was also a negative correlation between increasing N concentration and root initiation and development.

No decrease in rooting was observed when concentrations were considered high in another study involving stock plant fertilization of chrysanthemum (Dreuge et al., 2000). Stock plants were fertilized once weekly with three levels of N at 60, 150, or 400 $mg \cdot L^{-1}$. Cuttings were excised and placed in perlite for 12 d. The number of roots per cutting and mean root length were determined. As the N supply increased there was a higher tissue N concentration in the cuttings and the number and length of subsequently formed adventitious roots was positively correlated with pre-rooting N concentration. No decrease in rooting at the high level may have been due to the low impact of once weekly fertilizations at 400 $mg \cdot L^{-1}$. It is recommended that chrysanthemums be fertilized on a continual basis at 300 to 400 $mg \cdot L^{-1}$ N (Yoder Brothers, 1995).

Nitrogen Form: NO_3-N/ NH_4-N Ratio Effects

Not only has the concentration of N been investigated, but the form as either ammoniacal-nitrogen (NH_4-N) or nitrate-nitrogen (NO_3-N) has been shown to affect cutting quantity. Both ammonium and nitrate forms of N are utilized by plants (Mills and Jones, 1996).

Researchers in Israel evaluated the effects of NH_4-N:NO_3-N ratios on cutting quantity and quality of geranium (*Pelargonium* x *hortorum* L. H. Bailey) stock plants (Ganmore-Neuman and Hagiladi, 1990). Nitrogen at 200 $mg \cdot L^{-1}$ was provided at ratios of 40:60, 60:40, or 70:30 NH_4-N:NO_3-N. Stock plants were subjected to two irradiance levels in the greenhouse: one under natural conditions [approximately 95% of sunlight transmittance (1400 to 1600 $\mu mol \cdot m^{-2} \cdot s^{-1}$] and one with 30% shading [approximately 70% of sunlight transmittance (1000 to 1200 $\mu mol \cdot m^{-2} \cdot s^{-1}$)]. The NH_4-N:NO_3-N ratio did not

affect the number of stem cuttings produced per plant under natural conditions, but under low irradiance, fertilizing with a NH_4-N:NO_3-N ratio of 70:30 negatively affected cutting yield per plant. Although cutting numbers were similar for all ratios under natural irradiance, stock plant cuttings grown under low irradiance with NH_4-N:NO_3-N ratios of 60:40 or 70:30 resulted in an improvement in rooting percentage and quality. Rooting percentage was affected by the interaction between N form and irradiance level. As the NH_4-N:NO_3-N ratio decreased from 70:30 to 40:60, rooting percentage increased from 83% to 89% under natural irradiance, but there was a reduction from 94% to 88% under low irradiance.

A second study by Ganmore-Neuman and Hagiladi (1992) investigated the effect of N concentration and the NH_4-N:NO_3-N ratio on both the production of geranium stem cuttings and stock plant growth. Concentrations of N were at 50, 100, 200, or 400 $mg \cdot L^{-1}$ with three NH_4-N:NO_3-N ratios: 30:70, 40:60, or 60:40. Cutting number was not affected by fertilizer rates or ratios, except for stock plants fertilized with N at 50 $mg \cdot L^{-1}$, which produced lower numbers of vegetative cuttings. The N form did not affect the production of cuttings or the fresh weight of cuttings. Root fresh weight and the root:shoot ratio of the stock plants were negatively correlated with increasing N concentration and an increased NO_3-N percentage.

Based on the initial study by Ganmore-Neuman and Hagiladi, cutting production was maximized at a high irradiance level, but rooting percentage was maximized at a low irradiance level. Greenhouse propagators of geraniums need to adjust their NH_4-N:NO_3-N balance in fertilizer in accordance to the irradiance levels during the stock plant production season. From the second study, root growth of the stock plant was less when

the N concentration increased, but did not affect the number of cuttings produced. Based on research by Ganmore-Neuman and Hagiladi (1990;1992), stock plants of geranium should be fertilized with N at 100 to 200 $mg \cdot L^{-1}$ with an NH_4-N:NO_3-N ratio of 60:40.

Pierman et al. (1989) fertilized poinsettias (*Euphorbia pulcherrima* Willd. Ex. Klotsch) with N at 250 $mg \cdot L^{-1}$ with three NH_4-N:NO_3-N ratios of 0:1, 1:2, or 2:1 to investigate the influence of N form on the poinsettia disorder, leaf edge burn (LEB). During heavy cutting production, the disorder can cause a delay in harvesting because the shoots need time to elongate over the necrotic regions of the shoot. LEB has been associated with limited calcium (Ca) translocation, N fertilizer source, and vegetative growth rate (Zakkour et al., 1986). When plants were fertilized with NH_4-N:NO_3-N ratios of 1:2 or 2:1, the number of LEB leaves increased nearly 100%, but the number of cuttings per plant increased nearly 40%. The researchers concluded that fertilizer with NO_3-N as a sole source limited LEB, but maximum cutting production required a combination of both ammoniacal and nitrate-nitrogen.

An increase in cutting number from poinsettia stock plants fertilized with higher NH_4-N:NO_3-N ratios was also demonstrated by Rose (1992). Stock plants were fertilized with N at 200 $mg \cdot L^{-1}$ with ratios of 0:1, 1:2, or 2:1. Shoot and root dry weight, number of cuttings, and shoot lengths were significantly greater from stock plants fertilized with solutions containing ammoniacal-nitrogen. Stock plant height was slightly less when fertilized at an NH_4-N:NO_3-N ratio of 0:1.

N P K Interaction

Not only has N been the focus of investigation, but phosphorus (P) and potassium (K) fertilization treatments have also been incorporated into stock plant research. Stock plants of geranium were fertilized with a 3 x 3 x 3 factorial combination of N, P, and K (in milliequivalents) at 1, 3, or 9; 0.5, 1.5, or 4.5; and 1, 3, or 9, respectively (Haun and Cornell, 1951). The three milliequivalent concentrations by element represented deficient, optimal, or excessive nutrient levels. After rooting mallet cuttings of geranium in a quartz sand substrate, researchers evaluated percentage of cuttings rooted and mean number and length of primary roots per cutting. They also recorded the number of cuttings which died prior to rooting and after rooting. Nitrogen level resulted in a more pronounced variation in rooting response of the cuttings than either P or K. Low and medium levels of N resulted in a significantly higher percentage of rooted cuttings (67%), than the high level (56%). Although the rooting percentages were lower with the highest level of N, it did result in a greater number and longer length of roots.

Potassium

Potassium has also been reported to increase the number of stem cuttings of chrysanthemum when applied as a top dressing (Krause, 1981). Stock plants were routinely fertilized by supplying (in $mg \cdot L^{-1}$) 250 N, 100 P, and 350 K. Stock plants were harvested every 3 weeks and supplementary fertilizer was applied on a weekly basis by either top-dressing with ammonium-nitrate at 20 $mg \cdot L^{-1}$ or Florovit (N-P-K fertilizer with micronutrients) at 20 $mg \cdot L^{-1}$. When fertilized with Florovit, stock plants produced a greater number of cuttings, but no differences in fresh weight and rooting percentage

were observed. Results of Krause's experiment were not definitive; K may not be the only element influencing the increase in the number of cuttings. He also suspected the increase in yield may have been due to micronutrients contained in Florovit, such as iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), and boron (B). Kraus's results contrast with Roeber (1976; 1978) who reported that K did not increase the number of cuttings, but found that K stimulates root development under low light conditions.

N P K Fertilization

Research on chrysanthemum, poinsettia, coleus (*Solenostemon scutellariodes* (L.) Codd), and carnation (*Dianthus caryophyllus* L.) by Good and Tukey (1966) demonstrated the importance of proper nutrition to stock plants. Cuttings were inserted into quartz sand and misted with distilled water. There was no significant change in the total mineral nutrient content per cutting before and after rooting, therefore little or no leaching from these herbaceous species occurred. The difficulty of leaching in herbaceous cuttings is due to quick metabolization of nutrients within cells and cell walls (Good and Tukey, 1966). For herbaceous cuttings to increase in dry weight, macronutrients are redistributed from mature parts of the cuttings to the new growth. Roots and leaves of chrysanthemum cuttings, propagated under distilled water mist, developed and grew due to the redistribution of N, P, and K (Good and Tukey, 1967). This research demonstrates the importance of fertilizing stock plants with a fertilizer containing N, P, and K. After roots have formed, providing a low concentration fertilizer solution with low ammoniacal-N and P is recommended for floricultural crops (Jack Williams, personal communication).

Cultural System Effects on Stock Plant Productivity

Four cultural systems in which stock plants are grown were investigated to compare stock plant productivity, stem cutting quality, and rooting of harvested stem cuttings (Vetanovetz and Peterson, 1985). Experimentation involved a weekly fertilization of N at 400 $mg \cdot L^{-1}$ to geranium stock plants grown in three cultural systems: peat-lite bag culture, conventional pot, and ground bed culture. The fourth system or nutrient film technique (NFT) involved a continual flow of nutrient solution with N at 400 $mg \cdot L^{-1}$. Cuttings were rooted in 1 peat:1 vermiculite medium (by volume) and after 3 weeks cuttings were evaluated. Results indicated that all of the cultural systems worked equally well. There were no significant differences in the number of cuttings produced, cutting dry weight, or cutting basal stem caliper among cultural systems.

Nutrient Stresses on Stock Plant Yield and Subsequent Rooting of Stem Cuttings

Little has published on the effects of nutrient stresses on rooting of stem cuttings of plants. Optimal rooting occurs when N is marginally low and carbohydrates are high in cuttings (Blazich, 1988). High N tends to inhibit rooting (McAvoy, 1995). Calcium and B interact with each other in their roles within the plant. Thus, a deficiency of one can cause symptoms of the other (Mills and Jones, 1996; Smith and Loneragan, 1997). By inference, one would suspect that either deficiency would inhibit rooting of cuttings. Zinc is required by the plant for formation of auxin, which stimulates adventitious root formation in cuttings (Blazich, 1988). Again, one would suspect that Zn would be beneficial for rooting. Little is known about any roles of the remaining nutrients with regards to rooting.

Conclusion

Propagators should adopt a nutrient program which produces the maximum quantity of stem cuttings with the highest quality. Nutrition is one of the factors that has been reported to affect stock plant development and the production of cuttings (Read, 1987). Propagators should consider other external factors such as humidity, irradiance, and temperature before establishing a fertilization program. The concentration of N as well as the form of N has been shown to effect cutting number and rooting performance of floricultural crops. Several species of herbaceous plants have been studied with varied results in cutting quality and quantity. Unfortunately, mineral nutrition of stock plants is based rather on practical knowledge, with reference to cultivation of flowering plants (Krause, 1981). Maximizing productivity of stock plants in the propagation industry may reflect the opposite of what is to be considered common growing strategies for the finished product.

Objectives

A. Determine the productivity of stock plants of New Guinea impatiens and scaevola that were fertilized with increasing concentrations of N and K, along with evaluating cutting stem caliper, length, and leaf area. Evaluate adventitious rooting of stem cuttings removed from the stock plants.

B. Generate visual symptoms of nutrient deficiencies in the chronological order in which they appear from incipient to advanced stages. Establish foliar analysis standards by correlating nutrient levels with initial and advanced stages of deficiencies for N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, and B in strawflower.

C. Determine the impact of a light and a moderate deficiency of each of 11 essential mineral nutrients on rooting of stem cuttings of strawflower.

D. Determine the productivity of stock plants of strawflower that were fertilized with increasing concentrations of K. Determine tissue K concentrations that produce high-quality cuttings. Evaluate adventitious rooting and length of cuttings removed from the stock plants.

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Chapter 2

Nitrogen and Potassium Concentration Affect Yield and Subsequent Rooting of Stem Cuttings from Stock Plants of New Guinea Impatiens and Scaevola

(in the format appropriate for submission to HortScience)

Subject Category: Propagation and Tissue Culture

Nitrogen and Potassium Concentration Affect Yield and Subsequent Rooting of Stem Cuttings from Stock Plants of New Guinea Impatiens and Scaevola

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Nitrogen and Potassium Concentration Affect Yield and Subsequent Rooting of Stem Cuttings from Stock Plants of New Guinea Impatiens and Scaevola

Additional index words. *Impatiens* x *hawkeri, Scaevola aemula*, foliar analysis, vegetative propagation

Abstract. Effects of N and K concentration on yield, cutting quality, and adventitious rooting were investigated to establish a scientifically based program for light and moderate to heavy nutrient requiring stock plants. Stock plants of New Guinea impatiens (*Impatiens* x *hawkeri* Bull.) 'Grenada' (light) and scaevola (*Scaevola aemula* R. Br.) 'Purple Fan' (moderate to heavy) were fertigated with a factorial arrangement of N and K at concentrations of 100, 200, or 300 $mg \cdot L^{-1}$. Shorter cuttings with smaller leaf areas occurred when stock plants of New Guinea impatiens were fertilized with N at 100 $mg \cdot L^{-1}$, however the greatest yield, root number, and shoot dry weight were achieved with N at 300 $mg \cdot L^{-1}$. Cutting quality of scaevola was not influenced by N or K concentration and decreased over time. Stock plants of scaevola fertilized with N at 300 $mg \cdot L^{-1}$ produced more cuttings and more roots per cutting than N at 100 $mg \cdot L^{-1}$. Greater cutting root and shoot dry weight of New Guinea impatiens were achieved at the lower concentration of K at 100 $mg \cdot L^{-1}$. No improvement occurred in cutting production and rooting of scaevola at K concentrations over 100 $mg \cdot L^{-1}$. Excessive K leached from the substrate when applied to New Guinea impatiens at 200 and 300 $mg \cdot L^{-1}$ and scaevola at

300 $mg \cdot L^{-1}$ suggesting that the lower concentrations be used. Based on these results, stock plants of New Guinea impatiens and scaevola should be fertilized with N and K at 300 and 100 $mg \cdot L^{-1}$, respectively.

Introduction

As vegetatively propagated material has increased in popularity over time, growers have experienced difficulty receiving adequate quantities of rooted stem cuttings from suppliers of young plant material (Williams, 2001). Cutting quality has varied and growers have received shipments of poorly rooted or nutrient deficient plants with weak stems and poor axillary shoot development. Grower frustration has led to an increase in the demand for unrooted material so that quality control of rooted material and the success of their crops can be achieved (Konjoian, 2001).

Cutting quality can be linked directly to how stock plants are managed. Mineral nutrition is a key factor which affects stock plant development and the production of quality cuttings (Read et al., 1985). Nitrogen concentration affects cutting yield of stock plants and rooting performance of cuttings. Adequate N content is crucial in cuttings as it is important for nucleic acid and protein synthesis in plant tissue (Hartmann et al., 2002). However, rooting performance can be affected negatively when excessive N is applied to the stock plant (McAvoy, 1995). Ganmore-Neuman and Hagiladi (1990, 1992) fertilized stock plants of geranium (*Pelargonium* x *hortorum* L. H. Bailey) at N concentrations of 50, 100, 200, or 400 $mg \cdot L^{-1}$. Cutting yield was similar for all fertilizer concentrations, except for stock plants fertilized with N at 50 $mg \cdot L^{-1}$ which produced lower numbers of vegetative cuttings. Roeber and Reuther (1982) provided N concentrations of 56, 112, or

168 $mg \cdot L^{-1}$ to stock plants of chrysanthemum (*Dendranthema* x *grandiflorum* Kitam.) grown in nutrient solution. In this hydroponic setting, supplying N at 168 $mg \cdot L^{-1}$ surpassed the level necessary for maximum stock plant growth and resulted in fewer harvested cuttings.

Another major influence on stock plants is K concentration and how it affects the quantity and quality of vegetative cuttings. Link and Shanks (1952) fertilized stock plants of poinsettia (*Euphorbia pulcherrima* Willd. Ex. Klotsch) with K at 0, 39, or 117 $mg \cdot L^{-1}$. A larger number of rooted cuttings and a higher degree of rooting occurred with the highest K concentration, however fertilizing at 117 $mg \cdot L^{-1}$ did not increase cutting production. Krause (1981) reported that the amount of K in a fertilizer increased the number of chrysanthemum cuttings when applied as a top dressing. Roeber (1976, 1978) maintains that K does not contribute to increased cutting production of chrysanthemum, but instead enhances the ability of stem cuttings to develop roots more easily under low light conditions.

Fertilizing stock plants at different rates of N and K to determine the effects on rooting of stem cuttings has been conducted on geranium and chrysanthemum. Research on geraniums by Haun and Cornell (1951) used a 3 x 3 factorial with N at 14, 42, or 126 $mg \cdot L^{-1}$ and K at 39, 117, or 351 $mg \cdot L^{-1}$. The N x K interaction was not significant, therefore only the effects of N were reported. They found an inverse relationship of decreased rooting as N concentration increased. Rober and Reuther (1982) also observed a negative correlation when rooting cuttings of chrysanthemum as N increased from 56 to 168 $mg \cdot L^{-1}$. However, Dreuge et al. (2000) reported a positive correlation with the number and length of roots when N increased from 60 to 400 $mg \cdot L^{-1}$.

Previous research indicates that N and K play an important role in stock plant productivity and the rooting performance of cuttings taken from these plants. Propagators have tended to adopt the 1N:1K fertilization standard for finishing plants in the floriculture industry. Stock plant research has been conducted on chrysanthemum, geranium, and poinsettia, but little has been conducted on recent herbaceous plant introductions. Fertilization protocols need to be established for species that are light [New Guinea impatiens (*Impatiens* x *hawkeri* Bull.) (Williams and Ruis, 1995)] or moderate to heavy [scaevola (*Scaevola aemula* R. Br.) (Rader, 1998)] nutrient requiring plants, and ultimately these protocols can then be made applicable to the numerous vegetatively propagated species available today. The first objective of our experiment was to determine the effects of N and K concentration on cutting quantity and quality from stock plants of New Guinea impatiens and scaevola. The second objective was to evaluate adventitious rooting of stem cuttings removed from the stock plants.

Materials and Methods

Rooted stem cuttings of New Guinea impatiens 'Grenada' and scaevola 'Purple Fan' from 3.5 x 3.8 cm (1.4 x 1.5 inch) cells were transplanted two per pot into 2.54-L (0.671-gal) (19.0-cm [7.5-inch diameter]) round plastic containers on 17 Aug. 2001. The root substrate consisted of 4 sphagnum peat : 2 pine bark : 2 vermiculite : 1 perlite (by volume). A continual liquid fertilization program was initiated on 28 Aug. with a 3 x 3 N x K factorial system (9 fertilizer treatments) with N and K concentrations of 100, 200, or 300 $mg \cdot L^{-1}$ and P was held constant at 15 $mg \cdot L^{-1}$. Macronutrients and micronutrients were obtained from reagent grade salts to create stock solutions (Table 2.1). Specific

amounts of stock solution (Table 2.2) were used to develop 113-L nutrient solutions (Table 2.3). The plants were fertigated by a sub-pump drip irrigation system. The experiment was a randomized complete block design with six single-plant replications of the nine treatments. Foliar sprays of ethephon [(2-chlorethyl) phosphonic acid] (Florel, Rhone-Poulenc Ag. Co., Research Triangle Park, N.C.) at 250 $mg \cdot L^{-1}$ (using a volume of 204 $mL \cdot m^{-2}$) were applied on 5 and 26 Oct. and 23 Nov. Stock plants were grown in a greenhouse under natural photoperiod and irradiance with days/nights of 20/18 °C. Stock plants were pinched by removing 2.5 cm of the distal portion of lateral shoots on 31 Aug. and 14 and 28 Sept. 2001 to develop a canopy for harvesting cuttings.

Leachate sampling. Leachate samples were collected initially [4 weeks after potting (WAP)] and every 14 days thereafter until 22 WAP via a modified VTEM extraction method (Wright, 1986) to determine pH, electrical conductivity (EC), nitrate nitrogen (NO_3-N), ammoniacal nitrogen (NH_4-N), P, and K levels. Distilled water (85 ml) was added onto the substrate surface to displace 50 ml of leachate which represented the nutrient reserve of the rhizosphere (Wright, 1986). The leachate solutions were analyzed for pH (pHep pH meter; Hanna Instruments, Woonsocket, R.I.) and EC (DiST WP4 EC meter; Hanna Instruments). Leachate NO_3-N, NH_4-N, and P levels were determined using colorimetric procedures established by Cataldo et al. (1975), Chaney and Marbach (1961), and Murphy and Riley (1962), respectively, using a Perkin-Elmer Lambda 3 UV/VIS spectrophotometer (Perkin-Elmer, Norwalk, Conn.). Calcium, Mg, and K were determined using a Perkin-Elmer 373 atomic absorption spectrophotometer (Perkin-Elmer, Norwalk, Conn).

Foliar nutrient analysis. The youngest fully expanded leaves were sampled from three replicates per treatment 12 and 20 WAP from stock plants of New Guinea impatiens. Stock plants of scaevola were sampled 11 and 23 WAP. Harvested tissue was washed in a solution of 0.5 N HCl for 1 min and rinsed with deionized water before drying at 70 °C for tissue analysis. Dried tissue was ground in a stainless steel Wiley mill to pass a 20-mesh (1.27 mm) screen. Tissue was then analyzed for macro and micronutrients with the exceptions of N, using a Perkin Elmer 3300 Inductively Coupled Argon Plasma Emission Spectrophotometer (Perkin Elmer, Shelton, Conn.) while N was analyzed using a Carlo Erba NA 1500 Series 1, O_2 combustion N Analyzer (Carlo Erba, Lakewood, N.J.) at the N.C. Department of Agriculture Laboratory, Raleigh.

Cutting quantity and quality. Stock plants were "hedged" or "grazed" to remove all commercially acceptable cuttings each time cuttings were harvested (Healy, 1994). Terminal stem cuttings (≥ 3.0 cm in length) from stock plants of New Guinea impatiens were excised at the second visible node from the shoot tip 9, 12, 14, 17, 20, and 22 WAP. Similar sized cuttings were taken from stock plants of scaevola initially (19 Oct.) and every 14 d thereafter until 24 Jan. 2002 (9, 11, 13, 15, 17, 19, 21, and 23 WAP). Once yield was recorded 17 WAP, stock plants were trimmed to reshape the plant and encourage the development of cuttings from the interior of the plant canopy. Cuttings harvested 9 to 17 WAP represented the first cycle of production, while 18 to 23 WAP represented the second cycle of cutting production. The number of cuttings were recorded and seven cuttings per replicate from each treatment were selected randomly 9, 12, 14, and 17 WAP from stock plants of New Guinea impatiens and 9, 11, 13, 15, 17, and 19 WAP from stock plants of scaevola to measure stem base caliper (in mm) and

shoot length (in cm). Cutting leaf area was also measured with a LI-COR LI-3100 leaf area meter (LI-COR, Lincoln, Nebr.) 12 and 14 WAP from stock plants of New Guinea impatiens and 11, 13, and 15 WAP from stock plants of scaevola.

Adventitious rooting. A total of 72 cuttings per treatment were randomly selected for measurement of root and shoot dry weight and total root number over time. The experimental design was a completely randomized design with nine N x K treatments and 12 replications per treatment with six sub-samples per replication. Basal portions of cuttings (1 cm) were inserted into moist perlite in 3.8 x 3.8 x 8.9 cm 6-cell containers and placed under intermittent mist. Cuttings were maintained under natural photoperiod and irradiance with days/nights of 20/18 °C, and misted daily for 6 s every 8 min (8:00 AM-4:30 PM) for 1 week, then for 4 s every 30 min (8:00 AM-4:30 PM) the following week. For the remaining 2 weeks, perlite was moistened by overhead hand irrigation with tap water. Bottom heat at 21 °C was provided for 3 weeks.

Adventitious roots ≥ 2.0 mm in length from cuttings of New Guinea impatiens planted 12, 14, 20, and 22 WAP were counted 14, 16, 22, and 24 WAP. Adventitious roots from cuttings of scaevola planted 11, 13, 15, and 23 WAP were counted 13, 15, 17, and 25 WAP. Cutting root (adventitious roots plus 1 cm of the cutting base) and shoot dry weights were measured 4 weeks after sticking (WAS) (18 and 26 WAP) from cuttings harvested 14 and 22 WAP for cuttings of New Guinea impatiens, and 17 and 25 WAP for cuttings planted 13 and 21 WAP from stock plants of scaevola. The recently mature leaves were harvested 4 WAS to conduct foliar analysis 16 and 24 WAP from cuttings of New Guinea impatiens and 15 and 27 WAP from cuttings of scaevola. Data

were subjected to analysis of variance using general linear model procedures (SAS Inst., Cary, N.C.). Means were separated by least significant differences (LSD) at $P \leq 0.05$.

Results and Discussion

There were no significant effects of the N x K interaction on any measurements. Only the remaining significant sources of variation from the analysis of variance were reported.

New Guinea impatiens

Cutting quantity and quality. Cutting yield increased then decreased after the initiation of each cutting production cycle (Fig. 2.1). This fluctuation in yield has been observed by the senior author in commercial greenhouse operations. As stem cuttings are continually being harvested, the ability of stock plants of New Guinea impatiens to regenerate cuttings declines, which can inhibit a propagator's ability to predict yield on a weekly basis. To overcome this, Sawaya (1994) suggests that stock plants of New Guinea impatiens should be harvested "gradually" during the cutting production cycle. Over time, fertilizing stock plants with N at 300 $mg \cdot L^{-1}$ produced 17% more cuttings than with ≤ 200 $mg \cdot L^{-1}$ N (Fig. 2.1).

The initial stem caliper 9 WAP was 3.9 mm while the caliper for 12 to 17 WAP was 3.4 mm (LSD=0.2, n=54). Cutting lengths were longest 9 WAP (9.4 cm) and then declined, fluctuating over time from 5.7 to 7.2 cm as the plant aged (LSD=0.3, n=54). Leaf area increased 15.6 cm^2 to 18.9 cm^2 from 12 to 14 WAP, respectively. Stock plants fertilized with N at 200 to 300 $mg \cdot L^{-1}$ produced cuttings that were 7% longer with a 15%

larger leaf area than cuttings from stock plants fertilized with N at 100 $mg \cdot L^{-1}$ (data not shown).

Rooting performance. Cuttings taken 16 WAP (18 roots) in cycle 1 had 50% more roots than cuttings harvested 14 WAP (12 roots). Likewise, cuttings taken 24 WAP (24 roots) had 60% more roots than cuttings harvested 22 WAP (15 roots) in cycle 2. There was a 19% increase in cutting root number when stock plants were fertilized with N at 300 $mg \cdot L^{-1}$ (19 roots) versus 100 to 200 $mg \cdot L^{-1}$ (16 roots) (LSD=2.0, n=72). A 24% increase in root dry weight occurred in cuttings taken from 18 (0.033 g) to 26 (0.041 g) WAP (LSD=0.005, n=162). Only the main effects of N and K had a significant effect on shoot and root dry weight. The greatest shoot dry weight was measured on cuttings from stock plants fertilized with N at 300 $mg \cdot L^{-1}$ and K at 100 $mg \cdot L^{-1}$ (data not shown). Root dry weight was 15% larger on cuttings from stock plants fertilized with K at 100 $mg \cdot L^{-1}$ (0.041 g) versus 200 to 300 $mg \cdot L^{-1}$ (0.035 g) (LSD=0.006, n=108).

More and longer cuttings, larger leaf areas, more roots, and greater shoot dry weights were produced with N at 300 $mg \cdot L^{-1}$. These results counter other reports that high N levels were detrimental to cutting yield and performance (McAvoy, 1995; Roeber and Reuther, 1982) or did not improve cutting yield (Ganmore-Neuman and Hagiladi, 1990, 1992) of other floriculture crops.

Similar to reports with chrysanthemums by Roeber (1976, 1978), varying K levels from 100 to 300 $mg \cdot L^{-1}$ had no influence on cutting yield. Fertilizing with K at 100 $mg \cdot L^{-1}$ was beneficial to rooting in our study. Rooting was also greatest with cuttings from stock plants of poinsettias fertilized with K at 117 $mg \cdot L^{-1}$ (Link and Shanks, 1952).

Based on our findings, propagating cuttings of New Guinea impatiens from 300 $mg \cdot L^{-1}$ N and 100 $mg \cdot L^{-1}$ K-fertilized stock plants produced desirable characteristics for a 72-cell propagation tray. However, if one were to use higher density propagation trays, fertilizing with N at 300 $mg \cdot L^{-1}$ might adversely affect cutting quality by leading to the incidence of excessive stem elongation and disease reported by Williams and Ruis (1995).

Leachate analysis. Based on regression analysis, leachate pH values increased over time from 6.5 to 6.9 (Fig. 2.2), and were within the acceptable range of 5.3 to 7.0 reported by Williams and Ruis (1995). Leachate EC values increased over time and values were significant for both the week x N and week x K interactions. At 14 to 22 WAP leachate EC values were highest with the greatest concentration of N (Fig. 2.3). A similar trend occurred with K, as 300 $mg \cdot L^{-1}$ had the highest EC values (Fig. 2.4). Differences among K concentrations were expressed earlier in the crop (10 WAP), than among N concentrations (18 WAP).

The leachate NO_3-N levels remained constant for stock plants fertilized with N at 100 $mg \cdot L^{-1}$ (Fig. 2.5). An increase in NO_3-N leached began 4 WAP at 300 $mg \cdot L^{-1}$ and 8 WAP at 200 $mg \cdot L^{-1}$. Leachate NH_4-N and P values remained < 5 $mg \cdot L^{-1}$ throughout the experiment for all fertilization concentrations (data not shown). The constant leachate level of K over time in the 100 $mg \cdot L^{-1}$ treatment suggests that adequate K was applied (Fig. 2.6). An increase in K leached began 4 WAP at 300 $mg \cdot L^{-1}$ and 8 WAP at 200 $mg \cdot L^{-1}$. Leachate concentrations of Ca (Fig. 2.7) and Mg (Fig 2.8) increased over time with N $\geq$ 200 $mg \cdot L^{-1}$, and may be due to increased concentrations of Ca and Mg associated with higher root substrate pH (Peterson, 1982).

Tissue analysis. Levels of N, P, K, Ca, Mg, S and B in the stock plant tissue were within the acceptable range published by Mills and Jones (1996), while Cu, Fe, Mn, and Zn were lower (Table 2.4). Since Mills and Jones have not identified the minimum critical levels for each nutrient and deficiency symptoms for these latter four nutrients did not occur, it appears that their recommended ranges were adequate. Low levels of the micronutrients may be due to the high pH effect of the root substrate. With the exception of S, all nutrient levels within stock plant tissue were significantly different among N treatments (Table 2.5). Nitrogen concentration was greatest at 300 $mg \cdot L^{-1}$ N, while B, P and K concentrations were greater in 100 $mg \cdot L^{-1}$ N-fertilized plants. Ca, Mg, Fe, Cu, Mn and Zn increased with N concentration. As the concentration of K increased from 100 to 300 $mg \cdot L^{-1}$, Ca and Mg concentration in the tissue decreased (data not shown). A reduction in Ca and Mg concentration, due to competition from K, has been reported in poinsettias by Cox and Seely (1984). Concentrations of all nutrients, except Cu, Fe and Zn, declined dramatically in cuttings by the time they rooted (Table 2.4). Nitrogen and Ca fell to deficient levels while the remaining nutrients remained above the minimum critical levels published for New Guinea impatiens by Pitchay (2002). A complete fertilizer should be applied to New Guinea impatiens cuttings once roots are visible to avoid nutrient deficiencies.

Scaevola

Cutting quantity and quality. Cutting numbers increased over time as the N fertilization concentration increased from 100 to 300 $mg \cdot L^{-1}$ (Fig. 2.9). Based on regression analysis, stock plants fertilized with N at 200 to 300 $mg \cdot L^{-1}$ had greater yields

than stock plants fertilized with N at 100 $mg \cdot L^{-1}$. Leaf area was not influenced by N or K with a larger area of 8.4 cm^2 11 WAP than 7.8 cm^2 for 13 and 15 WAP (LSD=0.5, n=54). Stem caliper was not influenced by N or K concentration with a 14% wider caliper 9 and 11 WAP, compared to 13 to 19 WAP (data not shown). During the first cycle of production, cutting length decreased 9% from 9 to 13 WAP, followed by a 13% increase to 17 WAP (Fig. 2.10). During the second cycle of production, cutting length decreased by 11%.

Rooting performance. There was a 100% increase in root production from 13 to 23 WAP where root number was maximized at 10, followed by a 50% decrease 25 WAP (Fig. 2.11). There was a 15% increase in root production when stock plants were fertilized with N at 300 $mg \cdot L^{-1}$ compared to 100 to 200 $mg \cdot L^{-1}$ (data not shown). Root dry weight was 19% greater when stock plants were fertilized with N at 200 to 300 $mg \cdot L^{-1}$ (0.026 g) compared to 100 $mg \cdot L^{-1}$ (0.021) (LSD=0.003, n=108). Shoot dry weight was 10% greater on cuttings harvested from stock plants fertilized with K at 300 $mg \cdot L^{-1}$ (0.139 g) compared to 100 to 200 $mg \cdot L^{-1}$ (0.125 g) (LSD=0.013, n=108).

Stock plants of scaevola fertilized with N at 300 $mg \cdot L^{-1}$ produced more cuttings and more roots per cutting than when fertilized with N at 100 $mg \cdot L^{-1}$. Fertilizing with K at 200 to 300 $mg \cdot L^{-1}$ did not prove to be advantageous to scaevola cutting production as yield, root number, and root dry weight were similar to K at 100 $mg \cdot L^{-1}$, however a greater shoot dry weight was achieved with K at 300 $mg \cdot L^{-1}$. Thus, the best fertilizer formulation for stock plants of scaevola was N at 300 $mg \cdot L^{-1}$ N and K at100 $mg \cdot L^{-1}$.

Leachate analysis. From 4 to 22 WAP leachate pH increased from 6.4 to 7.0 (Fig. 2.12). Scaevola performs best in well-aerated substrates at pH 5.5 to 6.3 and Fe

deficiency (chlorosis of the young leaves) may occur with high pH substrates (Paul Ecke Ranch, 2003). Iron deficiency symptoms did not appear in our study. The high pH values may be attributed to the low percentage of NH_4-N (14% of total N) in the treatment fertilizers or limestone activation in the root substrate.

Leachate EC began to increase 10 WAP with similar EC values produced with N at 100 to 300 $mg \cdot L^{-1}$ (Fig. 2.13), however, K concentration produced differences in EC with 300 $mg \cdot L^{-1}$ resulting in the highest EC values (Fig. 2.14). Leachate concentrations of NO_3-N, NH_4-N, and P decreased over time as stock plants aged (data not shown). Our data agree with Rader (1998) that scaevola are moderate to heavy nutrient requiring plants because of the increased uptake of N. Stock plants fertilized with K at 100 or 200 $mg \cdot L^{-1}$ produced similar leachate K values over time, however inefficient uptake occurred with K at 300 $mg \cdot L^{-1}$ beginning 4 WAP with a positive linear increase of K ions (Fig 2.15). A steady increase in the amount of Ca (Fig. 2.16) and Mg (Fig. 2.17) ions leached were observed over time. Higher amounts were leached when plants were fertilized with K at 200 to 300 $mg \cdot L^{-1}$. Higher concentrations of K can antagonize the uptake of Ca and Mg (Mills and Jones, 1996).

Tissue analysis. Levels of P, Ca, Mg, S, B, Fe, Mn, and Zn in the stock plant were within the sufficient range provided by N.C. Department of Agriculture Plant Analytical Laboratory (Brenda Cleveland, personal communication), however K and Cu on both dates as well as N and P at 11 WAP were lower (Table 2.6). The NCDA sufficiency ranges do not necessarily extend to the minimum critical concentrations, thus it is possible that nutrients below their sufficiency ranges were adequate. Fertilizing with N at 100 $mg \cdot L^{-1}$ resulted in N-deficient symptoms in stock plants which included red

pigmentation with some lower leaf chlorosis. No other deficiencies occurred. After 15 and 27 WAP, N, P, K, Ca, B, Cu, and Mn levels in the cutting tissue were below the NCDA sufficient range (Table 2.6). A complete fertilizer should be applied to scaevola cuttings upon visible detection of roots.

With the exception of K (2.53%), B (46.6 $mg \cdot kg^{-1}$), and Fe (66.6 $mg \cdot kg^{-1}$), all nutrient levels within stock plant tissue were significantly different among N treatments (Table 2.7). Nitrogen, Mg, and Cu concentrations were greatest with N at 300 $mg \cdot L^{-1}$, while P, Ca, S, Mn, and Zn concentrations were greater in plants fertilized with N at 100 $mg \cdot L^{-1}$. As the concentration of K supplied increased from 100 to 300 $mg \cdot L^{-1}$, tissue Ca concentration declined (data not shown). A reduction in Ca concentration, due to competition from K, has been reported in poinsettias by Blom and Brown (1992). While there were differences among N or K treatments for nutrient concentrations in cutting tissue, all levels except S, Fe, and Zn were below the sufficiency range (data not shown). Most soils in Australia, the origin of scaevola, are deficient in micronutrients (Isbell and Russell, 1986), and scaevola may be efficient at utilizing Fe and Zn at low levels.

Based on cutting production and rooting, excess potassium leaching and avoidance of nutrient deficiencies, the optimal fertilization program for stock plants of scaevola encompasses N at 300 $mg \cdot L^{-1}$ and K at 100 $mg \cdot L^{-1}$.

Conclusions

Our data indicate that stock plants of New Guinea impatiens and scaevola produced the greatest yield with the optimal cutting attributes and rooting with N at 300 $mg \cdot L^{-1}$. These conclusions apply to a 72-cell propagation tray. Propagators who use

higher density trays should evaluate this N level to be certain that excessive growth does not occur which could lead to excessive stem elongation and increased disease occurrence. Fertilizing with K at 200 to 300 $mg \cdot L^{-1}$ did not prove to be advantageous to New Guinea impatiens or scaevola cutting yield and rooting with the one exception of greater shoot dry weight in scaevola with K at 300 $mg \cdot L^{-1}$. However, an increase in shoot dry weight without a concomitant increase in root weight would be undesirable. For this reason, as well as prevention of K leaching from the substrate, K at 100 $mg \cdot L^{-1}$ appears optimal. Foliar analysis standards for scaevola establish nutrient concentrations associated with the sufficiency range, but do not identify the minimum critical standards for each nutrient. These minimum critical standards need to be established before it is possible to confirm deficiencies. Based on our research, the standard fertilization ratio of 1N:1K is not applicable to cutting production for light and moderate to heavy nutrient requiring stock plants. Successful propagation of New Guinea impatiens and scaevola occurred at a 300 $mg \cdot L^{-1}$ N:100 $mg \cdot L^{-1}$ K ratio.

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Table 2.1. Nutrient stock solutions used in this research. The following concentrates were prepared in deionized water and used in making the final nutrient solutions. All stock solutions were stored under cool, dark conditions.

Stock solution	Salt	Concn ($g \cdot L^{-1}$)
A	$MgSO_4 \cdot 7H_2O$	253.0
B	$MgNO_3 \cdot 6H_2O$	200.0
C	$Ca(NO_3)_2 \cdot 4H_2O$	300.0
D	KNO_3	125.0
E	K_2HPO_4	200.0
F	KH_2PO_4	80.0
G	K_2SO_4	100.0
H	NH_4NO_3	170.0
I	$NH_4H_2PO_4$	100.0
J	FeEDTA (Sequestrine)	40.0
	H_3BO_3	28.6
	$MnSO_4 \cdot H_2O$	15.38
K	$ZnSO_4 \cdot 7H_2O$	2.19
	$CuSO_4 \cdot 5H_2O$	0.78
	$(NH_4)_6MoO_2 \cdot 2H_2O$	0.37
L	$CaCl_2$	111.0

Table 2.2. Volume of nutrient stock solutions (in milliliters) (from Table 2.1) added to prepare the final nutrient solutions of 113 L.

	Nutrient Solution Treatments ($mg \cdot L^{-1}$ of N x K)								
Stock solution	100 100	100 200	100 300	200 100	200 200	200 300	300 100	300 200	300 300
A	318	318	318	241	241	241	0	0	0
B	0	0	0	102	102	105	420	420	420
C	250	250	250	311	311	311	311	311	311
D	0	0	0	198	198	198	200	200	200
E	0	0	0	20	20	20	0	0	0
F	0	0	0	0	0	0	41	41	41
G	252	506	759	0	252	506	18	270	522
H	30	30	30	93	93	93	166	166	166
I	61	61	61	36	36	36	36	36	36
J	113	113	113	113	113	113	113	113	113
K	11	11	11	11	11	11	11	11	11
L	79	79	79	0	0	0	0	0	0

Table 2.3. Calculated nutrient concentration of the final nutrient solutions ($mg \cdot L^{-1}$) used for stock plant nutrient fertilization rates.

	Nutrient Solution Treatments ($mg \cdot L^{-1}$ of N x K)								
	100	100	100	200	200	200	300	300	300
Element	100	200	300	100	200	300	100	200	300
NO_3-N	86.1	86.1	86.1	171.8	171.8	171.8	252.4	252.4	252.4
NH_4-N	14.3	14.3	14.3	28.3	28.3	28.3	47.4	47.4	47.4
P	14.5	14.5	14.5	15.0	15.0	15.0	15.2	15.2	15.2
K	99.6	200.1	300.0	100.3	199.9	300.4	100.5	200.2	300.0
Ca	140.0	140.0	140.0	139.5	139.5	139.5	139.5	139.5	139.5
Mg	70.0	70.0	70.0	70.0	70.0	70.0	70.2	70.2	70.2
S	133.0	174.2	215.0	69.8	110.6	151.8	2.9	43.8	84.6
Fe	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
B	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Mn	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Zn	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cu	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mo	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Table 2.4. Elemental concentration of stock plant tissue (12 and 20 weeks after potting) and cutting tissue 4 weeks after sticking (16 and 24 weeks after potting) of 'Grenada' New Guinea impatiens.

Treatment	Element										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B ($mg \cdot kg^{-1}$)	Cu ($mg \cdot kg^{-1}$)	Fe ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)	Zn ($mg \cdot kg^{-1}$)
	Stock plant										
12 WAP	3.59	0.26	2.54	1.29	0.62	0.26	58.7	4.9	69.3	38.0	31.0
20 WAP	3.53	0.29	2.64	1.31	0.50	0.24	57.4	3.6	73.8	33.6	26.0
Significance	NS	***	**	NS	***	***	NS	***	**	***	***
	Cutting										
16 WAP	1.42	0.13	1.39	0.79	0.26	0.20	20.2	5.5	100.6	16.0	42.0
24 WAP	1.64	0.15	1.46	0.82	0.26	0.14	25.9	2.7	95.3	20.2	21.7
Significance	***	***	**	**	NS	NS	***	**	NS	***	**

NS, **, *** Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively.

Table 2.5. Effects of N on the elemental concentration of stock plant tissue of 'Grenada' New Guinea impatiens.

Treatment	Element										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B ($mg \cdot kg^{-1}$)	Cu ($mg \cdot kg^{-1}$)	Fe ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)	Zn ($mg \cdot kg^{-1}$)
100 N	3.19	0.29	2.70	1.25	0.54	0.24	62.3	4.1	66.8	36.2	26.3
200 N	3.65	0.27	2.61	1.30	0.57	0.26	55.4	4.0	74.3	34.0	29.4
300 N	3.84	0.27	2.45	1.36	0.57	0.25	57.0	4.6	73.5	37.3	29.8
LSD	0.15	0.01	0.08	0.07	0.02		2.6	0.5	3.3	2.4	1.9
Significance	***	**	***	**	*	NS	***	*	***	*	***

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

Table 2.6. Elemental concentration of stock plant tissue (11 and 23 weeks after potting) and cutting tissue 4 weeks after sticking (15 and 27 weeks after potting) of 'Purple Fan' scaevola.

Treatment	Element										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B ($mg \cdot kg^{-1}$)	Cu ($mg \cdot kg^{-1}$)	Fe ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)	Zn ($mg \cdot kg^{-1}$)
						Stock plant					
11 WAP	3.38	0.19	2.44	1.98	0.50	0.67	46.2	4.2	61.5	41.9	33.0
23 WAP	4.22	0.22	2.62	1.73	0.45	0.47	47.0	3.4	71.7	31.0	18.7
Significance	***	***	**	***	***	***	NS	**	***	***	***
						Cutting					
15 WAP	1.27	0.08	0.94	0.97	0.23	0.32	21.3	3.7	94.3	21.4	67.3
27 WAP	1.02	0.07	1.27	0.64	0.20	0.24	17.1	6.3	82.2	15.6	41.2
Significance	***	*	***	***	***	***	***	**	***	NS	***

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

Table 2.7. Effects of N on the elemental concentration of stock plant tissue of 'Purple Fan' scaevola.

Treatment	Element										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B ($mg \cdot kg^{-1}$)	Cu ($mg \cdot kg^{-1}$)	Fe ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)	Zn ($mg \cdot kg^{-1}$)
100 N	3.23	0.22	2.59	2.10	0.44	0.69	47.0	3.2	64.9	40.4	29.3
200 N	3.74	0.20	2.53	1.81	0.48	0.64	46.5	4.2	67.2	36.5	25.2
300 N	4.42	0.20	2.47	1.67	0.51	0.37	46.3	4.0	67.8	32.7	23.2
LSD	0.19	0.01		0.07	0.03	0.04		0.6		3.7	3.0
Significance	***	***	NS	***	***	***	NS	**	NS	***	***

NS, **, *** Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively.

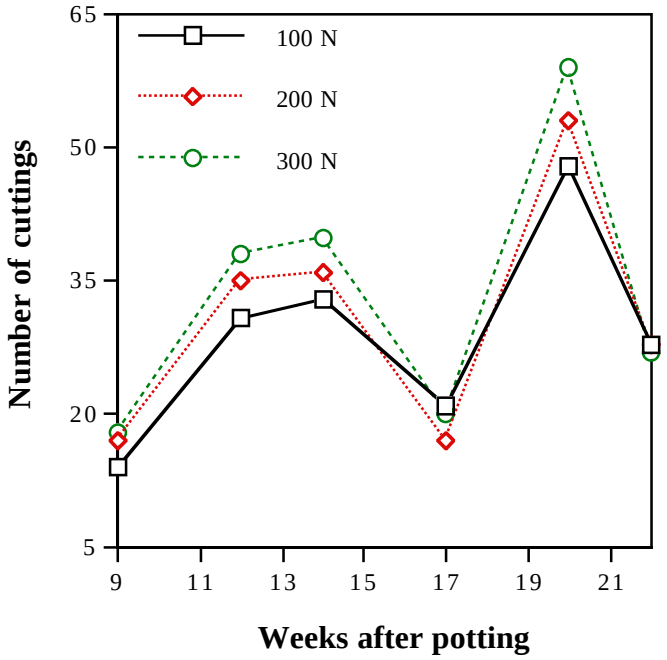


Fig. 2.1. Effect of N concentration on yield of stem cuttings over time of stock plants of 'Grenada' New Guinea impatiens. Each symbol is the mean of 18 stock plants.

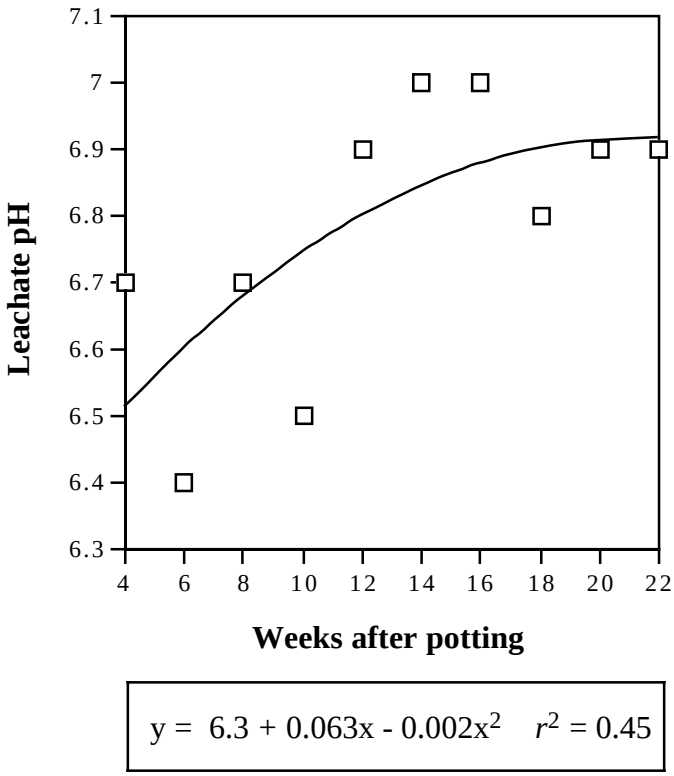


Fig. 2.2. Leachate pH by weeks after potting (WAP) of stock plants of 'Grenada' New Guinea impatiens. Regression line was generated from means of the treatments, and symbols are means of the treatments (n=27). *** Significant at the $P \leq 0.001$; L = linear, Q = quadratic. L*** Q***.

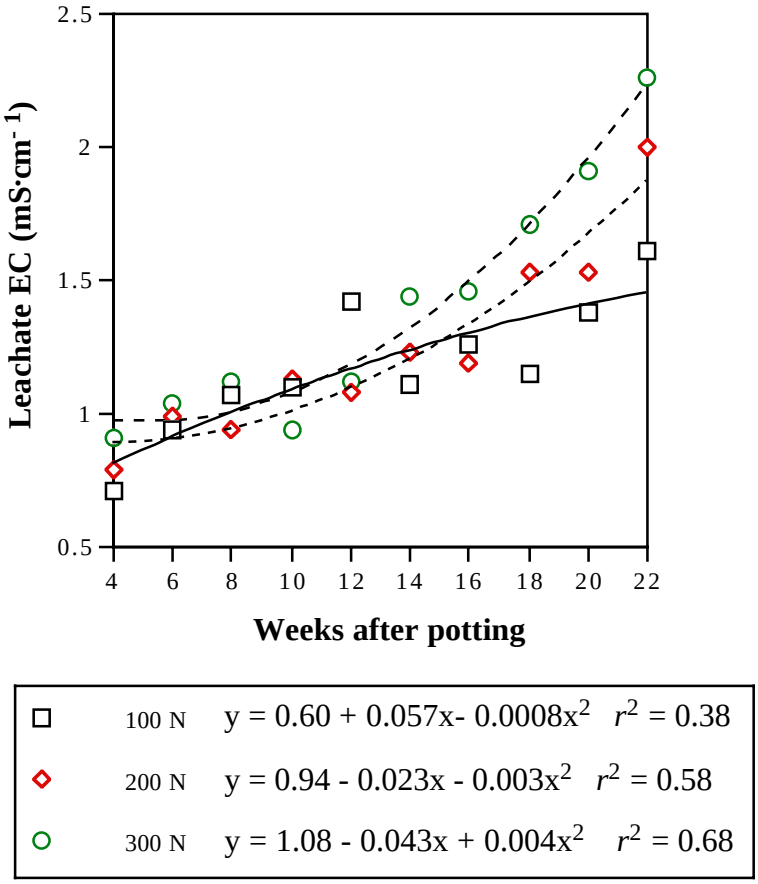


Fig. 2.3. Effect of N concentration on leachate EC over time of stock plants of 'Grenada' New Guinea impatiens. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *** Significant at $P \leq 0.001$; L = linear, Q = quadratic. N at 100 mg·L^{-1}: L*** Q***; N at 200 mg·L^{-1}: L*** Q***; N at 300 mg·L^{-1}: L*** Q***.

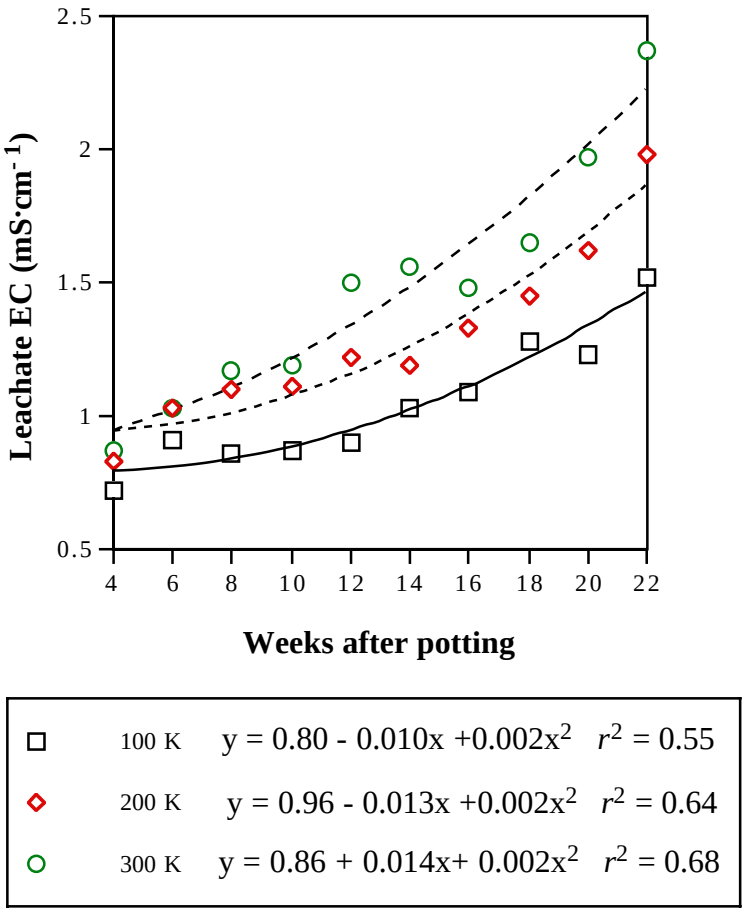


Fig. 2.4. Effect of K concentration on leachate EC over time of stock plants of 'Grenada' New Guinea impatiens. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *** Significant at $P \leq 0.001$; L = linear, Q = quadratic. K at 100 mg·L^{-1}: L*** Q***; K at 200 mg·L^{-1}: L*** Q***; K at 300 mg·L^{-1}: L*** Q***.

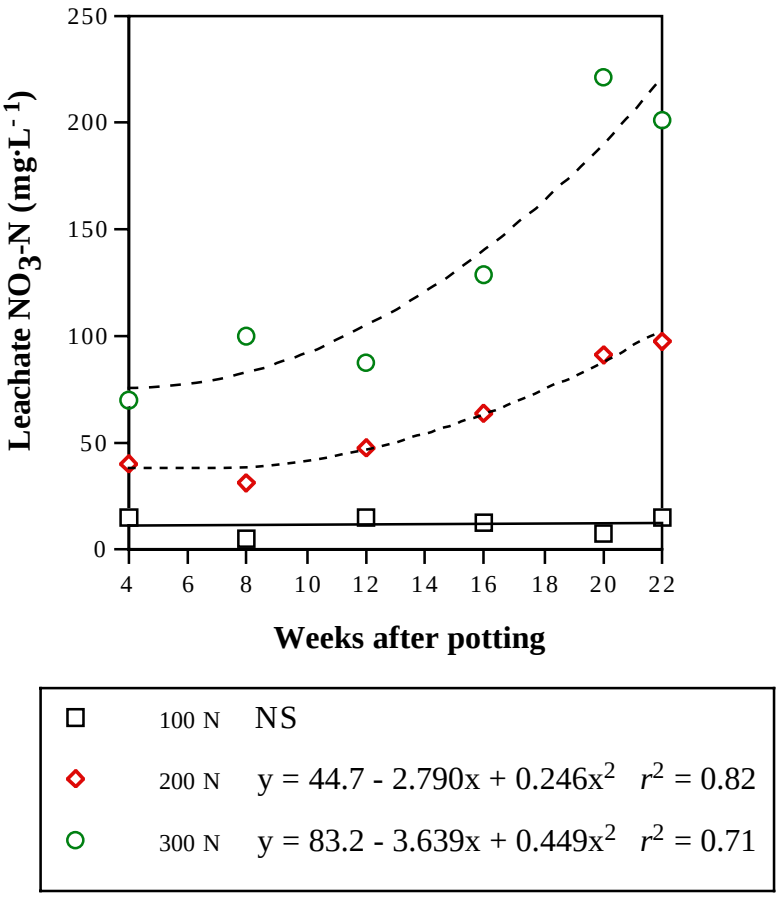


Fig. 2.5. Effect of N concentration on leachate nitrate nitrogen (NO_3-N) over time of stock plants of 'Grenada' New Guinea impatiens. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). NS, *** Nonsignificant or significant at $P \leq 0.001$, respectively; L = linear, Q = quadratic. N at 100 mg·L^{-1}: L^{NS} Q^{NS}; N at 200 mg·L^{-1}: L*** Q***; N at 300 mg·L^{-1}: L*** Q***.

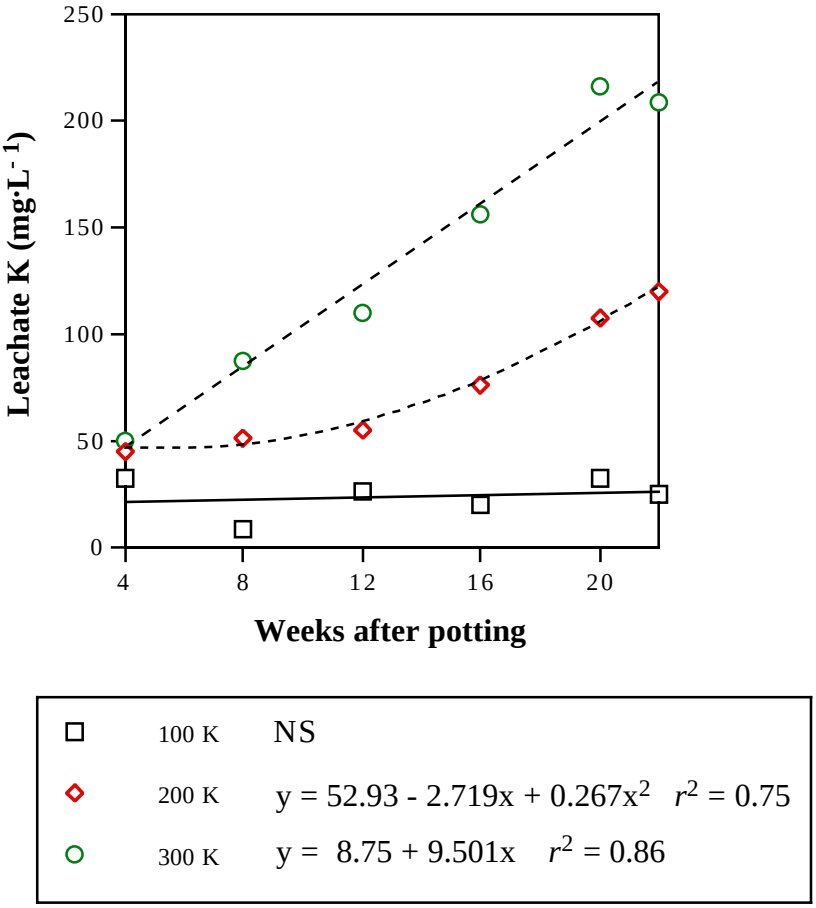


Fig. 2.6. Effect of K concentration on leachate K over time of stock plants of 'Grenada' New Guinea impatiens. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). NS, *** Nonsignificant or significant at $P \leq 0.001$, respectively; L = linear, Q = quadratic. K at 100 $mg \cdot L^{-1}$: L^{NS} Q^{NS}; K at 200 $mg \cdot L^{-1}$: L*** Q***; K at 300 $mg \cdot L^{-1}$: L*** Q***.

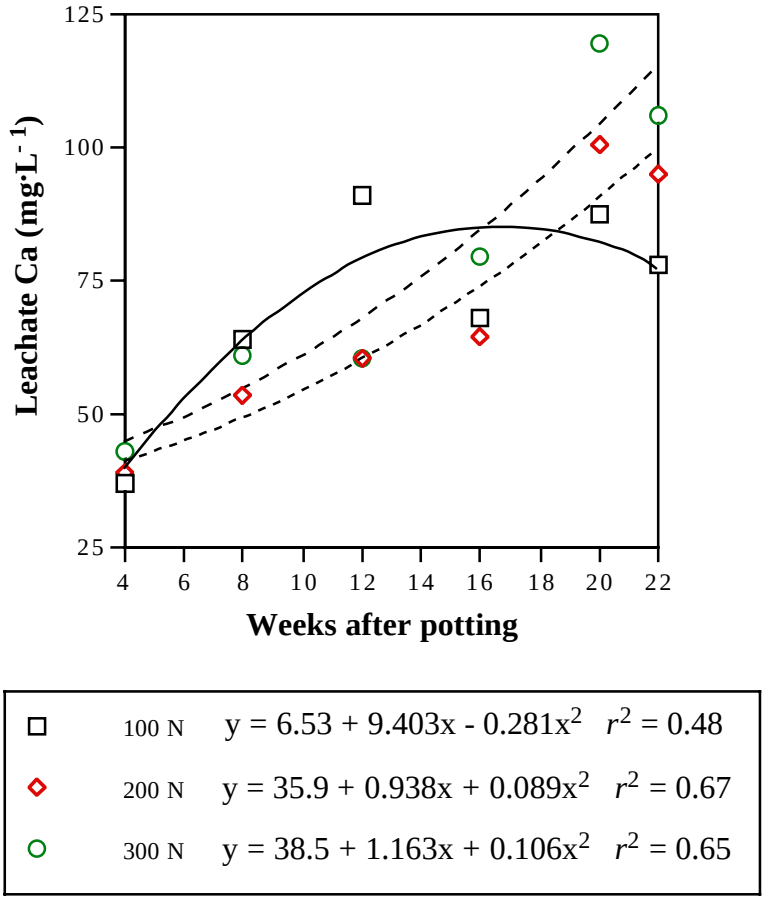


Fig. 2.7. Effect of N concentration on leachate Ca over time of stock plants of 'Grenada' New Guinea impatiens. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *** Significant at $P \leq 0.001$; L = linear, Q = quadratic. N at 100 mg·L^{-1}: L*** Q***; N at 200 mg·L^{-1}: L*** Q***; N at 300 mg·L^{-1}: L*** Q***.

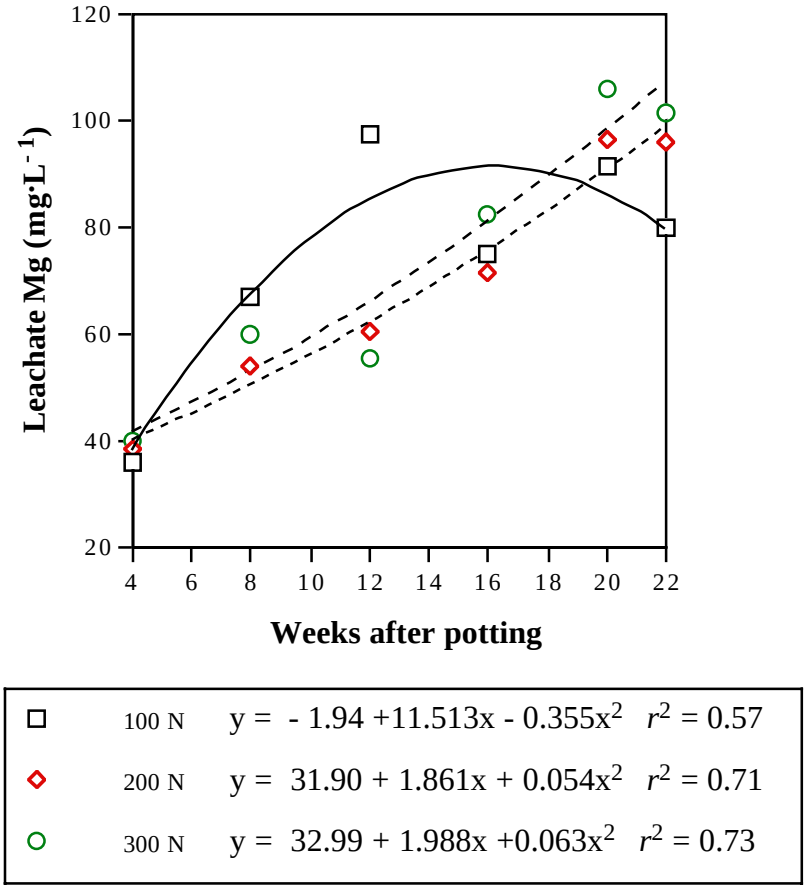
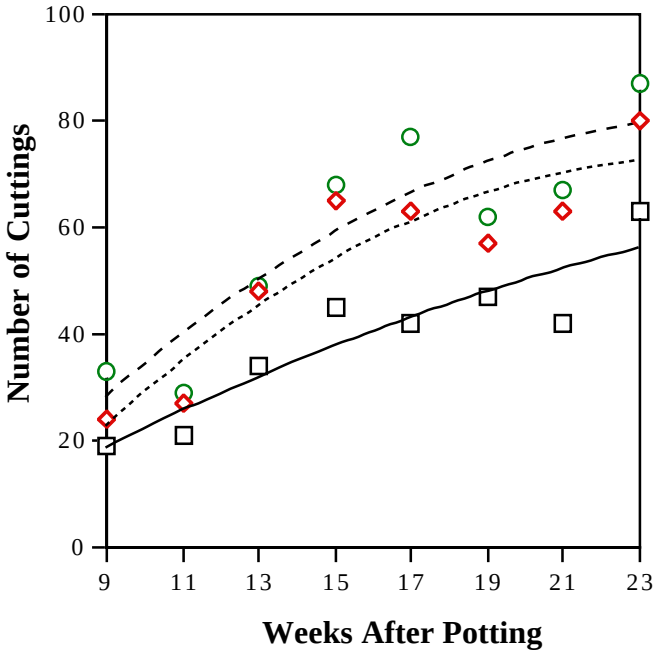


Fig. 2.8. Effect of N concentration on leachate Mg over time of stock plants of 'Grenada' New Guinea impatiens. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *** Significant at $P \leq 0.001$; L = linear, Q = quadratic. N at 100 mg·L^{-1}: L*** Q***; N at 200 mg·L^{-1}: L*** Q***; N at 300 mg·L^{-1}: L*** Q***.



□	100 N	y = - 18.01 + 4.620x - 0.061x^2	r^2 = 0.54
◇	200 N	y = - 48.83 + 9.765x - 0.195x^2	r^2 = 0.55
○	300 N	y = - 43.51 + 9.614x - 0.185x^2	r^2 = 0.56

Fig. 2.9. Effect of N concentration on yield of stem cuttings over time of stock plants of 'Purple Fan' scaevola. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=18). *** Significant at the $P \leq 0.001$; L = linear, Q = quadratic. N at 100 mg·L^{-1}: L*** Q***; N at 200 mg·L^{-1}: L*** Q***; N at 300 mg·L^{-1}: L*** Q***.

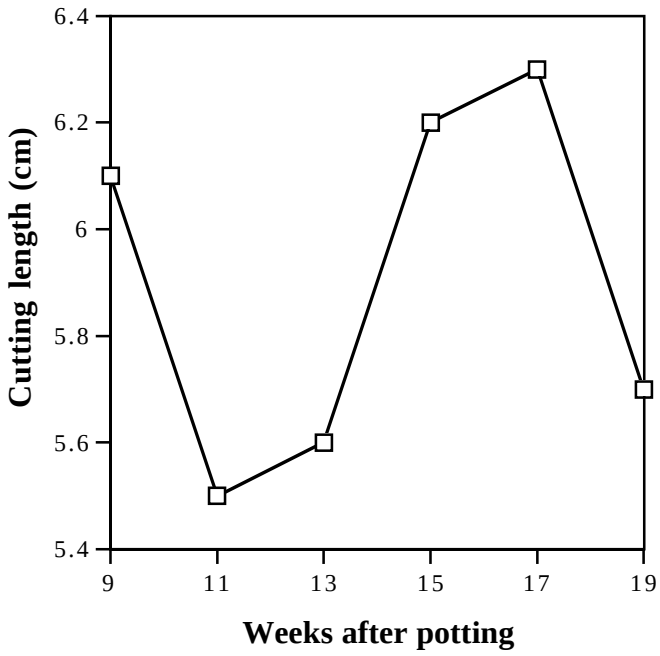


Fig. 2.10. Stem length over time of cuttings of ‘Purple Fan’ scaevola. Each symbol is the mean of 54 stem cuttings.

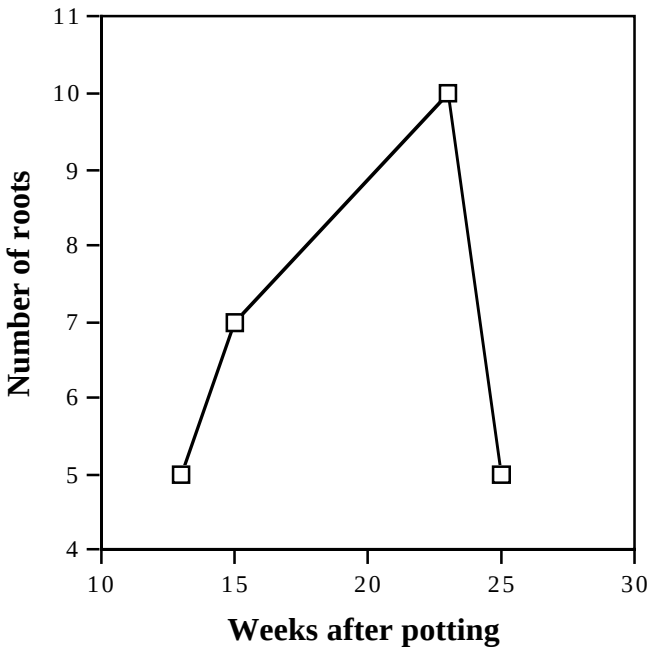


Fig. 2.11. Number of adventitious roots over time of stem cuttings of 'Purple Fan' scaevola. Each symbol is the mean of 54 stem cuttings.

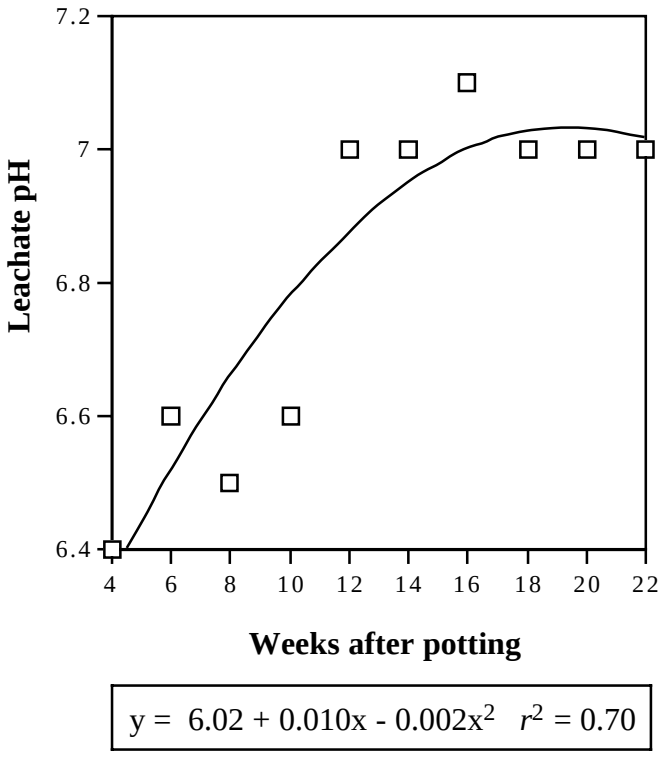


Fig. 2.12. Leachate pH by weeks after potting (WAP) of stock plants of 'Purple Fan' scaevola. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=27). *** Significant at $P \leq 0.001$; L = linear, Q = quadratic. L*** Q***.

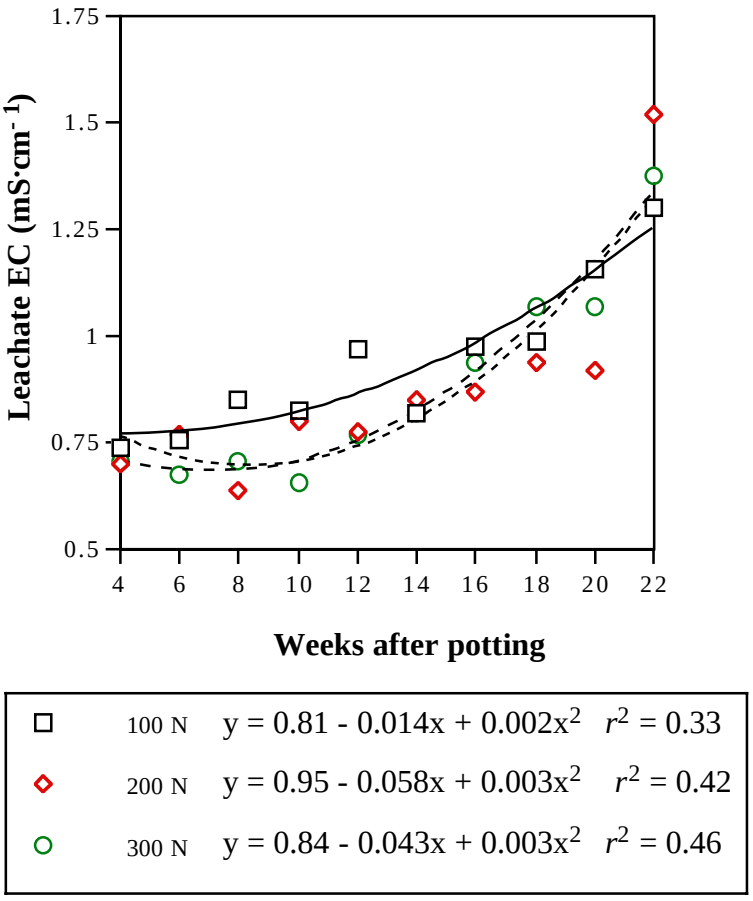


Fig. 2.13. Effect of N concentration on leachate EC over time of stock plants of 'Purple Fan' scaevola. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *** Significant at $P \leq 0.001$; L = linear, Q = quadratic. N at 100 mg·L^{-1}: L*** Q***; N at 200 mg·L^{-1}: L*** Q***; N at 300 mg·L^{-1}: L*** Q***.

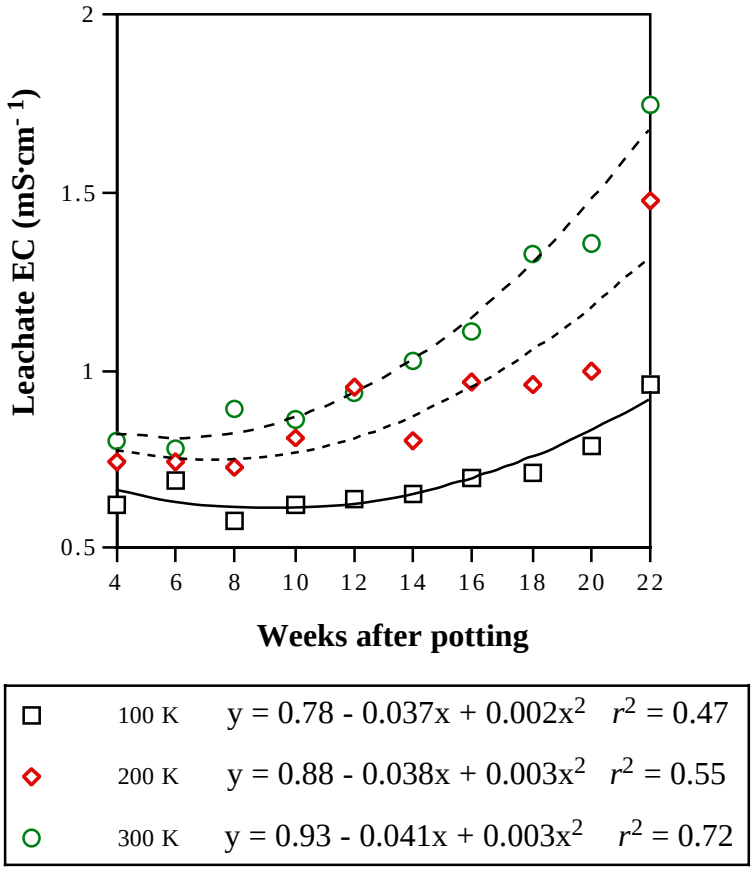


Fig. 2.14. Effect of K concentration on leachate EC over time of stock plants of 'Purple Fan' scaevola. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *** Significant at $P \leq 0.001$; L = linear, Q = quadratic. K at 100 mg·L^{-1}: L*** Q***; K at 200 mg·L^{-1}: L*** Q***; K at 300 mg·L^{-1}: L*** Q***.

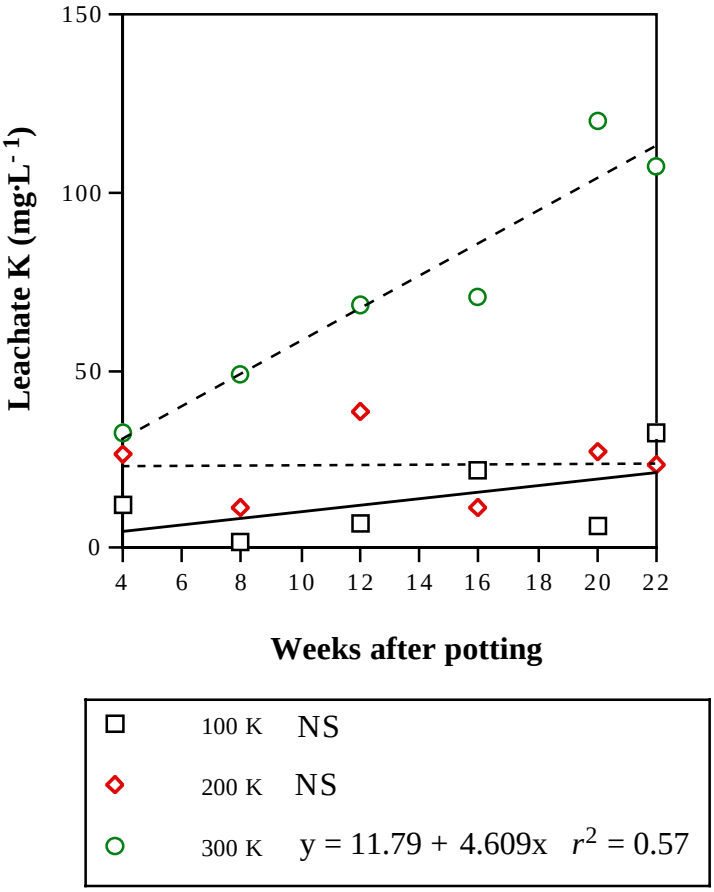


Fig. 2.15. Effect of K concentration on leachate K over time of stock plants of 'Purple Fan' scaevola. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). NS,*** Nonsignificant or significant at $P \leq 0.001$, respectively. L = linear, Q = quadratic. K at 100 mg·L^{-1}: L^{NS} Q^{NS}; K at 200 mg·L^{-1}: L^{NS} Q^{NS}; K at 300 mg·L^{-1}: L*** Q***.

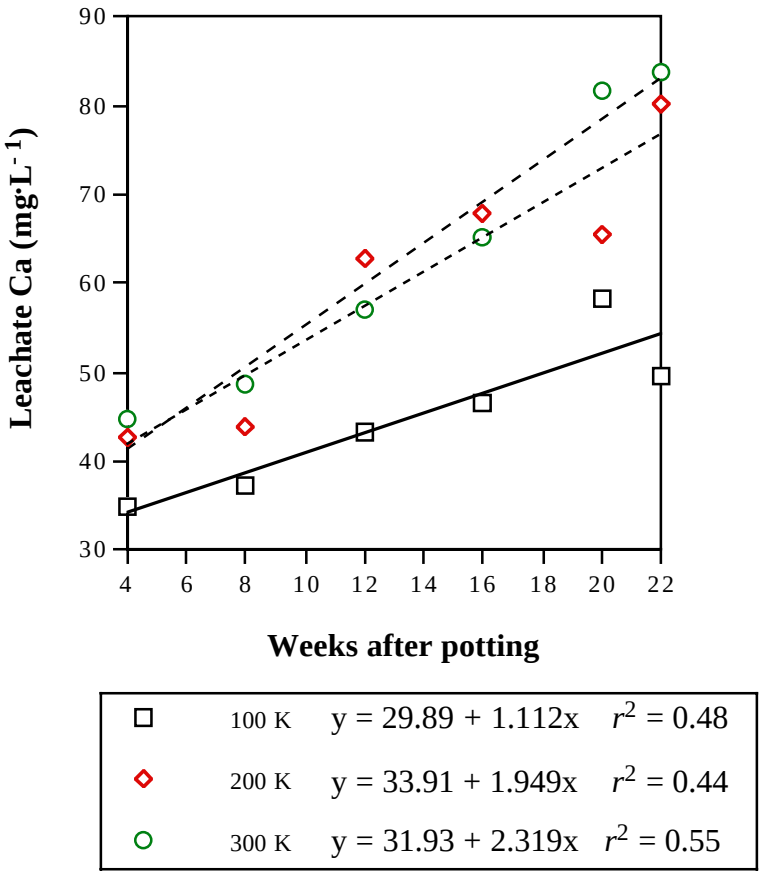


Fig. 2.16. Effect of K concentration on leachate Ca over time of stock plants of 'Purple Fan' scaevola. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *** Significant at $P \leq 0.001$; L = linear, Q = quadratic. K at 100 mg·L^{-1}: L*** Q***; K at 200 mg·L^{-1}: L*** Q***; K at 300 mg·L^{-1}: L*** Q***.

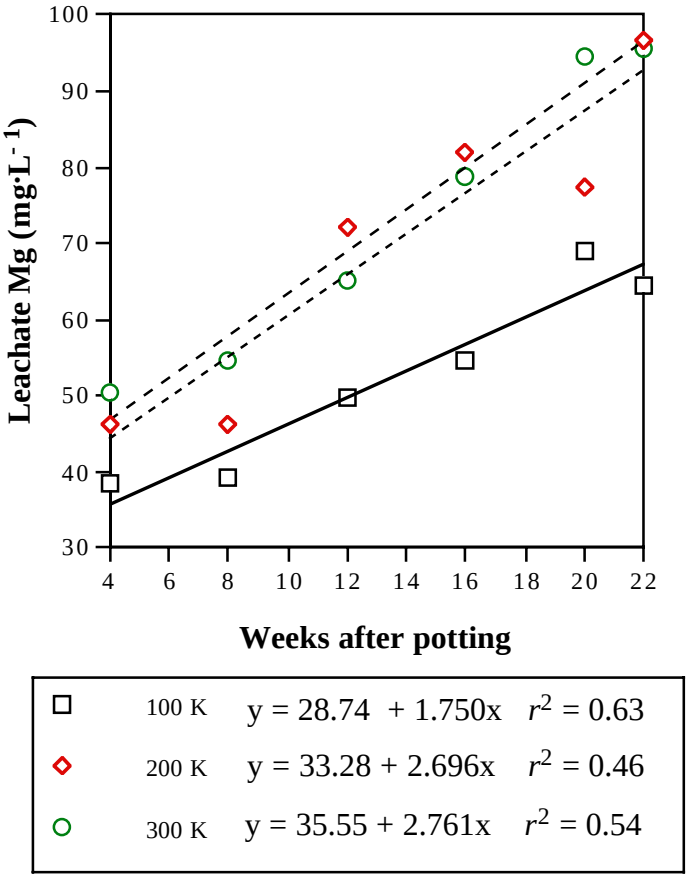


Fig. 2.17. Effect of K concentration on leachate Mg over time of stock plants of 'Purple Fan' scaevola. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *** Significant at the $P \leq 0.001$; L = linear, Q = quadratic. K at 100 mg·L^{-1}: L*** Q***; K at 200 mg·L^{-1}: L*** Q***; K at 300 mg·L^{-1}: L*** Q***.

Chapter 3

FOLIAR SYMPTOMOLOGY AND TISSUE CONCENTRATIONS OF NUTRIENT DEFICIENT PLANTS OF VEGETATIVE STRAWFLOWER

(in the format appropriate for submission to Journal of Plant Nutrition)

FOLIAR SYMPTOMOLOGY AND TISSUE CONCENTRATIONS OF NUTRIENT DEFICIENT PLANTS OF VEGETATIVE STRAWFLOWER

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ABSTRACT

Elemental deficiencies of N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, or B were induced in plants of 'Florabella Pink' strawflower [*Bracteantha bracteata* (Vent.) A.A. Anderberg]. Rooted stem cuttings were planted in 4.87 L plastic containers and fertilized with a complete modified Hoagland's solution or this solution minus the element that was to be investigated. Plants were harvested for tissue analyses as well as dry weights when initial foliar symptoms were expressed and later under advanced deficiency symptoms. Deficiency symptoms for all treatments were observed within 7 weeks. The most dramatic expression of foliar symptoms occurred with N (chlorotic lower foliage leading to necrotic margins on the mature leaves), Ca (black necrotic spots on the tips of the

young leaves), S (uniform chlorosis of young leaves and recently mature leaves), B (thick, leathery, and deformed young leaves), Fe (uniform yellowish-green chlorosis on the young leaves), and Zn (brownish-gray necrosis on the tips of the mature leaves). At the initial stage, only Fe-deficient plants weighed less than the control, whereas K, Ca, and Mg-deficient plants had greater dry weights than the control. Dry weights of plants treated with solutions not containing N, P, Ca, S, Cu, or Mn were significantly lower when compared to the control under an advanced deficiency. Foliar tissue concentration data will assist plant tissue analysis laboratories in establishing foliar symptom standards for growers.

INTRODUCTION

The vegetatively-propagated strawflower [*Bracteantha bracteata* (Vent.) A.A. Anderberg] is native to eastern Australia (Sharman and Sedgley, 1988) and is related to the seed-propagated strawflower [*Helichrysum bracteatum* (Vent.) Andr.] which is indigenous to South Africa and New Guinea (Morley, 1978). These plants are known for their rigid, papery, colorful bracts, making the plants excellent cut flowers and bedding plants. Plants perform best in dry, low P containing soils, because their native terrestrial habitat is scrub and open rangeland with sandy and gravelly soils.

Strawflower is an important crop for greenhouse growers that wish to market a durable plant for U.S. landscapes because it can withstand light frosts and survive extreme heat and humidity (Proven Winners, 2003). Strawflower performs best in well-aerated substrates at pH 5.5 to 6.3 that contain low amounts of P (Paul Ecke Ranch, 2003). Fertilizer recommendations suggest N at 200 to 250 $mg \cdot L^{-1}$ supplied by rotating

20N-4.4P-16.6K with 15N-0P-12.5K continually until anthesis (Ball FloraPlant, 2003). Nutrient deficiencies can occur during production, the symptoms of which have been reported as chlorosis of the young leaves (iron deficiency), lower leaf yellowing (N or Mg deficiency), and discolored foliage (P toxicity) (Paul Ecke Ranch, 2003). Fertility monitoring and management for vegetative strawflower require a balancing of the plant's requirements. Growers must monitor and manage the root substrate pH and electrical conductivity (EC) and provide adequate, but not excessive, levels of essential elements. Nutrient deficiency descriptions are unavailable for vegetative strawflower, yet growers must often make quick diagnoses.

Therefore, the following research was conducted to generate visual symptoms of nutrient deficiencies in the chronological order in which they appear from incipient to advanced stages, and to establish foliar analysis standards by correlating nutrient levels with initial and advanced stages of deficiencies for N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, and B in plants of vegetative strawflower.

MATERIALS AND METHODS

Unrooted stem cuttings of strawflower 'Florabella Pink' were inserted in Oasis LC1 foam cubes (Smithers Oasis, Kent, Ohio) containing only Ca and Mg from dolimitic limestone on 21 Dec. 2001. The experiment was conducted in a glass greenhouse in Raleigh, N.C. at 35°N latitude that was set at night/cloudy day/clear day temperatures of 17/21/24 °C. During the establishment phase, cuttings were fertilized at each irrigation with the following mM concentrations of 0.35 NH_4, 5.15 NO_3, 0.35 PO_4, 1.0 K, 1.25 Ca, 1.0 Mg, and 36 μM Fe using the following reagent grade chemicals NH_4NO_3, KNO_3,

K_2HPO_4, $Ca(NO_3)_2 \cdot 4H_2O$, $MgSO_4 \cdot 7H_2O$, and FeDTPA (Pitchay, 2002). Cuttings were grown with this nutrient regime until roots were visible at the edges of the rooting cube.

Cuttings were pinched on 8 Jan. 2002 by removing 2 cm of growth from the terminal tip. After establishment, plants were transplanted on 24 Jan. into 4.87-L aluminum painted plastic tubs with six circular holes in the lids. Six replications, each consisting of one tub with six rooted cuttings, were assigned to 12 treatments. To provide sufficient plant biomass for foliar analysis, plants were grown initially with a complete modified Hoagland's all nitrate solution: (macronutrients in mM) 15 NO_3-N, 1.0 PO_4-P, 6.0 K, 5.0 Ca, 2.0 Mg, and 2.0 SO_4-S (Hoagland and Arnon, 1950), plus μM concentrations of micronutrients, 72 Fe, 9.0 Mn, 1.5 Cu, 1.5 Zn, 45.0 B, and 0.1 Mo. On 1 Feb., three treatments were induced that included a complete nutrient formula and complete minus one of the nutrients S, Cu, and Zn. Because deficiency symptoms of N, P, K, Ca, Mg, Fe, Mn and B typically develop more quickly, than S, Cu, and Zn (Pitchay, 2002), the introduction of these treatments were delayed until 7 Feb in order to have sufficient biomass for tissue sampling. Reagent grade chemicals and deionized water of 18-mega ohms purity was used to formulate treatment solutions. Tubs were inspected daily and deionized water was added as needed to maintain the nutrient solution volume for two weeks, and in subsequent weeks tubs were topped with nutrient solution as needed. A complete replacement of nutrient solutions was done weekly.

Plants were monitored daily to document and photograph sequential series of symptoms on youngest, young, recently mature, and mature leaves as they developed. The youngest leaves represented tissue 1 cm from the shoot tip measuring 0.5 to 2.0 cm in length, while young leaves were 2.0 to 7.0 cm long, recently mature were 7.0 to 15.0

cm, and mature leaves were ≥ 15.0 cm in length. When the first visible symptoms occurred, the recently mature leaves were sampled from three replications of deficiency treatment and the control treatment to establish incipient deficiency tissue levels. When symptoms progressed to an advanced level, another set of recently mature leaves were sampled from the remaining three replications of the deficiency treatment and the control treatment to establish tissue concentrations associated with advanced deficiency. The tissue samples were first rinsed in deionized water, then washed in 0.2 N HCl for 30 s, and dried at 70 °C for 24 h. Dried tissue was ground in a stainless steel Wiley mill to pass 1 mm screen (20-mesh). Tissue was then analyzed for macro and micronutrients with the exceptions of N, using a Perkin Elmer 3300 Inductively Coupled Argon Plasma Emission Spectrophotometer (Perkin Elmer, Shelton, Conn.), while N was analyzed using Carlo Erba NA 1500 Series 1, O_2 combustion Nitrogen Analyzer (Carlo Erba, Lakewood, N.J.) at the N.C. Dept of Agric Laboratory, Raleigh.

The experiment was a randomized complete-block design with 6 blocks. Each block consisted of four plastic tubs of control treatment and one plastic tub of each deficient treatment (each tub was an experimental unit). All the data were subjected to ANOVA using PROC GLM SAS program (SAS Inst., Cary, N.C.). Where the F test indicated evidence of significant difference among the means, LSD ($P \leq 0.05$) was used to establish differences between means.

RESULTS AND DISCUSSION

Following are the progressions of visual deficiency symptoms for each nutrient. The number of days to each symptom refers to time from the start of deficiency

treatments (Fig. 3.1). Initial and advanced shoot dry weight comparisons to the control are indicated in Fig. 3.2. Corresponding tissue concentrations at incipient and late stages are found in Table 3.1.

Nitrogen

On day seven, the young and youngest leaves were lighter and paler green than the control, with the mature leaves equal in color to young leaves. At this point, the incipient foliar N concentration of the most recently mature leaves was 3.19%, as compared to 6.33% for the control. Recently mature leaves were narrower, sword-like and had a more upright leaf architecture than the control plants. On day 11, the oldest set of leaves were yellow along the margins and leaf tips, which quickly progressed to a complete light yellow with small green patches towards the tip, whitish-yellow leaf bases, and white midveins. By day 15, N-deficient plants were approximately 25% smaller than control plants. The young and youngest leaves were yellowish-green. On young leaves, margins rolled under giving the leaves a sword-like appearance. Plants felt stiff and rigid with an overall upright architecture. Oldest leaves expressed a basipetal necrosis.

On day 20, mature leaves expressed a whitish-yellow veination across the entire lamina. Mature leaves were pale yellow. Some of the tannish-brown oldest leaves were completely shriveled and subsequently abscised. The oldest set of leaves had small random clusters of black necrotic spots and random greenish-yellow patches. Young and youngest leaves were a deeper green color than recently mature and mature leaves. Axillary development was restricted on N deficient plants. The foliar N concentration was 1.76%, as compared to 5.51% for the control.

Phosphorus

Phosphorus deficiency was initially observed 9 d after treatments were induced as pale-green plants that were similar in size to the control. The foliar P concentration was 0.26%, as compared to 0.82% for the control. By day 12, the youngest, young, and recently mature leaves were darker green than the lower mature foliage. The young and recently mature leaves were narrower and had an elongated appearance compared to leaves on the control plants (day 15). The oldest set of leaves had also developed necrosis. On day 17, the recently mature and mature leaves were a deep dull green, while the youngest and young leaves were light green. Recently mature leaf tips were twisted slightly with marginal rolling initiating approximately 1 cm back from the tip. By day 19, the rolled margin was greenish-yellow and chlorosis began to move toward the midvein.

On day 22, roots were stringy and hair-like, with a denser root system, and greater length than the control. By day 24, the youngest and young leaves had a similar dark green color and the youngest leaves were narrower than the control leaves. Mature leaf tips were pointed and turned downward and appeared twisted to one side (day 26). At this time roots had become reddish-brown and were at least 50% longer than the control. Mature leaf tip necrosis had increased, and many of the P deficient plants had light greenish-brown mature leaves. These leaves had a variety of necrotic spots from very small clusters of brown peppered specks to dense clusters of small brown and black spots. Random patches of brown to black spots to large, dark greenish-brown or brownish-black, patchy rings and spots were also observed. In the center of some of the rings, a translucent light brown papery necrosis appeared. Some recently mature leaves

also expressed this patchy necrosis, but most of the recently mature leaves were greenish-yellow.

On day 32 the oldest mature leaves became brittle and withered as the necrosis progressed. By day 34, purplish spots appeared on the adaxial surface of the recently mature leaves, while the lower mature foliage remained pale green. A brownish-black necrosis progressed basipetally. The midvein of the affected leaf was necrotic from the leaf tip to the midpoint of the blade. Affected leaves eventually shriveled and abscised. By day 39, mature leaves that had previously expressed purpling had dark green circles (approximately 3 to 7 mm in diameter) that ultimately developed a grayish-brown necrosis. At this point, the foliar P concentration was 0.07%, as compared to 0.76% for the control.

Potassium

Initial deficiency symptoms appeared 13 d after treatments were initiated with foliar K concentrations at 1.08%, as compared to 6.04% for the control. Faint, random, and irregular chlorotic patches developed close to the midvein on the mature leaves while young leaves were darker green than the mature leaves, as compared to the control. By day 15, recently mature leaves expressed a distinct interveinal chlorosis. Two days later potassium-deficient plants were darker green with a bluish-green or gray cast when compared to the control. The margins of recently mature leaves and some young leaves began to fold down at the margins, and had a glossy lamina.

On day 19, mature leaves had interveinally chlorotic light green tips. Mature leaves also developed small brown to tan necrotic spots on the leaf tips that followed the

margin and progressed basipetally. On day 20, the interveinal chlorosis on the margins intensified as yellowing and plants appeared to be less turgid than the control. The interveinal chlorosis expressed a bronze color, and the tips and margins developed a tan and papery necrosis (day 22). There was also withering of oldest mature leaves.

On day 24, the oldest leaves had a marginal chlorosis that moved inwards towards a stiff and dark green midvein. The necrotic regions were blackish-brown to papery tan in color with green splotches and spots in the pale brown chlorotic regions. The young leaves expressed a greenish-yellow interveinal chlorosis, and a translucent greenish-gray tissue formed before necrosis on the recently mature leaves. Potassium-deficient plants were shinier and glossy than the controls. Some young and recently mature leaves began to twist and spiral 29 days after treatments were induced. On day 32 plants were stunted and compact, spongy, and rubbery with a foliar K concentration of 0.77%, as compared to 6.74% for the control.

Calcium

Initial deficiency symptoms appeared 9 d after treatments were initiated with a foliar Ca concentration of 0.29%, as compared to 1.46% for the control. There was a dullish gray-green cast on the upper leaves. Roots were reddish-brown in color with stunted root tips. Lateral roots were also shorter and more bristle-like in appearance. By day 11, small irregular blackish-brown spots developed acropetally on the margins and in the interior of the young and youngest leaves. The overall color of calcium deficient plants was pale green with the mature leaves having a dark green color. On day 12 young leaves developed a spoon-like appearance with narrow petioles and wide leaf blades. In

the middle of the young leaves, small, brownish-tan necrotic spots fused together to form irregular patches. Mature and recently mature leaves were darker green than the control. More root tips were blackened on the calcium deficient roots compared to the controls. Lateral root growth appeared thicker and shorter, when compared to the control.

On day 13, the youngest leaves had margins that rolled inward and this rolling developed acropetally from the lower one third of the leaf. The youngest leaves expressed chlorosis in the shoot tip region. The necrotic blackish-brown spotting merged together to cause a collapse of the young and youngest leaves by day 15. Spotting followed the midvein and eventually progressed to the secondary veins. Mature leaves also developed necrotic spotting. By day 17, the young and youngest leaves lost turgor. The young leaves twisted upside down where the midrib collapsed (approximately 2.5 cm from the leaf base). By day 20, approximately 95% of the young and youngest leaves were completely withered with a dark blackish-brown necrosis. Flowers were stunted and reflexed ray petals ceased to expand further. The foliar Ca concentration was 0.24%, as compared to 1.42% for the control.

Magnesium

Early deficiency symptoms appeared 8 d after treatments were initiated with the foliar Mg concentration at 0.12%, as compared to 0.21% for the control. A faint interveinal chlorosis developed on the recently mature leaves. Tissue that spanned 0.5 cm from the midvein remained dark green. Secondary dark green veins were equal in color to the midvein. On day 9, the interveinal chlorosis further developed as chlorotic patches closest to the midvein developed basipetally. The chlorosis gave the entire plant

a greenish-yellow cast. By day 11, the interveinal chlorosis appeared on the mature leaves. Mature leaves expressed a 0.5 cm wide greenish-yellow chlorosis on the tip and margins. Mature and recently mature leaves expressed undulating margins 12 d after treatments were induced while narrow young leaves had a sword-like appearance. A thin band of tannish-brown necrotic tissue developed on the recently mature leaf margins (day 13). By day 15, mature leaves had small, dark and brownish-black necrotic spotting on the margins that progressed basipetally to one quarter of the leaf. Recently mature leaves had greenish-yellow interveinal chlorosis, while the young and youngest leaves were light green with a moderate interveinal chlorosis.

By day 17, mature chlorotic leaves with marginal necrosis were cupped downwards. Approximately 0.25 cm of the tips on mature leaves were brown and leathery. There was some bronzing on the downward rolled margins. Tips of mature leaves, 1.5 cm from tip, were bent upward. The oldest set of leaves showed no necrosis, but expressed a faint interveinal chlorosis. On day 20, the older mature leaves had dark brownish-black margins and dark green midveins, while the young and youngest leaves were medium green. Older mature leaves were convex. At this point, the foliar Mg concentration was 0.06%, as compared to 0.29% for the control.

Sulfur

Incipient deficiency symptoms appeared 13 d after treatments were initiated with a foliar S concentration at 0.09% compared to 0.21% for the control. Recently mature leaves expressed lighter green bases compared to the control plants. By day 15, a chlorotic shoot tip was observed by a well-defined bright green color on young leaves,

when compared to control plants. Young leaves were more upright while recently mature leaves were narrower and had darker green leaf tips than the control. On day 17, the oldest mature leaves were darker green, while recently mature leaves developed a pale greenish-yellow color. Foliage was more rigid with sulfur deficient plants. Roots had a darker brownish-red color when compared to the control. Roots appeared thinner and stringier at the root tip region of primary roots with less lateral root growth than control plants.

By day 18, axillary shoots were uniformly yellow-green. Sulfur-deficient plants had a paler color than control plants with olive green mature leaves and pale olive-green recently mature leaves. The young and youngest leaves had curled and wavy leaf margins. By day 23, the young and youngest leaves were lime green, while recently mature leaves remained darker green with faint light green chlorotic patches. Young leaves had bent tips that began to spiral. On day 28, roots were thinner, but were 30 to 35% denser than the control. The root system was approximately 40% longer than the root system of the control. Recently mature leaves developed a sword-like appearance as the margins curled under. By day 40, the lowest set of mature leaves turned yellow on one side of the midvein which progressed to the other side while the leaf tips turned necrotic. Some old leaves were uniformly light yellow color, while others expressed random green and yellow patches. By day 45, the foliar S concentration was 0.05%, as compared to 0.21% for the control.

Boron

Incipient deficiency symptoms appeared 5 d after treatments were initiated with the foliar B concentration at 17.1 $mg \cdot kg^{-1}$, as compared to 28.5 $mg \cdot kg^{-1}$ for the control. Boron deficient plants had an overall spongy texture with deeper green recently mature leaves than the control. There was a loss of dominance in the growing point, youngest leaves became narrow and the young leaf margins smooth. Young leaves also had a dull green basipetal chlorosis. On day 11 boron deficient plants were compact with dark green leaves. The shoot tip had aborted. The base of the midvein of young leaves had a chalky-brown necrosis and chlorosis progressed acropetally. Outer margins on recently mature leaves curled downward while mature leaves drooped downward. Roots were blackish-brown with blackened tips. Primary and secondary roots were thicker and stubbier than the control.

On day 12, the young leaves began to wither. On the young and youngest leaves, a brown necrosis was expressed on the basipetal one third of the midvein. By day 13, recently mature and mature leaves became thick and leathery. These leaves expressed a pale green to white chlorotic interior and a reddish-brown margin. Youngest leaves were twisted, narrow and distorted, especially at the leaf tip. The young leaves were devoid of green color with brown to blackish streaks along the midrib. At this point the foliar B concentration was 5.6 $mg \cdot kg^{-1}$, as compared to 31.2 $mg \cdot kg^{-1}$ for the control.

Copper

Incipient deficiency symptoms appeared 15 d after treatments were initiated with the foliar Cu concentration at 2.9 $mg \cdot kg^{-1}$, as compared to 6.8 $mg \cdot kg^{-1}$ for the control.

There was a loss in sheen and a dull green cast over the plant. Young and youngest leaves were chlorotic and curled which spiraled around themselves. There was a basipetal chlorosis on the recently mature leaves. Young leaves and recently mature leaves were slightly narrower than the control. While there was no color difference between Cu-deficient and control roots, Cu-deficient plants had herring bone-like, short lateral roots.

By day 17, roots were reddish, rusty-brown when compared to the light beige control roots. The young leaves developed a greenish-yellow interveinal chlorosis with a net-like appearance (day 18). On day 28 the youngest, young and recently mature leaves had the appearance of dark veinal netting. On the central-most portion of the young and recently mature leaves, following the midvein, was a greenish-yellow chlorosis. On day 30, the young leaves were narrower and lighter green than the control leaves. The veinal netting became more clearly visible in the basal region of the young and recently mature leaves.

By day 35, some mature and recently mature leaf margins and tips were dark green and withered. The young and youngest leaves had brown leaf tips that were dry and brittle. Some recently mature and mature leaves had black necrotic spotting on the basal region which progressed acropetally along the outside of the midvein and margin. By day 38, there was an increase in necrotic spotting on the basal region of the leaf midvein. The root system was approximately 20 to 30% less dense than the control. Some recently mature and mature leaves possessed brownish-gray necrotic spots at the stem and the petiole junction. Two days later the young axillary leaves shriveled because of advanced necrosis on the petiole and leaf base. The mature leaves had blackish-brown

necrotic spots that fused together, while the petiole and leaf base became narrow and thinner. The necrotic spots were slightly sunken and developed a grayish-black coloration. Interveinal regions had some papery brown necrosis in the upper two thirds of recently mature leaves. The foliar Cu concentration was 1.4 $mg \cdot kg^{-1}$, as compared to 5.8 $mg \cdot kg^{-1}$ for the control by day 45.

Iron

Incipient deficiency symptoms appeared 3 d after treatments were initiated with a foliar Fe concentration of 41.2 $mg \cdot kg^{-1}$, as compared to 89.9 $mg \cdot kg^{-1}$ for the control. Youngest leaves became greenish-yellow and expressed a faint interveinal chlorosis. Lateral shoots were also pale and chlorotic. By day 5, young leaves turned greenish-yellow and expressed a faint interveinal pattern. There was basipetal chlorosis on the recently mature leaves. On day 9, the young and youngest leaves had light yellow and green splotches at the base, while the recently mature leaves became light yellowish-green. Mature leaves were dark green with some interveinal chlorosis expressed at the tip. Youngest leaves proceeded to turn bright yellow on day 11. There were some whitish-yellow patches on the bases and margins of the young leaves. Recently mature leaves became light yellow, with some greenish-yellow chlorosis at the leaf tip. Mature leaves were cupped downward and had wavier leaf margins than the control. The oldest leaves were darker green than the control.

By day 12, the mature leaves developed interveinal chlorosis. Recently mature leaves were light yellow-green while young and youngest leaves were pale and light yellow with bleaching at the basal region. The midvein region on young and youngest

leaves was a bleach-white color. Three days later the young and recently mature leaf petioles were bleached on the base and the chlorosis moved acropetally. By day 20, there were patches of white on young and recently mature leaves. The veins turned white on recently mature leaves while the young and youngest leaves had a slight green pigmentation in the veins. The bleach-white margins of youngest leaves developed small necrotic spots. On day 22, the Fe deficient plants had shorter primary roots than the control and the roots had developed a light brown, tan, and red coloration. Lateral roots were thick and stunted. On day 24, there was some reversion from a yellow-green to greenish-yellow color in some young shoots. Some youngest leaves were completely white, while some had whitish-yellow margins. Some of the recently mature leaves reverted from a yellow-green to a greenish-yellow color with distinct interveinal chlorosis. By day 32, there was a light whitish-green chlorosis on the margins and leaf tips of young leaves that moved basipetally. At this point the foliar Fe concentration was 27.2 $mg \cdot kg^{-1}$, as compared to 61.4 $mg \cdot kg^{-1}$ for the control.

Manganese

Incipient deficiency symptoms appeared 11 d after treatments were initiated with foliar Mn concentrations at 40.1 $mg \cdot kg^{-1}$, as compared to 174.3 $mg \cdot kg^{-1}$ for the control. Mature leaves were wider at the base and appeared larger than the control. There were some patches of greenish-yellow chlorosis on the young and recently mature leaves. There was some leaf cupping, as the tips and margins bowed downward. By day 17, the axillary shoots expressed a random chlorosis while the young leaves developed a faint interveinal pattern. There was basipetal uniform chlorosis on the recently mature leaves.

On day 20, an interveinal chlorosis developed on recently mature leaves. The mature leaves began to show interveinal chlorosis with the leaf tips remaining medium dark green while a greenish-yellow chlorosis progressed acropetally (day 22). On day 29, there was withering of young leaf tips and spiraling of the youngest leaf tips. By day 32, Mn deficient plants were soft and spongy to the touch, when compared to the control. Recently mature leaves expressed beige to light brown necrotic spotting on the upper two thirds of the leaf tips 34 days after treatments were induced. On day 39 the necrotic spots fused together to form papery, light brown patches. At this point the foliar Mn concentration was 5.4 $mg \cdot kg^{-1}$, as compared to 117.4 $mg \cdot kg^{-1}$ for the control.

Zinc

Incipient deficiency symptoms appeared 11 d after treatments were initiated with a foliar Zn concentration of 18.3 $mg \cdot kg^{-1}$, as compared to 32.0 $mg \cdot kg^{-1}$ for the control. Young and youngest leaf margins were curved under slightly and gave the plant a weeping effect. There was a pale-green color on the base of the young leaves while the oldest leaves remained dark green. Young leaves had a more rigid texture. By day 15, Zn deficient plants had young leaves that were narrower than the control. Recently mature leaves expressed a papery brown to tan necrosis on the terminal one third to one half of the leaf 17 days after treatments were induced. The necrosis moved inward toward the midvein while the margins rolled downward. Young and youngest olive-green leaves were narrower than the control and developed wavy margins. Roots were slightly darker brown in color when compared to the control.

By day 18, Zn deficient plants had developed a thick and brittle texture. The margins of recently mature, young, and youngest leaves had a necrosis that moved inward rapidly to an olive-gray to light green interior. All of the leaves had wrinkled margins except the oldest leaves that drooped downward. The foliar Zn concentration was 10.8 $mg \cdot kg^{-1}$, as compared to 34.4 $mg \cdot kg^{-1}$ for the control 19 days after treatments were initiated. The youngest leaves were lime-green with severe tip necrosis. Leaf tips withered to a brown color while leaves curled upward or downward.

CONCLUSION

The rate at which symptoms occurred is an indication of the plant's sensitivity to a deficiency of a particular element (Fig. 3.1). 'Florabella Pink' strawflower appears to be most sensitive to deficiencies of Fe and B due to the rapid appearance of symptoms at day three and five, respectively after treatments commenced. Deficiencies of N (7 d) and Mg (8 d) also developed shortly after treatments were induced. Ca and P deficiencies first occurred after 9 d followed by Mn and Zn at 11 d, K and S at 13 d, and Cu at 15 d.

Necrosis significantly affects the marketability of greenhouse crops because the opportunity to recover from cell death is not possible. N, Ca, Mg, and B-deficient plants developed necrotic symtoms 11 to 13 d after treatments were initiated (Fig. 3.1). Necrotic symptoms did not develop on P and K deficient plants until 15 and 19 d, respectively. This delay in necrosis may indicate the tolerance strawflower plants have to low concentrations of the primary macronutrients P and K. Necrotic symptoms were observed on Zn, Mn, and Cu-deficient plants of strawflower after 17, 29, and 35 d, respectively. Necrosis never developed on S and Fe-deficient plants, which may indicate

that plants under a severe S or Fe deficiency could recover from advanced chlorosis in production.

The only nutrient deficiency which resulted in a smaller shoot dry weight as compared to the control at the incipient stage was Fe, while K, Ca, and Mg deficient plants all had greater shoot dry weights than the control (Fig. 3.2). By the time of advanced deficiency, there were smaller shoot dry weights for plants deficient in the nutrients N, P, Ca, S, Cu, and Mn, when compared to the control.

Synoptic and unique visual symptoms for strawflower were as follows: N - pale yellow lower foliage progressing basipetally to whitish-yellow mature leaves with necrotic margins; P - olive-green recently mature and mature foliage to brown necrotic patches; K - mature foliage with yellow leaf margins and tips to downward cupped foliage with papery-brown necrosis; Ca - black necrotic spots on the tips of the young leaves and bristle-like lateral roots with blackened tips; Mg - mature foliage with deep green veins and severe yellowish-green chlorosis to brown necrotic margins and tips; S - uniform greenish-yellow chlorosis of young and recently mature leaves to thin and spindly bright green young shoots; B - deformed and curled young leaves with thick and leathery fully expanded leaves to mature leaves with basal necrosis and white midveins; Cu - dark veinal netting with yellowish-green chlorosis on young leaves to blackish-brown necrosis at the petiole and leaf base of mature leaves; Fe - uniform yellowish-green chlorosis on the young leaves to bleach white young leaves with pale green veins; Mn - greenish-yellow chlorosis on the young and recently mature leaves to light brown necrotic spotting within veins; Zn - olive-green young and youngest leaves to brownish-gray necrosis on the tips of the mature leaves.

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Table 3.1. Tissue mineral nutrient concentration at initial and advanced stages of 11 nutrient deficiencies in recently matured leaves of 'Florabella Pink' strawflower.

Treatment	-N	-P	-K	-Ca	-Mg	-S	-B	-Cu	-Fe	-Mn	-Zn
Nutrient	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	Percent dry wt.						mg·kg^{-1} of dry wt.				
						Initial Deficiency					
Control	6.33	0.82	6.04	1.46	0.21	0.21	28.50	6.77	89.87	174.33	32.03
Deficient	3.19	0.26	1.08	0.29	0.12	0.09	17.13	2.87	41.20	40.07	18.33
Significance[Z]	***	***	***	***	***	***	**	***	**	**	*
						Advanced Deficiency					
Control	5.51	0.76	6.74	1.42	0.29	0.21	31.17	5.84	61.40	117.43	34.40
Deficient	1.76	0.07	0.77	0.24	0.06	0.05	5.60	1.40	27.23	5.43	10.77
Significance[Z]	***	***	***	***	***	***	***	***	***	***	**

[Z] *, **, ***; Significant by column and stage of deficiency $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$.

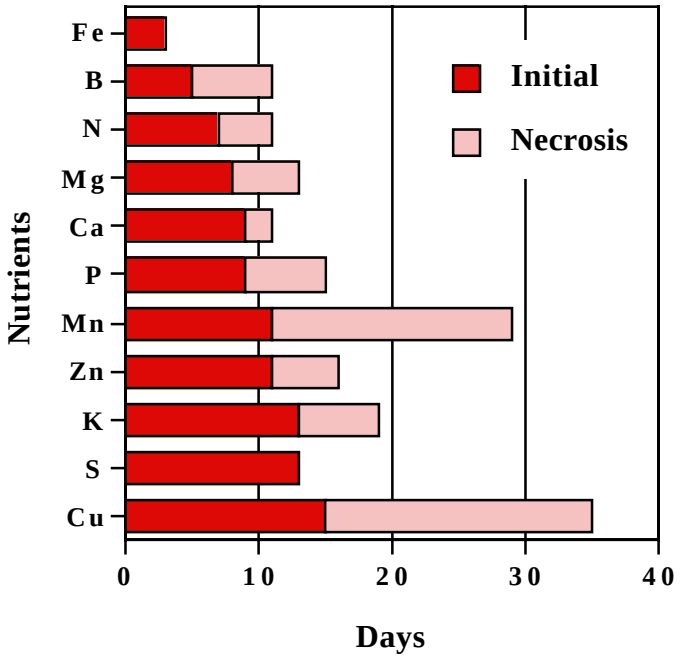

Fig. 3.1. Days to develop specific initial nutrient deficiency symptoms or necrosis for 'Florabella Pink' strawflower.

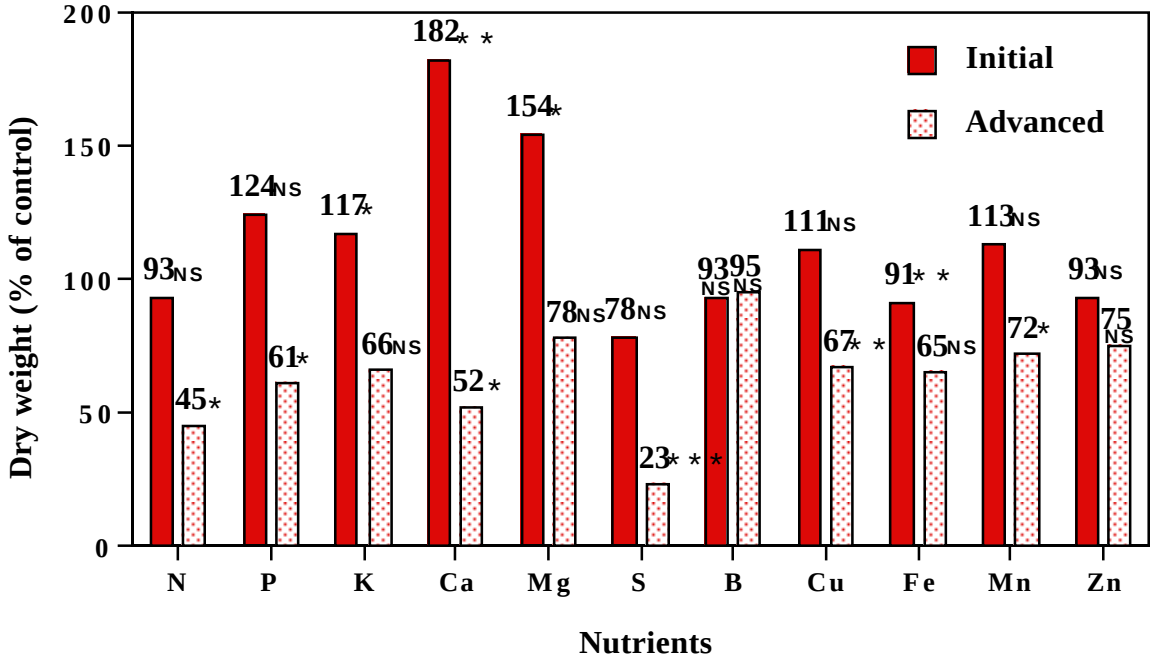

Fig. 3.2. Shoot dry weight of nutrient deficient plants of 'Florabella Pink' strawflower expressed as a percentage of control plants at incipient and advanced stages. NS, *, ** denotes not significant at $P \leq 0.05$, significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Chapter 4

Impact of Light and Moderate Deficiencies of 11 Mineral Nutrients on Rooting of Stem Cuttings of Vegetative Strawflower

(in the format appropriate for submission to HortScience)

Subject Category: Propagation and Tissue Culture

Impact of Light and Moderate Deficiencies of 11 Mineral Nutrients on Rooting of Stem Cuttings of Vegetative Strawflower

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Impact of Light and Moderate Deficiencies of 11 Mineral Nutrients on Rooting of Stem Cuttings of Vegetative Strawflower

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Abstract. Elemental deficiencies of N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, or B were induced in stock plants of 'Florabella Pink' strawflower [*Bracteantha bracteata* (Vent.) A.A. Anderberg]. Stem cuttings were harvested when initial foliar symptoms were first expressed and later under moderate deficiency symptoms. A sub-set of cuttings were analyzed for mineral nutrient levels and the remainder rooted in perlite for 3 weeks and evaluated for root quality and root and shoot dry weight. Nutrients at an incipient or moderate stage of deficiency that affected rooting quality negatively were P, Ca, and Zn. Low K tissue levels near 1.5% affected rooting positively. Calcium and B should be applied to stock plants at recommended concentrations because cuttings will develop shoot tip necrosis under high humidity environments. Although Cu, Fe, Mg, Mn, N, and S deficiencies did not affect rooting of cuttings at an incipient stage, they produced cuttings with foliar symptoms not desired by propagators. Copper, Fe, Mg, Mn, N, and S should always be applied to stock plants at recommended concentrations.

Introduction

The vegetatively-propagated strawflower [*Bracteantha bracteata* (Vent.) A.A. Anderberg] is native to eastern Australia (Sharman and Sedgley, 1988) and is related to the seed-propagated strawflower [*Helichrysum bracteatum* (Vent.) Andr.] which is from South Africa and New Guinea (Morley, 1978). These plants are known for their rigid, papery, colorful bracts, making them excellent cut flowers and bedding plants. Plants perform optimally in dry, low P containing soils, because their native terrestrial habitat is scrub and open rangeland with sandy and gravelly soils.

Strawflower is an important crop for greenhouse growers wishing to market a durable plant for use in U.S. landscapes because it can withstand light frosts and survive extreme heat and humidity (Proven Winners, 2003). The species prefers well-aerated substrates containing low amounts of P with a pH of 5.5 to 6.3 (Paul Ecke Ranch, 2003). Fertilizer recommendations suggest N at 200 to 250 $mg \cdot L^{-1}$ supplied by rotating 20N-4.4P-16.6K with 15N-0P-12.5K continually until anthesis (Ball FloraPlant, 2003). During propagation of 'Florabella' strawflower, mineral nutrient imbalances observed in stock plants have been suspected of affecting rooting negatively (Ron Cramer, Paul Ecke Ranch, personal communication).

Little has published on the effects of mineral nutrient deficiencies on rooting of stem cuttings. Optimal rooting has been reported to occur when N is marginally low and carbohydrates are high in cuttings (Blazich, 1988). High N tends to inhibit rooting (McAvoy, 1995). Calcium and B interact with each other in their roles within the plant. Thus, a deficiency of one can bring on symptoms of the other (Mills and Jones, 1996;

Smith and Loneragan, 1997). By inference, one would suspect that either deficiency would inhibit rooting of cuttings.

Zinc is required by plants for the synthesis of auxin, which stimulates adventitious root formation in cuttings (Blazich, 1988). Again, one would suspect that Zn would be beneficial for rooting. However, little is known about the roles of the other macro- and micronutrients with regards to adventitious rooting. The influence on rooting and correlations made to critical tissue concentrations have yet to be discovered for many of the nutrients. Therefore, the objective of this research was to determine the impact of a light and a moderate deficiency of each of 11 essential mineral nutrients on rooting of stem cuttings of strawflower.

Materials and Methods

Expt. 1. Stem cuttings of 'Florabella Pink' strawflower were inserted into Oasis LC1 foam cubes (Smithers Oasis, Kent, Ohio) containing only Ca and Mg from dolimitic limestone on 27 Feb. 2002. The experiment was conducted in a glass greenhouse in Raleigh, N.C. at 35°N latitude that was set at night/cloudy day/clear day temperatures of 17/21/24 °C. During the establishment phase, cuttings were fertilized at each irrigation with the following mM concentrations, 0.35 NH_4, 5.15 NO_3, 0.35 PO_4, 1.0 K, 1.25 Ca, and 1.0 Mg plus 36 μM Fe. Solutions were formulated in 18 mega-ohm deionized water from the following reagent grade chemicals, NH_4NO_3, KNO_3, K_2HPO_4, $Ca(NO_3)_2 \cdot 4H_2O$, $MgSO_4 \cdot 7H_2O$, and FeDTPA (Pitchay, 2002). Cuttings were grown with this nutrient regime until roots were visible at the edges of the rooting cube.

Cuttings were pinched on 13 Mar. 2002 by removing 2 cm of growth from the terminal tip. After establishment, these plants were transplanted on 2 Apr. into 4.87-L aluminum painted plastic tubs with six circular holes in the lids. Ten replications, each consisting of one tub with six rooted cuttings, were assigned to 12 treatments. The experiment was a randomized complete-block design with 10 blocks. Each block consisted of 11 plastic tubs of a control treatment and one plastic tub of each deficient treatment (each tub was an experimental unit). To provide sufficient plant biomass for foliar analysis, plants were grown initially with a complete modified Hoagland's all nitrate solution: (macronutrients in mM) 15 NO_3-N, 1.0 PO_4-P, 6.0 K, 5.0 Ca, 2.0 Mg, and 2.0 SO_4-S (Hoagland and Arnon, 1950), plus micronutrients (in μM), 72 Fe, 9.0 Mn, 1.5 Cu, 1.5 Zn, 45.0 B, and 0.1 Mo. On 9 Apr., three treatments were induced that included a complete nutrient formula and complete minus one of the following nutrients S, Cu, and Zn. Because deficiency symptoms of N, P, K, Ca, Mg, Fe, Mn, and B typically develop more quickly, than S, Cu, and Zn (Pitchay, 2002), the introduction of these treatments was delayed until 16 Apr. to have sufficient biomass for tissue sampling. Reagent grade chemicals and deionized water of 18-mega ohms purity was used to formulate treatment solutions. Tubs were inspected daily and deionized water was added as needed to maintain the nutrient solution volume for 2 weeks, and in subsequent weeks tubs were topped with nutrient solution as needed. A complete replacement of nutrient solutions was done weekly.

Based on prior research (Gibson et al., 2003), stock plants were monitored daily to determine initial and moderate stages of mineral nutrient deficiency. Photographs and descriptions of symptoms on youngest, young, recently mature, and mature leaves were

taken. The youngest leaves represented tissue 1 cm from the shoot tip measuring 0.5 to 2.0 cm in length, while young leaves were 2.0 to 7.0 cm long, recently mature were 7.0 to 15.0 cm, and mature leaves were ≥ 15.0 cm in length. When the first visible symptoms occurred, the recently mature leaves were sampled from five replications of deficiency treatment and the control treatment to establish incipient deficiency tissue levels. When symptoms progressed to a moderate level, another set of recently mature leaves were sampled from the remaining five replications of the deficiency treatment and the control treatment to establish tissue concentrations associated with a moderate deficiency. The tissue samples were first rinsed in deionized water, then washed in 0.2 N HCl for 30 s, and dried at 70 °C for 24 h. Dried tissue was ground in a stainless steel Wiley mill to pass 1 mm screen (20-mesh). Tissue was then analyzed for macro and micronutrients with the exceptions of N, using a Perkin Elmer 3300 Inductively Coupled Argon Plasma Emission Spectrophotometer (Perkin Elmer, Shelton, Conn.), while N was analyzed using Carlo Erba NA 1500 Series 1, O_2 combustion Nitrogen Analyzer (Carlo Erba, Lakewood, N.J.) at the N.C. Dept. of Agric. Laboratory, Raleigh.

Terminal stem cuttings (≥ 9.0 cm in length) from stock plants of 'Florabella Pink' strawflower were excised on six dates that were based on the expression of initial and moderate deficiency symptoms: 26 and 30 Apr.; 3, 6, 9, and 12 May. Cuttings were trimmed from the bases to a final length of 8.25 cm and dipped for 1 s in 3,000 $mg \cdot L^{-1}$ indole-3-butyric acid (IBA). A total of 60 cuttings per treatment were randomly selected; the experimental design was a completely randomized design with one deficiency treatment and a control with 10 replications per treatment and 6 sub-samples per replication. Basal portions of cuttings (1.0 cm) were inserted into moist perlite in 3.8 x

3.8 x 8.9 cm 6-cell containers. Cuttings were hand misted daily as needed to prevent wilting with deionized water under a white plastic humidity tent. Bottom heat at 21 °C was provided for 3 weeks. Cuttings were maintained under natural photoperiod, with days/nights of 20/18 °C. Three WAS (weeks after sticking), cuttings were evaluated for rooting quality based on a 0 to 5 scale: 0= no roots, 1= one root, 2= two or more roots with uneven rooting around the cutting base, 3= uniform rooting around base with roots shorter than 1 cm, 4= uniform rooting with roots 1.0 to 2.0 cm long, 5= uniform rooting with roots ≥ 2.0 cm. Cutting root (adventitious roots plus 1 cm of the cutting base) and shoot dry weight were also measured 3 WAS.

Expt. 2. The same procedures used in Expt. 1 were repeated in Expt. 2, except as noted. Unrooted stem cuttings of 'Florabella Pink' strawflower were inserted in Oasis LC1 foam cubes 28 Nov. 2002. Cuttings were pinched 13 Dec. 2002 and transplanted 29 Dec. On 16 Jan. 2003, all treatments were initiated that included a complete nutrient formula and complete minus one of the nutrients N, P, K, Mg, and S. Terminal stem cuttings (≥ 9 cm in length) were excised on six dates that were based on the expression of initial and moderate deficiency symptoms: 23, 25, 27, 29, and 31 Jan., and 11 Feb. 2003.

All the data were subjected to analysis of variance (ANOVA) procedures using PROC GLM SAS program (SAS Inst. Inc., Cary, N.C.). When the F test indicated evidence of significant difference among the means, LSD ($P \leq 0.05$) was used to establish differences between means.

Results and Discussion

Expt. 1. The following are the stock plant and cutting descriptions of visual symptoms of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn at the initial and moderate stages of deficiency. Corresponding tissue concentrations at incipient and moderate stages are listed in Table 4.1. The number of days to each symptom refers to the time from the start of deficiency treatments (Figure 4.1). Initial and moderate shoot and root dry weight comparisons to the control are indicated in Figures 4.2 and 4.3. Rooting quality ratings and root:shoot ratios of nutrient deficient cuttings versus control cuttings are reported in Tables 4.2 and 4.3, respectively.

Nitrogen. On day 16, the young and youngest leaves became lighter and paler green than the control. At this point, the incipient foliar N concentration was 3.66%, compared to 6.61% for the control (Table 4.1). Recently mature leaves were narrower and mature and recently mature leaf architecture was more upright compared to control plants. By day 25, N-deficient plants had entered a moderate stage of deficiency with a foliar N concentration of 1.46%, compared to 4.70% for the control (Table 4.1). The young and youngest leaves were yellowish-green. On young leaves, margins rolled under giving the leaves a sword-like appearance.

Three WAS, N-deficient and control cuttings harvested at the initial stage had a similar rooting quality rating of 1.58. The older leaves of the N-deficient cuttings expressed a veinal chlorosis. This chlorosis progressed basipetally to a bleach white color from the mature leaf tips. The upper growth was darker green compared to the lower foliage with a uniform medium green color on the young, youngest and recently

mature leaves. Both shoot and root dry weights were similar to the control cuttings (Figs. 4.2 and 4.3). The root:shoot ratio was similar (0.143) for the N-deficient and control cuttings.

N-deficient and control cuttings harvested at the moderate stage expressed a similar rooting quality rating of 2.04. The youngest leaves were dark green while the oldest set of mature leaves was dark brown and shriveled. The next set of mature leaves exhibited leaf tip necrosis that covered one quarter of the lamina. Recently mature leaves and young leaves remained a medium green color while a uniform bleach-white chlorosis moved basipetally on mature leaves with extensive marginal necrosis. Control cuttings had a greater shoot dry weight than N-deficient cuttings (Fig. 4.2), but had similar root dry weights (Fig. 4.3). However, the root:shoot ratio was larger with N-deficient cuttings (0.132) than the control (0.101) (Table 4.3).

Lower concentrations of N in the foliage of the cuttings did not affect the rooting performance of cuttings of strawflower at an incipient or moderate stage of deficiency. This contrasts reports with stock plants of eastern redcedar (Henry et. al, 1992) and chrysanthemum (*Dendranthema* x *grandiflorum* Kitam.) (Roeber and Reuther, 1982) where the lowest N treatments, not optimal for growth, maximized rooting of cuttings. However, nutrient deficiencies were not induced and reported with eastern redcedar and chrysanthemum and tissue concentrations were not listed. While low N in the tissue had no impact on rooting quality, lower leaf yellowing occurred at the initial stage and necrosis of the mature leaves of cuttings occurred at the moderate stage. If propagators harvested cuttings at an incipient stage of deficiency, chlorosis of the lower cutting foliage could be corrected during propagation with a N-containing fertilizer.

Phosphorus. Phosphorus deficiency was observed initially 19 d after treatments were initiated as pale-green plants, compared to medium-green control plants. The foliar P concentration was 0.19%, compared to 0.74% for the control (Table 4.1). The young and recently mature leaves were narrower and had an elongated appearance compared to leaves on the control plants by day 25. At this point, the moderate foliar P concentration was 0.09%, compared to 0.51% for the control (Table 4.1).

Three WAS, rooting quality was greater for the control cuttings (2.62) versus the P-deficient cuttings (2.10). P-deficient cuttings had narrower young and youngest leaves than control cuttings. The upper growth was darker than the lowest mature set of leaves and the recently mature leaves. Cuttings also expressed an upright leaf architecture. Some cuttings expressed uniform lower leaf yellowing with pale green upper-growth. Shoot dry weight was similar to the control cuttings (Fig. 4.2), but the P-deficient cuttings had smaller root dry weights than the control (Fig. 4.3). The root:shoot ratio was similar (0.161) for the P-deficient and control cuttings.

P-deficient cuttings harvested at the moderate stage had a lower rooting quality rating of 1.48 compared to 2.00 for the control cuttings (Table 4.2). The youngest, young, and recently mature leaves were deeper green than the oldest set of mature leaves and the youngest and young leaves were narrower than leaves of the control. A dull green color occurred on some of these mature leaves, while the oldest set of mature leaves developed shriveled, dark, brownish-black tissue. Shoot and root dry weights and the root:shoot ratio (0.100) were similar to the control cuttings (Figs. 4.2 and 4.3).

A P deficiency at an incipient or moderate stage negatively affected cutting rooting quality. Propagators maintaining a 0.19% foliar P concentration in the stock

plant may produce darker green cutting foliage, however, the rooting quality and root dry weight will diminish. Less rooting with low P shows evidence that P may be important for root initiation, as Good and Tukey (1967) showed than P is translocated from the foliage to the basal stem tissue during propagation. Poorer rooting with strawflower may also be due to the low P requirement of this species in its native soils of eastern Australia (Sharman and Sedgley, 1988). Stock plants may tolerate low P, but stem cuttings may require higher concentrations for root initiation and root growth and development.

Potassium. Initial deficiency symptoms appeared 16 d after treatments were initiated with foliar K concentrations at 1.58%, compared to 5.88% for the control (Table 4.1). Faint, random, and irregular chlorotic patches developed close to the midvein on the mature leaves. The moderate stage of deficiency occurred when mature leaves developed interveinally chlorotic light green tips. At this point (day 22), foliar K concentration was 0.97%, compared to 4.91% for the control (Table 4.1).

After rooting K-deficient cuttings for 3 weeks, rooting quality was greater (2.43) than the 1.66 rating for the control cuttings (Table 4.2). Mature leaves on the cuttings were light green with brownish-black veins throughout the lamina. The upper growth of some cuttings was lighter green with distinct interveinal chlorosis, compared to medium-green control cuttings. A thin band of marginal chlorosis with some dark brown necrotic regions occurred on the mature leaves. The upper-growth was also compact with young and youngest leaves curled downward. Shoot dry weight was similar to the control cuttings, but the K-deficient cuttings had smaller root dry weights than the control (Figs.

4.2 and 4.3). There was also a similar root:shoot ratio of 0.161 for the K-deficient and control cuttings.

Three WAS, K-deficient and control cuttings harvested at the moderate stage expressed a similar rooting quality value of 2.49. Mature leaves were chlorotic, expressed marginal necrosis, and exhibited a puckered texture (bumpy and blistered) with undulating margins. The necrotic margins became papery and deep brown in color. Some older leaves had a dark brown mottling that fused to form necrotic patches. The recently mature and mature leaves expressed a distinct interveinal chlorosis. The youngest leaf margins were rolled. K-deficient cuttings were compact, but had a similar shoot and root dry weight to the control (Figs. 4.2 and 4.3). However, the root:shoot ratio was greater with K-deficient cuttings (0.187) compared to control cuttings (0.146) (Table 4.3).

Cuttings under an incipient stage of deficiency were more compact and had a higher rooting quality rating than control cuttings. These traits would be of benefit to propagators who wish to ship stockier cuttings with more roots in shipping boxes. These results suggest that tissue concentrations near 1.5% positively impact the rooting performance of strawflower, however the leaves of the young and youngest cuttings developed a distinct interveinal chlorosis during propagation. Nelson (2002) suggests that more research is needed to determine if low K fertility strategies improve height control without reducing the aesthetic traits of floriculture crops.

Calcium. Initial deficiency symptoms appeared 19 d after treatments were initiated with a foliar Ca concentration of 0.30%, compared to 1.06% for the control (Table 4.1). A

dullish gray-green cast appeared on the upper leaves while the roots became reddish-brown in color with stunted root tips. Lateral roots were also shorter and more bristle-like in appearance. The moderate stage of deficiency occurred when small, irregular, blackish-brown spots developed acropetally on the margins and in the interior of the young and youngest leaves. At this point (day 22), foliar Ca concentration was 0.17%, compared to 0.94% for the control (Table 4.1).

Three WAS, rooting quality was greater for the control cuttings (2.62) versus the Ca-deficient cuttings (1.41) (Table 4.2). Calcium deficiency progressed rapidly in propagation, as mature leaves shriveled while the youngest leaves developed tip necrosis. Cuttings had narrow young leaves with distinct interveinal chlorosis. Necrosis began as black streaks on the midvein of recently mature leaves, followed by death of the shoot tip, and finally the flower buds aborted. Shoot and root dry weights were smaller compared to the control cuttings (Figs. 4.2 and 4.3). There was a similar root:shoot ratio of 0.152 for the Ca-deficient and control cuttings.

Approximately 75% of the cuttings harvested at the moderate stage of deficiency were dead after 3 weeks in propagation. Root quality was greater for the control cuttings (2.34) versus the Ca-deficient cuttings (1.32) (Table 4.2). Youngest leaves were narrow, uniformly yellow, and had necrotic tips and a medium-green midvein. Midveins ultimately turned dark brown to black, especially in the lower one half of young leaves. Shoot and root dry weights were smaller compared to the control cuttings (Figs. 4.2 and 4.3). There was a similar root:shoot ratio of 0.140 for the Ca-deficient and control cuttings.

Low Ca tissue concentrations ≤ 0.30% in stem cuttings of strawflower resulted in severe shoot tip necrosis during periods of high humidity in propagation. This necrosis is due to poor translocation of calcium to the shoot because calcium is an immobile element (Marshner, 1995). However, Blazich et al. (1983) reported that calcium was transported to the upper portions of stem cuttings of Japanese holly (*Ilex crenata* Thunb. 'Convexa') during propagation. Rooting was poorer with cuttings of strawflower both under an incipient and moderate stage of deficiency, and these results confirm the importance Ca to root growth and development. Our results are similar to Eliasson (1978) in which root length of stem cuttings of pea (*Pisum sativum* L.) was significantly shorter when Ca was not applied to the stock plants.

Magnesium. Initial deficiency symptoms appeared 11 d after treatments were initiated with foliar Mg concentration at 0.12%, compared to 0.23% for the control (Table 4.1). A faint interveinal chlorosis developed on the recently mature leaves. By day 16, a thin band of light yellow tissue developed on the recently mature leaf margins. At this moderate stage of deficiency, foliar Mg concentration was 0.06%, compared to 0.21% for the control (Table 4.1).

Three WAS, Mg-deficient and control cuttings harvested at the initial stage expressed a similar root quality of 2.51. There was some interveinal chlorosis on the recently mature leaves. The upper growth maintained a uniform greenish-yellow color, while the oldest set of leaves began to abscise. The downward curled mature leaves had a distinct marginal band of yellowish-white chlorosis with yellow splotches and streaks of brown necrosis within the interior of the leaf. Shoot and root dry weights were similar

compared to the control cuttings (Figs. 4.2 and 4.3). However, the root:shoot ratio was greater with Mg-deficient cuttings (0.204) compared to control cuttings (0.171) (Table 4.3).

Rooting quality was similar between the control and the Mg-deficient cuttings (1.73) harvested at the moderate stage. The upper growth was either dark green or uniform light green, with the recently mature leaves exhibiting an interveinal chlorosis. The oldest set of leaves had a distinct interveinal chlorosis while some were completely necrotic. Shoot and root dry weights and the root:shoot ratio (0.160) were similar to the control cuttings (Figs. 4.2 and 4.3).

Magnesium concentrations 0.06% to 0.12% did not affect rooting of stem cuttings of strawflower. Despite dark green upper foliage and a greater root:shoot ratio than standard fertilized plants at an incipient stage of deficiency, Mg deficiency severely affects the lower leaves of cuttings. As the stock plant enters an advanced deficiency, cuttings harvested subsequently lose most of their lower leaves during propagation. Aesthetically, a Mg deficiency in cuttings is not desired. A Mg deficiency may occur in stock plants when irrigation water does not contain adequate Mg and is corrected with applications of $MgSO_4$ applied at a 1:100 ratio at a rate of 1 $kg \cdot L^{-1}$ (Nelson, 1996).

Sulfur. Incipient deficiency symptoms appeared 20 d after treatments were initiated with a foliar S concentration of 0.12% compared to 0.20% for the control (Table 4.1). Recently mature leaves expressed lighter green bases compared to the control plants. At the moderate stage of deficiency (day 24), chlorotic shoot tips were observed as a well-defined bright green cast on young leaves, compared to medium-green control shoots. At

this point, foliar S concentration was 0.09%, compared to 0.21% for the control (Table 4.1). Young leaves were also more upright while recently mature leaves were narrower and had darker green leaf tips than the control.

Rooting quality was similar (2.46) between the control and the S-deficient cuttings harvested at the initial stage. Older leaves were light yellow and expressed veinal chlorosis while young leaves were extremely narrow, wavy, and curled. Margins rolled inwards on young leaves. There was also a random leaf tip burn that appeared on the youngest leaves. Shoot and root dry weights and the root:shoot ratio (0.157) were similar to the control (Figs. 4.2 and 4.3).

Rooting quality was similar (1.62) between the control and the S-deficient cuttings harvested at the moderate stage. Upper leaves were narrower than the control because the margins were rolled inwards. Random leaf tip burn appeared on the youngest leaves while the mature leaves were light yellow with veinal chlorosis. Overall cuttings were a uniform pale green color. Shoot dry weight was similar to the control cuttings (Fig. 4.2), but the S-deficient cuttings had smaller root dry weights than the control (Fig. 4.3). The root:shoot ratio of control and S-deficient cuttings was similar (0.147).

Low S in the cutting tissue does not affect rooting at an incipient stage, however, root dry weights were smaller under a moderate deficiency. This decrease in root dry weight at 0.09% may have been due to lower concentrations of the amino acids methionine and cysteine in plant proteins (Marshner, 1995). Sulfur deficiency may occur in stock plants when irrigation water does not contain adequate S and is corrected with applications of $MgSO_4$ applied at a 1:100 ratio at a rate of 1 $kg \cdot L^{-1}$ (Nelson, 1996).

Boron. Initial deficiency symptoms appeared 20 d after treatments were initiated with foliar B concentration at 9.1 $mg \cdot kg^{-1}$, compared to 34.7 $mg \cdot kg^{-1}$ for the control (Table 4.1). At this point, there was a loss of dominance in the growing points, youngest leaves became narrow and the young leaf margins became smooth. Boron-deficient plants had an overall spongy texture with deeper green recently mature leaves than the control. On day 22, the base of the midvein of young leaves had a chalky-brown coloration and chlorosis progressed acropetally. At this moderate stage of deficiency, foliar B concentration was 8.2 $mg \cdot kg^{-1}$, compared to 33.8 $mg \cdot kg^{-1}$ for the control (Table 4.1). The shoot tips also aborted. Outer margins on recently mature leaves curled downward while mature leaves drooped downward.

Rooting quality was similar (2.65) between B-deficient and control cuttings harvested at the initial stage. The growing points were completely brownish-black and flower buds were a pale brownish-pink color. The growing point was completely visible due to the curled, deformed, and triangular-shaped youngest leaves. Tips of the youngest leaves were shriveled. Young leaves were narrow in shape with dark brownish-black midveins and secondary veins. Recently mature leaves also expressed a dark brown midvein necrosis that progressed acropetally. The recently mature leaves were buckled and curved downward while the mature leaves exhibited a medium-green color with veinal chlorosis. Shoot and root dry weights and the root:shoot ratio (0.166) were similar to the control cuttings (Figs. 4.2 and 4.3).

Root quality was similar (2.34) between the control and the B-deficient cuttings harvested at the moderate stage. Three WAS, B-deficient cuttings expressed compact growth with approximately 50% of the cuttings having twisted and scorched youngest

leaves. Some young leaves were needle-like, triangular, and elongated when compared to control cuttings. These narrow leaves had a distinct dark brown necrosis in the midvein. Shoot dry weight was greater with control cuttings (Fig. 4.2), but the B-deficient cuttings had similar root dry weights compared to the control (Fig. 4.3). The root:shoot ratio of B-deficient cuttings (0.210) was greater than control cuttings (0.146) (Table 4.3).

Despite a similar rooting performance to control cuttings, B-deficient cuttings harvested at an incipient and moderate stage developed severe shoot tip necrosis during periods of high humidity in propagation. Necrosis occurred rapidly in young leaves because B is an immobile nutrient (Mills and Jones, 1996). Boron should always be applied to stock plants of strawflower because of its importance in root growth and development. Middleton et al. (1978) reported that rooting did not occur with stem cuttings of mung bean (*Vigna radiata* (L.) R. Wilcz.) when B was not applied to the stock plants.

Copper. Incipient deficiency symptoms appeared 26 d after treatments were initiated with the foliar Cu concentration at 2.0 $mg \cdot kg^{-1}$, compared to 7.0 $mg \cdot kg^{-1}$ for the control (Table 4.1). There was a loss in sheen and a dull green cast over the plant. Basipetal chlorosis was observed on the recently mature leaves. Young leaves and recently mature leaves were slightly narrower than the control. The young leaves developed a greenish-yellow interveinal chlorosis with a net-like appearance (day 32). At this point, foliar Cu concentration was 1.9 $mg \cdot kg^{-1}$, compared to 4.3 $mg \cdot kg^{-1}$ for the control (Table 4.1).

Rooting quality was similar (2.54) between Cu-deficient and the control cuttings. Narrow, needlike-like young leaves with a distinct interveinal chlorosis were present on Cu-deficient cuttings, compared to the lobed leaves on control cuttings. There were blackish-brown spots on the midvein of recently mature leaves while the lower leaves were pale green. Shoot dry weight was similar to the control cuttings (Fig. 4.2), but the Cu-deficient cuttings had smaller root dry weights than the control (Fig. 4.3). The root:shoot ratio of Cu-deficient and control cuttings was similar (0.154).

Rooting quality was similar (1.93) between the Cu-deficient and control cuttings harvested at the moderate stage. Veinal and interveinal chlorosis were present on young leaves. There was also a visibly wider midvein on recently mature and young leaves with a whitish-green chlorosis in the basal region, compared to the control. Oldest leaves were dark brown and shriveled. Shoot and root dry weights were smaller with Cu-deficient cuttings (Figs. 4.2 and 4.3). The root:shoot ratio of Cu-deficient and control cuttings was similar (0.098).

While rooting quality was not affected, tissue Cu levels ≤ 2.0 $mg \cdot kg^{-1}$ produced a smaller root dry weight with interveinal chlorosis and necrotic foliar symptoms on cuttings of strawflower. Copper deficiency with floriculture crops occurs rarely, however, producing strawflower in root substrates > pH 6.3 may introduce Cu deficiency (Paul Ecke Ranch, 2003), therefore growers should monitor pH levels over time using the PourThru method (Cavins et al., 2000).

Iron. Incipient deficiency symptoms appeared 13 d after treatments were initiated with a foliar Fe concentration of 44.9 $mg \cdot kg^{-1}$, compared to 59.4 $mg \cdot kg^{-1}$ for the control (Table

4.1). Youngest leaves became greenish-yellow and expressed a faint interveinal chlorosis. Lateral shoots were also pale and chlorotic. By day 17, young leaves turned greenish-yellow and expressed a faint interveinal pattern. There was basipetal chlorosis on the recently mature leaves. At this point, foliar Fe concentration was 48.2 $mg \cdot kg^{-1}$, as compared to 72.3 $mg \cdot kg^{-1}$ for the control (Table 4.1).

Root quality was similar (2.53) between the Fe-deficient and control cuttings harvested at the initial stage. There was a greenish-yellow chlorosis on young and youngest leaves with a faint interveinal chlorosis on some of the young leaves. Shoot and root dry weights and the root:shoot ratio (0.161) were similar to the control cuttings (Figs. 4.2 and 4.3).

Three WAS, root quality was greater for the Fe-deficient cuttings (2.62) versus the control cuttings (2.10) harvested at the moderate stage (Table 4.2). The margins of young and youngest leaves were curled more when compared to the control. Dark green and greenish-yellow patches were present on the young leaves while recently mature leaves became lighter green compared to the control cuttings. Shoot and root dry weights and the root:shoot ratio (0.166) were similar to the control cuttings (Figs. 4.2 and 4.3).

With the exception of a greater rooting quality under a moderate Fe deficiency, low Fe in the cutting tissue does not affect rooting. Propagators should maintain Fe levels ≥ 60 $mg \cdot kg^{-1}$ in tissue of strawflower to avoid chlorosis. Iron deficiency occurred rapidly because Fe is an essential component of the chlorophyll molecule. Propagators can prevent Fe deficiency in stock plants of strawflower by maintaining a root substrate pH below 6.3 (Paul Ecke Ranch, 2003).

Manganese. Incipient deficiency symptoms appeared 16 d after treatments were initiated with foliar Mn concentrations at 20.0 $mg \cdot kg^{-1}$, compared to 183.0 $mg \cdot kg^{-1}$ for the control (Table 4.1). There were some patches of greenish-yellow chlorosis on the young and recently mature leaves accompanied by leaf cupping, as the tips and margins bowed downward. Mature leaves were wider at the base and appeared larger than the control. By day 22, the axillary shoots expressed a random chlorosis while the young leaves developed a faint interveinal pattern. At this moderate stage of deficiency, the foliar Mn concentration was 9.8 $mg \cdot kg^{-1}$, compared to 138.7 $mg \cdot kg^{-1}$ for the control (Table 4.1).

Rooting quality was similar (1.77) between Mn-deficient and control cuttings harvested at the initial stage. Youngest leaves had a basipetal chlorosis that progressed acropetally halfway up the lamina. Young and recently mature leaves were a medium green, while the mature leaves remained dark green. Shoot and root dry weights and the root:shoot ratio (0.160) were similar to the control cuttings (Figs. 4.2 and 4.3).

Rooting quality was similar (2.34) between Mn-deficient and control cuttings harvested at the moderate stage. Overall cuttings were greenish-yellow with the young leaves having a distinct interveinal chlorosis. Some recently mature leaves expressed basipetal yellowish-green chlorosis. Margins rolled downwards on some youngest leaves causing them to appear narrower than the control. Mn-deficient cuttings had smaller shoot and root dry weights than the control (Figs. 4.2 and 4.3). The root:shoot ratio was similar between Mn-deficient and control cuttings (0.151).

A Mn concentration of 20.0 $mg \cdot kg^{-1}$ did not affect root or shoot growth of the cuttings, however, a concentration of 9.8 $mg \cdot kg^{-1}$ did. This low concentration of Mn in the cutting tissue at the moderate stage of deficiency may have affected activity of

endogenous auxin which subsequently decreased rooting. Regardless of rooting performance, propagators do not desire uniform chlorosis and interveinal chlorosis on the young and youngest leaves of rooted cuttings. Propagators can prevent Mn deficiency in stock plants of strawflower by maintaining a root substrate pH below 6.3 (Paul Ecke Ranch, 2003).

Zinc. Incipient deficiency symptoms appeared 18 d after treatments were initiated with a foliar Zn concentration of 18.3 $mg \cdot kg^{-1}$, compared to 41.4 $mg \cdot kg^{-1}$ for the control (Table 4.1). There was a pale-green color on the base of the young leaves while the oldest leaves remained dark green. Young and youngest leaf margins were curved under slightly and had a more rigid texture. Recently mature leaves expressed a light green chlorosis on the tips by day 20. Zinc deficient plants had young leaves that were narrower than the control. The foliar Zn concentration for the moderate stage of deficiency was 19.4 $mg \cdot kg^{-1}$, compared to 35.6 $mg \cdot kg^{-1}$ for the control (Table 4.1).

Three WAS, root quality was greater for the control cuttings (2.44) versus the Zn-deficient cuttings (1.86) (Table 4.2). All Zn-deficient cuttings were thicker and more rigid when compared to control cuttings. The undulated margins on the youngest leaves were a uniform greenish-yellow color. Shoot dry weight was similar to the control cuttings (Fig. 4.2), but Zn-deficient cuttings had smaller root dry weights than the control (Fig. 4.3). The root:shoot ratio of Zn-deficient cuttings (0.193) was greater than the ratio of 0.171 of the control cuttings (Table 4.3).

Root quality was greater for the control cuttings (2.53) versus the Zn-deficient cuttings (2.10) harvested at the moderate stage (Table 4.2). Young leaves were curled

with a dull green color. The leaves were extremely thick and leathery. Shoot and root dry weights were similar to the control cuttings (Figs. 4.2 and 4.3). However, the root:shoot ratio was greater with Zn-deficient cuttings (0.183) compared to control cuttings (0.154) (Table 4.3).

An incipient or moderate deficiency of Zn negatively affected cutting rooting quality. Less rooting with lower Zn tissue concentrations provides evidence that Zn is important for root initiation. Zinc is required for synthesis of the auxin precurser tryptophan (Blazich, 1988). Most soils in eastern Australia, the origin of strawflower, are deficient in Zn (Isbell and Russell, 1986). While strawflower may have adapted to low Zn in soils of eastern Australia, rooting in propagation substrates that have lower cation exchange capacity values than mineral soils may introduce problems such as poorer rooting. Supplemental Zn applied to stock plants of strawflower may be required, and tissue concentrations should be maintained above 20.0 $mg \cdot kg^{-1}$.

Expt. 2. The following are descriptions of visual symptoms for N, P, K, Mg, and S at the initial and moderate stage of deficiency for stock plants and stem cuttings of strawflower. The number of days to each symptom refers to time from the start of deficiency treatments (Fig. 4.4). Corresponding tissue concentrations at incipient and moderate stages are found in Table 4.4. Initial and moderate shoot and root dry weight comparisons to the control are indicated in Figures 4.5 and 4.6.

Nitrogen. Incipient deficiency symptoms appeared 9 d after treatments were initiated with a foliar N concentration of 3.29%, compared to 6.08% for the control (Table 4.4).

Three WAS, rooting quality was similar (2.57) between N-deficient and control cuttings harvested at the incipient stage. Shoot and root dry weights and the root:shoot ratio (0.191) were similar to the control cuttings (Figs. 4.5 and 4.6).

On day 15, the foliar N concentration for the moderate stage of deficiency was 3.01%, as compared to 6.98% for the control (Table 4.4). Three WAS, rooting quality was similar (2.08) between N-deficient and control cuttings harvested at the moderate stage. Shoot dry weight was greater with N-deficient cuttings (Fig. 4.5), but root dry weights were similar (Fig. 4.6). The root:shoot ratio of control cuttings (0.171) was significantly greater than N-deficient cuttings (0.149) at $P \leq 0.01$.

Results indicate that low N levels of 1.46% to 3.66% in the cutting tissue did not affect rooting quality. In Expt. 2, N-deficient cuttings harvested at the moderate stage produced greater shoot dry weights and smaller root:shoot ratios than control cuttings. These results are contrary to the Thornley model, which states that a N deficiency causes the root:shoot ratio to increase because a greater part of the nutrient is used by the root system for growth (Wilson, 1988). Propagators should maintain N tissue levels in stock plants of strawflower above the minimum critical value of 3.66% to avoid the occurrence of cutting lower leaf yellowing followed by necrosis.

Phosphorus. Incipient deficiency symptoms appeared 15 d after treatments were initiated with a foliar P concentration of 0.34%, compared to 1.02% for the control (Table 4.4). Three WAS, rooting quality was similar (2.10) between P-deficient and control cuttings. Shoot dry weight was greater with P-deficient cuttings (Fig. 4.5), but root dry weights

were similar (Fig. 4.6). The root:shoot ratio of control cuttings (0.171). was significantly greater than P-deficient cuttings (0.143) at $P \leq 0.001$.

On day 26, P-deficient plants developed moderate symptoms with a foliar P concentration of 0.18%, compared to 0.86% for the control (Table 4.4). Three WAS, rooting quality was similar (2.40) between P-deficient and control cuttings. Shoot and root dry weights were greater with P-deficient cuttings (Figs. 4.5 and 4.6). The root:shoot ratio of P-deficient cuttings (0.115) was greater than the control (0.097) at $P \leq 0.05$.

Unlike in Expt. 1, P-deficient cuttings harvested at the incipient and moderate stage had similar root quality ratings and greater root:shoot ratios, compared to the control. Differences between experiments may have been due to varying P concentrations in the tissue. Similarities between experiments occurred with the appearance of dark green young and recently mature cutting leaves. Phosphorus-deficient cuttings at an incipient level may be more appealing to propagators than cuttings from standard fertilized plants, however, more research is needed to determine if low P fertilization of strawflower is a practical strategy in a stock plant fertilization program. At this time, propagators should maintain tissue P levels > 0.34%.

Potassium. Incipient deficiency symptoms appeared 7 d after treatments were initiated with a foliar K concentration of 3.55%, compared to 7.47% for the control (Table 4.4). Three WAS, rooting quality was similar (2.35) between K-deficient and control cuttings. Shoot and root dry weights and the root:shoot ratio (0.257) were similar to the control cuttings (Figs. 4.5 and 4.6).

At a moderate stage of deficiency (day 15), foliar K concentration was 2.24%, compared to 8.18% for the control (Table 4.4). Three WAS, rooting quality was similar (2.06) between K-deficient and control cuttings. Shoot dry weight was similar to the control cuttings (Fig. 4.5), but the K-deficient cuttings had smaller root dry weights than the control (Fig. 4.6). The root:shoot ratio of K-deficient cuttings (0.167) was similar to the control.

Based on our research, harvesting cuttings at the incipient stage of K deficiency does not decrease rooting, but does result in reduced leaf chlorosis. Harvesting cuttings at a moderate stage of deficiency resulted in severe K deficiency symptoms and smaller root dry weight. Low levels of K in the tissue resulted in shorter cuttings, a characteristic desired by propagators. Determining the lowest K concentration at which stock plants can be fertilized without the occurrence of deficiency symptoms, decreased rooting, and maintaining compact growth on cuttings should be investigated. At this time, propagators should maintain tissue K levels above the minimum critical level of 3.55%

Magnesium. Incipient deficiency symptoms appeared 11 d after treatments were initiated with a foliar Mg concentration of 0.14%, compared to 0.30% for the control (Table 4.4). Three WAS, rooting quality was similar (2.39) between Mg-deficient and control cuttings. Shoot and root dry weights and the root:shoot ratio (0.186) were similar to the control cuttings (Figs. 4.5 and 4.6).

At the moderate stage of deficiency (day 15), the foliar Mg concentration was 0.13%, compared to 0.31% for the control (Table 4). Three WAS, rooting quality was greater for the Mg-deficient cuttings (2.29) than the control cuttings (2.19) at $P \leq 0.05$.

Shoot and root dry weights and the root:shoot ratio (0.168) were similar to the control cuttings (Figs. 4.5 and 4.6).

Stock plant Mg tissue levels for strawflower should be maintained above 0.14% because of the potential for cuttings to lose their lower leaves to advanced interveinal chlorosis followed by necrosis. A greater root quality rating with cuttings harvested from a moderate stage of deficiency may be due to the translocation of nutrients from abscising leaves to the roots.

Sulfur. Incipient deficiency symptoms appeared 13 d after treatments were initiated with a foliar S concentration of 0.25%, compared to 0.25% for the control (Table 4.4). Three WAS, rooting quality was similar (2.06) between S-deficient and control cuttings. Shoot and root dry weights and the root:shoot ratio (0.182) were similar to the control cuttings (Figs. 4.5 and 4.6).

At the moderate stage of deficiency (day 26), foliar S concentration was 0.14%, compared to 0.23% for the control (Table 4.4). Rooting quality was similar (2.43) between S-deficient and control cuttings. Shoot and root dry weights were similar between the control and S-deficient cuttings (Figs. 4.5 and 4.6). The root:shoot ratio of S-deficient cuttings (0.119) was significantly greater than control cuttings (0.097) at $P \leq 0.01$.

Sulfur deficient stock plants produced cuttings with similar rooting quality values to the control for Expts. 1 and 2, however, foliar deficiency symptoms negatively affected the appearance of the cuttings. Propagators should maintain S tissue levels above the minimum critical value of 0.25%

Conclusions

The impact of a light and moderate deficiency of each of 11 essential plant nutrients on rooting of stem cuttings of strawflower was investigated. The macronutrients N, P, K, Mg, and S produced the most notable results in Expt. 1 and were repeated in Expt. 2. Levels of N between 1.46% and 3.66% in the cutting tissue did not affect rooting, but the mature cutting foliage developed chlorosis and necrosis at the incipient and moderate stages, respectively. Strawflower is tolerant of low P, however, low P in the cutting tissue negatively affected rooting in Expt. 1, but low P in the cutting tissue during the second experiment did not. Lower concentrations of K may improve rooting if cuttings are harvested at levels near 1.5%, however, similar rooting results occurred between K-deficient and control cuttings in Expt. 2. Future research is needed to determine the threshold levels of K in cutting tissue that does not result in severe foliar deficiency symptoms (interveinal chlorosis of the young leaves and marginal necrosis of the mature leaves), yet produces more roots than control cuttings.

Good and Tukey (1967) reported that macronutrients were redistributed from mature parts of chrysanthemum cuttings to the new growth. Roots and leaves of stem cuttings of chrysanthemum, rooted under distilled water mist, developed and grew due to translocation of N, P, and K. Translocation of nutrients was evident with N, P, K, and Mg deficiencies in strawflower, as upper foliage was darker green than the control. Translocation of Ca and B is hindered in propagation, therefore Ca and B should always be applied to the stock plant at recommended concentrations because cuttings will develop shoot tip necrosis under high humidity environments.

Zinc deficiency negatively affected rooting. Strawflower may have adapted to low Zn in its native soil, and as a result may be susceptible to poor rooting in soilless propagation substrates. Copper and Mn-deficient cuttings produced smaller root dry weights at a moderate stage of deficiency, but these deficiencies occur rarely during production. Although Cu, Fe, Mg, Mn, and S deficiencies did not affect cutting rooting quality at the incipient stage, they produced cuttings with foliar symptoms not desired by propagators.

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Table 4.1. Tissue nutrient concentration at initial and moderate stages of 11 nutrient deficiencies in recently matured leaves of stock plants of 'Florabella Pink' strawflower (Expt. 1).

Treatment	-N	-P	-K	-Ca	-Mg	-S	-B	-Cu	-Fe	-Mn	-Zn
Nutrient	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	Percent dry wt.						$mg \cdot kg^{-1}$ of dry wt.				
						Initial Deficiency					
Control	6.61	0.74	5.88	1.06	0.23	0.20	34.7	7.0	59.4	183.0	41.4
Deficient	3.66	0.19	1.58	0.30	0.12	0.12	9.1	2.0	44.9	20.0	18.3
Significance[z]	***	***	***	***	**	***	***	***	*	***	**
						Moderate Deficiency					
Control	4.70	0.51	4.91	0.94	0.21	0.21	33.8	4.27	72.3	138.7	35.6
Deficient	1.46	0.09	0.97	0.17	0.06	0.09	8.2	1.9	48.2	9.8	19.4
Significance[z]	***	***	***	***	***	***	***	***	***	***	*

[z] *, **, ***; Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 4.2. Rooting quality at initial or moderate stages of P, K, Ca, Fe and Zn deficiencies in cuttings of 'Florabella Pink' strawflower (Expt. 1).

Treatment	-P	-K	-Ca	-Zn	-P	-Ca	-Fe	-Zn
Nutrient	P	K	Ca	Zn	P	Ca	Fe	Zn
	Initial Deficiency				Moderate Deficiency			
Control	2.62	1.66	2.62	2.44	2.00	2.34	1.66	2.53
Deficient	2.10	2.43	1.41	1.86	1.48	1.32	2.17	1.49
Significance[z]	**	***	***	***	**	***	**	***

[z] **, ***; Significant at $P \leq 0.01$ or 0.001, respectively.

Table 4.3. Root to shoot ratio at initial or moderate stages of N, K, Mg, B, and Zn deficiencies in cuttings of 'Florabella Pink' strawflower. (Expt. 1).

Treatment	-Mg	-Zn	-N	-K	-B	-Zn
Nutrient	Mg	Zn	N	K	B	Zn
	Initial Deficiency		Moderate Deficiency			
Control	0.171	0.171	0.101	0.146	0.146	0.154
Deficient	0.204	0.193	0.132	0.187	0.210	0.183
Significance[z]	**	*	**	***	***	*

[z] *, **, ***; Significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

Table 4.4. Tissue nutrient concentration at initial and moderate stages of N, P, K, Mg and S deficiencies in recently matured leaves of stock plants of 'Florabella Pink' strawflower (Expt. 2).

Treatment	-N	-P	-K	-Mg	-S
Nutrient	N	P	K	Mg	S
			Percent dry wt.		
Initial Deficiency					
Control	6.08	1.02	7.47	0.30	0.25
Deficient	3.29	0.34	3.55	0.14	0.25
Significance[z]	***	***	***	***	NS
Moderate Deficiency					
Control	6.98	0.86	8.18	0.31	0.23
Deficient	3.01	0.18	2.24	0.13	0.14
Significance[z]	***	***	***	***	***

[z] ***; Significant at $P \leq 0.001$, or NS = not significant.

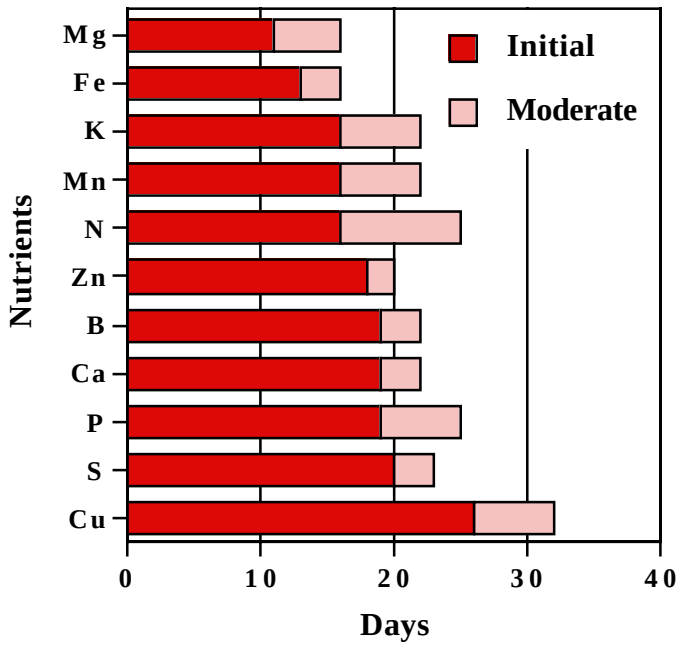

Figure 4.1. Days to develop specific initial or moderate nutrient deficiency symptoms for 'Florabella Pink' strawflower (Expt. 1).

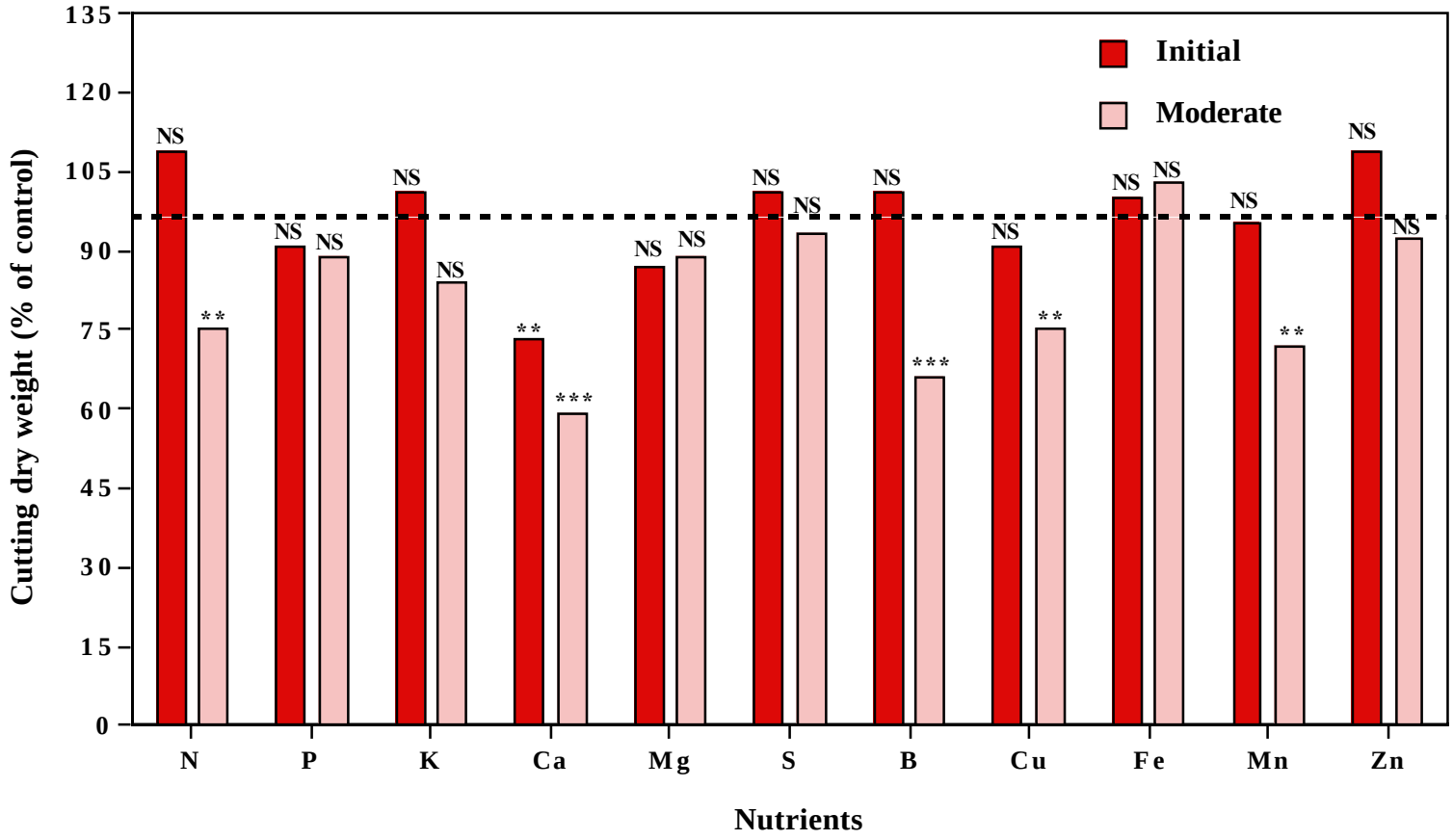

Figure 4.2. Shoot dry weight of nutrient deficient cuttings of 'Florabella Pink' strawflower expressed as a percentage of control cuttings at incipient and moderate stages (Expt. 1). **, ***, Significant at $P \leq 0.01$ or 0.001, respectively, or NS = not significant.

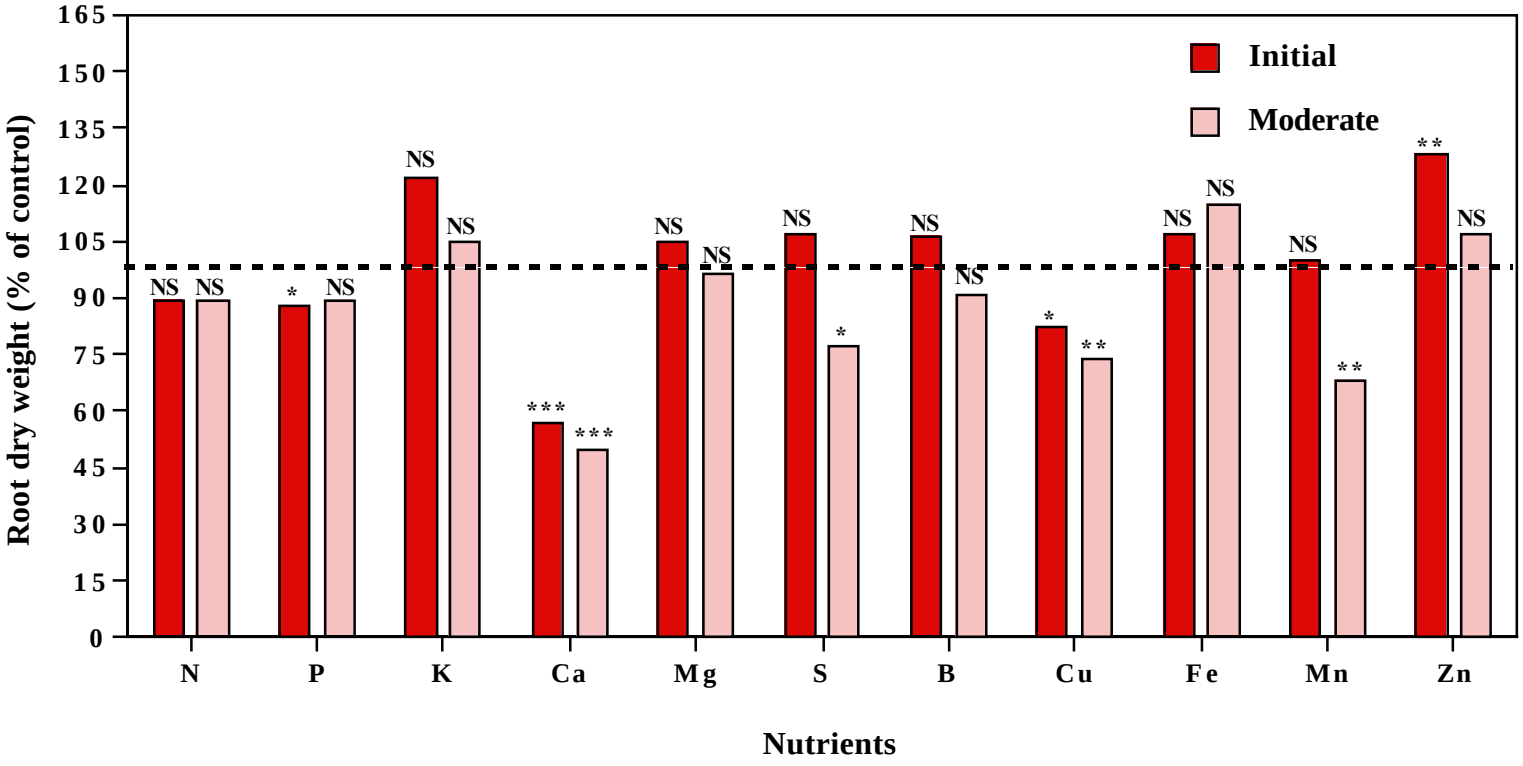

Figure 4.3. Root dry weight of nutrient deficient cuttings of 'Florabella Pink' strawflower expressed as a percentage of control cuttings at incipient and moderate stages (Expt. 1). *, **, ***, Significant at $P \leq 0.05, 0.01, 0.001$, respectively, or NS = not significant.

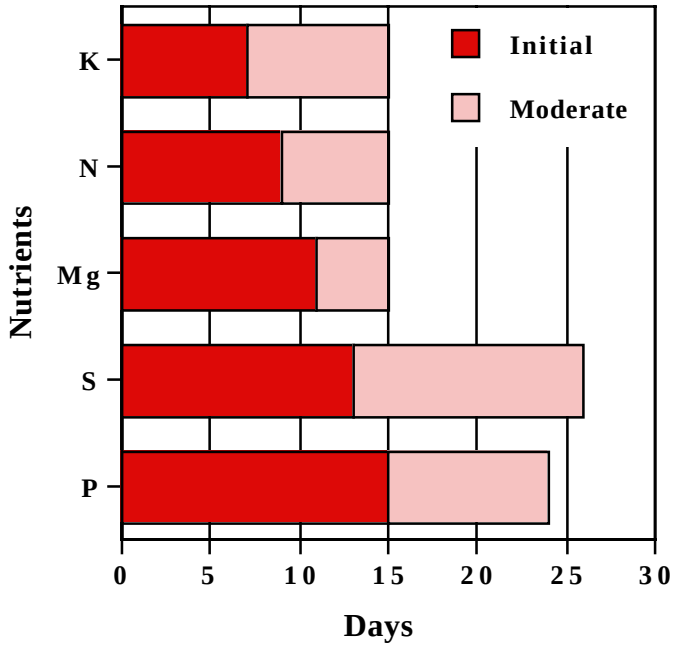

Figure 4.4. Days to develop specific initial or moderate nutrient deficiency symptoms for 'Florabella Pink' strawflower (Expt. 2).

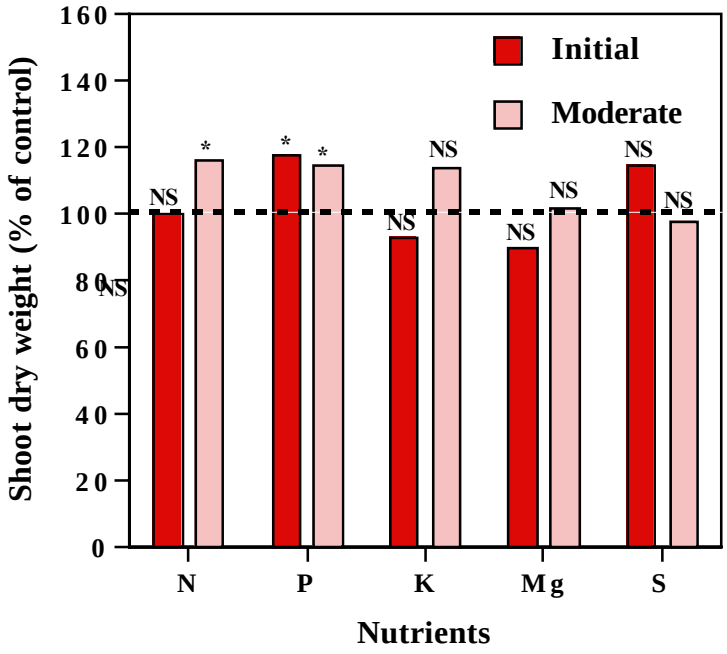

Figure 4.5. Shoot dry weight of nutrient deficient cuttings of 'Florabella Pink' strawflower expressed as a percentage of control cuttings at incipient and moderate stages (Expt. 2). * Significant at $P \leq 0.05$, or NS = not significant.

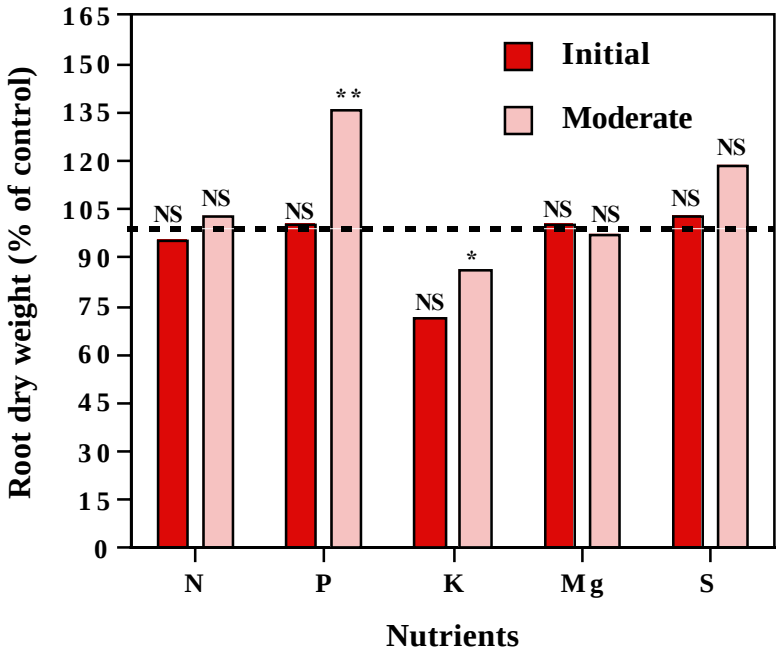

Figure 4.6. Root dry weight of nutrient deficient cuttings of 'Florabella Pink' strawflower expressed as a percentage of control cuttings at incipient and moderate stages (Expt. 2). * Significant at $P \leq 0.05$, or NS = not significant.

Chapter 5

Influence of Potassium Fertilization on Yield and Subsequent Rooting of Stem Cuttings from Stock Plants of Vegetative Strawflower

(in the format appropriate for submission to HortScience)

Subject Category: Propagation and Tissue Culture

Influence of Potassium Fertilization on Yield and Subsequent Rooting of Stem Cuttings from Stock Plants of Vegetative Strawflower

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Subject Category: Propagation and Tissue Culture

Influence of Potassium Fertilization on Yield and Subsequent Rooting of Stem Cuttings from Stock Plants of Vegetative Strawflower

Additional index words. *Bracteantha bracteata*, hydroponics, foliar analysis, mineral nutrition, vegetative propagation

Abstract. Yield and subsequent rooting of stem cuttings of stock plants of strawflower [*Bracteantha bracteata* (Vent.) A.A. Anderberg] were recorded when fertilized with K at 0, 29, 59, 117, or 234 $mg \cdot L^{-1}$. Cutting height was also evaluated because previous research had shown that lower concentrations of K produced compact shoots with commercially acceptable roots. While a threshold level of K at 32 $mg \cdot L^{-1}$ achieved the highest number of cuttings, rooting was not different with cuttings from stock plants fertilized with K at 59 to 234 $mg \cdot L^{-1}$. Deficiency symptoms appeared on stock plants fertilized with K at 59 $mg \cdot L^{-1}$ and less with necrosis on mature leaf tips and interveinal chlorosis on recently mature leaves. The minimum stock plant recently mature leaf K concentration necessary to avert unacceptable deficiency symptoms during subsequent rooting of cuttings was found to be between 4.7 and 6.6% K. Stock plants of strawflower can be fertilized at 1N:1.1K (N at 217 $mg \cdot L^{-1}$ and K at 234 $mg \cdot L^{-1}$) or 2N:1K

(N at 217 $mg \cdot L^{-1}$ and K at 117 $mg \cdot L^{-1}$) ratios because upper cutting foliage did not exhibit deficiency symptoms and optimal cutting yield and rooting occurred.

Introduction

Low K fertilization programs are not used commonly because most floriculture crops perform best at a 1N:1K ratio (Nelson, 1996). The exceptions are carnation (*Dianthus caryophyllus* L.) and cyclamen (*Cyclamen persicum* Mill.) which require a 1N:1.5K and 1N:2K ratio, respectively, during the active growth phase. Potassium is partly responsible for maintaining cell turgor, enzyme activation, stomate regulation, disease resistance, and protein synthesis (Marshner, 1995). Fertilizing stock plants at lower concentrations of K can be problematic. For example, K deficiency can reduce transpiration, which ultimately affects nutrient translocation and photosynthesis (Hsiao and Lauchli, 1986). Potassium is responsible for assisting in carbohydrate translocation to the meristematic regions (Marshner, 1995), thus K deficiencies can cause stunting of the growing tips. Henry et al. (1992) found a strong correlation between K level and rooting percentage and root length in stem cuttings of eastern redcedar (*Juniperus virginiana* L.). Krause (1981) reported that the amount of K in a fertilizer increased the number of stem cuttings of chrysanthemum (*Dendranthema* x *grandiflorum* Kitam.) when applied as a top dressing. Roeber (1976, 1978) maintains that K does not contribute to increased cutting production, but instead enhances the cutting's capacity to develop roots more easily under low light conditions.

A high root:shoot ratio is recommended for newly rooted cuttings because it avoids factors that reduce plug quality: stretched internodes, excessive soft foliage, and a

poorly developed root system. The root:shoot ratio increases with applications of high NO_3-N/ low NH_4-N and at least 6% Ca in the irrigation water (Styer and Koranski, 1997). Based on the Thornley model (Wilson, 1988), nutrient deficiencies cause the root:shoot ratio to increase, as a greater part of the nutrient is used by the root system for growth.

The preplant or postplant fertilization program should be reduced or eliminated to achieve shorter plugs and cuttings. Reducing P and K fertilizer concentrations have been recommended for impatiens (*Impatiens wallerana* Hook. f.), petunia (*Petunia* x *hybrida* Hort. Vil.-Andr.), salvia (*Salvia splendens* F. Sellow ex Roem. & Schult.), and vinca (*Catharanthus roseus* L.) plug production, due to their ineffectiveness on shoot growth (Van-Iersel, 1998a). However, eliminating the preplant or reducing the postplant N, P, and K causes a reduction in tone, but researchers found that it did not delay production of the finished crop (Nelson et al., 1996). Posttransplant growth of impatiens plugs was reduced when preplant concentrations of P and K decreased from 1 to 0.25 mM (Van-Iersel et al., 1998b).

Nutrient stresses on young plants has been shown to improve visual appearance of bedding plant plugs. Low applications of P (restricting P to 15% to 20% of the N level) have been shown to reduce plant height, improve tone, and increase rooting (Nelson et al, 1996). Crops such as marigold (*Tagetes patula* L.), impatiens, and gomphrena (*Gomphrena globosa* L.) were subjected to P deficiencies and were more compact and deeper green than fertilized plants, however the crops of impatiens and gomphrena were delayed by 5 d. Cox (2001) reported smaller plant heights in marigold, salvia, and petunia when a soilless medium was used with no starter charge and a low P fertilizer was applied, compared to commercial mixes containing starter charges.

Inducing nutrient deficiencies in floriculture crops has been shown to improve the tone and maintain shorter internodes of several seed propagated crops such as vinca, salvia, and pansy (*Viola* x *wittrockiana* Gams.) (Pitchay et al., 2002). Stem cuttings from K deficient stock plants were shorter and had more roots than control cuttings 3 weeks after sticking (WAS) (Gibson et al., 2003). These traits would be of benefit to propagators that wish to package higher quality, stockier cuttings with more roots per box.

The vegetatively-propagated strawflower [*Bracteantha bracteata* (Vent.) A.A. Anderberg] has introduced rooting challenges to propagators, even after standard growing conditions have been provided (Ron Cramer, Paul Ecke Ranch, personal communication). Indequate fertilization of the stock plants was suspected, and Gibson et al. (2003) determined that low cutting tissue concentrations of Ca, P, and Zn negatively affect rooting performance. However, one nutrient that was shown to improve rooting with lower concentrations in the cutting tissue was K.

Little research has been conducted on restricting K concentration for floriculture crops to maintain compact cutting shoots and increase rooting. Plants in an active growth phase have a higher K-requirement (Nelson, 2002). Because stock plants are continually producing new shoots, low K fertilization may be detrimental to cutting yield, quality, and rooting performance. Research is required to determine the threshold concentration of K where cutting yield and quality are not reduced and rooting is improved. Therefore, the objectives of this research were to determine the relationship between cutting yield of stock plants of strawflower and K fertilization, to determine stock plant tissue K

concentrations associated with quality cuttings, and to evaluate adventitious rooting and height of cuttings removed from the stock plants.

Materials and Methods

Unrooted stem cuttings 'Florabella Pink' strawflower were inserted in Oasis LC1 foam cubes (Smithers Oasis, Kent, Ohio) containing only Ca and Mg from dolimitic limestone on 28 Nov. 2002. The experiment was conducted in a glass greenhouse in Raleigh, N.C. at 35°N latitude that was set at night/cloudy day/clear day temperatures of 17/21/24 °C. During the establishment phase, cuttings were fertilized at each irrigation with the following mM concentrations of nutrients: 0.35 NH_4, 5.15 NO_3, 0.35 PO_4, 1.0 K, 1.25 Ca, and 1.0 Mg, plus 36 μM Fe. The following reagent grade chemicals were used: NH_4NO_3, KNO_3, K_2HPO_4, $Ca(NO_3)_2 \cdot 4H_2O$, $MgSO_4 \cdot 7H_2O$, and FeDTPA (Pitchay, 2002). Cuttings were grown with this nutrient regime until roots were visible at the edges of the rooting cube.

Cuttings were pinched 13 Dec. 2002 by removing 2.0 cm of growth from the terminal tip. After establishment, plants were transplanted 29 Dec. into 4.87-L aluminum painted plastic tubs with six circular holes in the lids. The experiment was a randomized complete-block design with nine replications assigned to five treatments, each consisting of one tub with six rooted cuttings. Plants were grown with modified Hoagland's all nitrate solutions containing K at 0, 29, 59, 117, or 234 $mg \cdot L^{-1}$(Hoagland and Arnon, 1950). Macronutrients and micronutrients were obtained from reagent grade salts to create stock solutions (Table 5.1). Specific amounts of stock solution (Table 5.2) and deionized water of 18-mega ohms purity were used to develop 113-L nutrient solutions

(Table 5.3). Tubs were inspected daily and nutrient solution was added as needed to maintain the nutrient solution volume as needed. A complete replacement of nutrient solutions was done weekly. Stock plant photographs and descriptions of foliage were taken 22 Jan., 12 Feb., and 5 Mar. 2003.

The most recently mature, fully expanded leaves on stock plants were sampled from three replicates per treatment 22 Jan., 12 Feb., and 5 Mar. 2003 [(3, 6, and 9 weeks after potting (WAP)] The tissue samples were first rinsed in deionized water, then washed in 0.2 N HCl for 30 s, and dried at 70 °C for 24 h. Dried tissue was ground in a stainless steel Wiley mill to pass a 1-mm screen (20-mesh). Tissue was then analyzed for macro and micronutrients with the exceptions of N, using a Perkin Elmer 3300 Inductively Coupled Argon Plasma Emission Spectrophotometer (Perkin Elmer, Shelton, Conn.), while N was analyzed using Carlo Erba NA 1500 Series 1, O_2 combustion Nitrogen Analyzer (Carlo Erba, Lakewood, N.J.) at the N.C. Dept. of Agric. Laboratory, Raleigh.

Harvests 1 and 2. Terminal stem cuttings (≥ 9.0 cm in length) from stock plants of 'Florabella Pink' strawflower were removed and counted three (22 Jan.) and six (12 Feb.) WAP. Cuttings were trimmed from the bases to a length of 8.25 cm and dipped for 1 s in 3,000 $mg \cdot L^{-1}$ indole-3-butyric acid (IBA). A total of 108 cuttings per treatment were randomly selected across the 9 replications within each treatment; the experimental design was a completely randomized design with 18 replications per treatment and six sub-samples per replication. Basal portions of cuttings (1.0 cm) were inserted into moist perlite in 3.8 x 3.8 x 8.9 cm 6-cell containers. Cuttings were hand misted daily as needed with deionized water under a white plastic humidity tent. Bottom heat at 21 °C was

provided for 3 weeks. Cuttings were maintained under natural photoperiod and irradiance with days/nights of 20/18 °C.

Basal 0.5-cm stem sections were selected randomly on 0, 2, 4, 6, 8, 10, or 12 days after sticking (DAS) and were fixed in formalin-acetic acid-ethanol (FAA) in vacuo, embedded in parafin after serial hydration in ethanol-tertiary butyl alcohol, serially sectioned at 14 μm, stained with safranin and alcial green, and then observed microscopically for root primordia formation and development (Davies et al., 1982).

Two weeks after sticking (WAS), cuttings were subirrigated with a nutrient solution containing 3.57 mM $Ca(NO_3)_2$ and 45 μM B. Three WAS, cuttings were evaluated for rooting quality based on a 0 to 5 scale: 0= no roots, 1= one root, 2= two or more roots with uneven rooting around the cutting base, 3= uniform rooting around base with roots shorter than 1 cm, 4- uniform rooting with roots 1.0 to 2.0 cm long, 5= uniform rooting with roots ≥ 2.0 cm. Cutting root (adventitious roots plus 1.0 cm of the cutting base) and shoot dry weight were recorded 3 and 4 WAS. Cutting height (measured from the container rim to the shoot tip) was measured 4 WAS. Cuttings were also harvested 4 WAS and data recorded on root area (in cm^2) and root length (in cm) (Decagon, Pullman, Wash.). Cutting photographs and descriptions of foliage were taken 2, 3, and 4 WAS.

Harvest 3. Terminal stem cuttings (≥ 9 cm in length) from stock plants of 'Florabella Pink' strawflower were harvested and counted nine (5 Mar.) weeks after potting. Five replications of the five treatments were also harvested for stock plant shoot and root dry weight on 5 Mar. Forty-eight cuttings per treatment were randomly selected and rooted in a 1 sphagnum peat : 1 perlite (v/v) substrate for evaluation of root and shoot

performance. Two WAS, cuttings were evaluated for rooting quality, root and shoot dry weight, and height. On 19 Mar. cuttings were fertilized with N at 200 $mg \cdot L^{-1}$ from KNO_3 (13N-0P-36.5K). Three WAS, cuttings were evaluated for rooting quality based on a 0 to 5 scale: 0= no visible roots, 1= roots in top quarter of the rootball, 2= roots in top half of the rootball, 3= roots in three quarters of the rootball, 4= roots to the bottom of the rootball, and 5= well-defined roots throughout the rootball. Cutting shoot weight and height were also measured 3 WAS.

All the data were subjected to analysis of variance (ANOVA) procedures using PROC GLM SAS program (SAS Inst., Cary, N.C.). Yield and K tissue concentration were subjected to ANOVA by general linear model procedures and regressions determined by PROC REG (SAS Inst., Cary, N.C.). The NLIN procedure in SAS (SAS Inst., Cary, N.C), as modified by Cox (1992), was used to calculate linear plateau functions model (IV) relating yield and shoot dry weight of stock plants and the root:shoot ratio of cuttings to K concentration. Where the F test indicated significant difference among the means, LSD ($P \leq 0.05$) was used to establish differences between means.

Results

Harvests 1 and 2

Stock plant descriptions. The following are the stock plant visual symptoms three (22 Jan.) and six (12 Feb.) WAP. Stock plants fertilized with K at 234 $mg \cdot L^{-1}$ exhibited a medium green color and uniform lateral shoot and leaf expansion. Narrower leaves and a more upright habit with smaller cuttings arising from the main shoots were observed on

stock plants fertilized with K at 117 $mg \cdot L^{-1}$, compared to 234 $mg \cdot L^{-1}$. Similar sized leaves to K at 117 $mg \cdot L^{-1}$ were produced on stock plants fertilized at 59 $mg \cdot L^{-1}$, along with downward curled mature leaves. Marginal necrosis on the oldest set of leaves and stunted shoots were first observed on stock plants fertilized with K at 29 $mg \cdot L^{-1}$. Stock plants not fertilized with K were compact and had narrow and twisted young leaves with pointed tips. The oldest set of leaves was either glossy with dark green tips or expressed distinct yellow-green margins with necrotic tips.

Tissue analysis. Corresponding tissue concentrations 3 and 6 WAP are listed in table 5.4 and 5.5, respectively. Three WAP, stock plant N (7.46%) and Zn (37.9 $mg \cdot kg^{-1}$) were similar for all K treatments. Stock plants fertilized with K at 29 to 234 $mg \cdot L^{-1}$ had similar S, Cu, and Mn tissue levels which were lower than K at 0 $mg \cdot L^{-1}$ (Table 5.4). There was an overall trend for P and B concentrations to decrease and Fe to increase as K concentration increased. As the concentration of K increased from 0 to 234 $mg \cdot L^{-1}$, K tissue concentration increased from 0.97 to 8.22% (Fig. 5.1), while Ca and Mg tissue concentrations were highest with K at 59 $mg \cdot L^{-1}$ and then declined (Table 5.4). A reduction in Ca and Mg concentration, due to competition from K, has been reported in poinsettia (*Euphorbia pulcherrima* Willd. Ex. Klotsch) by Cox and Seely (1984). Potassium tissue concentrations, associated with K fertilizer levels of 29 to 234 $mg \cdot L^{-1}$, were above the minimum critical level for deficiency of 3.55% as reported by Gibson et al. (2003).

Six WAP stock plant N tissue levels were similar (6.67%) for all K treatments (Table 5.5). Phosphorus, S, B, Cu, Mn, and Zn tissue levels were greater for K at 0 $mg \cdot L^{-1}$ when compared to K at 29 to 234 $mg \cdot L^{-1}$. Smaller leaf size with K at 0 $mg \cdot L^{-1}$ may have

influenced nutrient concentration, as tissue levels become diluted in larger-sized leaves (Rueter and Robinson, 1997). Iron levels were equivalent from K at 0 to 117 $mg \cdot L^{-1}$ and then increased with increasing K concentration. As the concentration of K increased from 0 to 234 $mg \cdot L^{-1}$, K tissue concentration increased from 0.62 to 7.72% (Fig. 5.1). Stock plants fertilized with K at 29 $mg \cdot L^{-1}$, produced tissue deficient in K (2.95%) based on the minimum critical value of 3.55% established by Gibson et al. (2003). Calcium and Mg tissue concentrations were highest with K at 59 $mg \cdot L^{-1}$ and then declined (Table 5.5), again suggesting a K antagonism.

Cutting yield. A similar number of cuttings (24) were harvested 3 WAP for all of the K treatments (Figure 5.2). Similar yield among the K treatments may have been due to stock plants having sufficient K reserves due to luxurious consumption during their nursing phase in propagation. Young actively growing plants readily absorb K (Nelson, 1996). Yield differences began to occur 6 WAP when more cuttings were generated from stock plants fertilized with K at 234 $mg \cdot L^{-1}$ than 0 to 59 $mg \cdot L^{-1}$. Fertilizing with K at 117 to 234 $mg \cdot L^{-1}$ produced a similar yield, however a similar quantity of cuttings was generated with K at 29 to 117 $mg \cdot L^{-1}$.

Histology. It was determined on day 4 that root primordia initiation in the basal stems of all treatments occurred (Fig. 5.3A). The root primordia began to elongate by day 6 (Fig. 5.3B) and on day 8 (Fig. 5.3C), visible rooting had occurred for all K treatments. Although cutting tissue was deficient in K when stock plants were fertilized at concentrations $\leq$ 29 $mg \cdot L^{-1}$, root initiation was not affected. Potassium has not been reported to have an effect on root initiation (Blazich, 1988), and Good and Tukey (1967)

reported that only P was translocated from the foliage to the basal stem tissue of stem cuttings of chrysanthemum during root initiation.

Harvest 1 cutting descriptions. Cuttings harvested from stock plants fertilized with K at 117 to 234 $mg \cdot L^{-1}$ had young leaves that were darker green than the lower foliage. Some older leaves had a pale yellow chlorosis, while the midvein remained darker green. Cuttings from plants fertilized with K at 59 $mg \cdot L^{-1}$ had narrower young leaves than plants fertilized with K at 117 to 234 $mg \cdot L^{-1}$. The oldest leaves were curled downward and had a more pronounced number of chlorotic leaves than K at 117 to 234 $mg \cdot L^{-1}$. Some lower leaves had a marginal necrosis with a chlorotic band that started at the base of the cutting and moved to the tip of the leaves. There was also visible signs of patchy chlorosis on the recently mature leaves. Cuttings from stock plants fertilized with K at 29 $mg \cdot L^{-1}$ had mature leaves with a tip burn and some marginal necrosis, while the youngest leaves had a patchy chlorosis near the midvein. Cuttings from stock plants not fertilized with K were more compact than cuttings from plants fertilized with K at 29 to 234 $mg \cdot L^{-1}$ and had mature leaves with a distinct marginal necrosis; some leaves were completely necrotic. The oldest set of leaves were patchy with green and yellow splotches. Overall cuttings were pale yellowish-green with interveinal chlorosis on the youngest leaves. These youngest leaves were rolled, narrow, and needle-like. The axillary shoots were completely necrotic and hidden in the stem axils.

Harvest 2 cutting descriptions. Cuttings from stock plants fertilized with K at 234 $mg \cdot L^{-1}$ had youngest leaves that were dark green with medium-green young leaves. Some of the young leaves were rolled inwards. The mature leaves had a whitish yellow petiole leading to a pale yellow lamina with some necrosis on the tip. The older leaves were

upright in habit and darker green, but some expressed an interveinal chlorosis. Youngest leaves from stock plants fertilized with K at 117 $mg \cdot L^{-1}$ were medium green, more needle-like and more upright in growth habit than K at 234 $mg \cdot L^{-1}$. The recently mature leaves were rolled upward. The oldest mature leaves turned medium green color and progressed to a greenish-yellow color with some necrosis on the tips. These leaves also had whitish midribs with a droopier habit than K at 234 $mg \cdot L^{-1}$. Cuttings from stock plants fertilized with K at 59 $mg \cdot L^{-1}$ had interveinal chlorosis on the young leaves while the recently mature leaves had undulating leaf margins and were narrower than K at 117 $mg \cdot L^{-1}$. The oldest mature leaves turned a medium green color and progressed to a greenish-white. The lower leaves bowed downwards while upper growth became greenish-yellow and similar to the lower foliage. Cuttings from stock plants fertilized with K at 29 $mg \cdot L^{-1}$ had young leaves with interveinal chlorosis, while the youngest leaves had either a deep brown necrotic tip or chlorotic tip. Some of the youngest leaves were twisted and rolled at the tip and were narrower than K at 234 to 59 $mg \cdot L^{-1}$. The recently mature leaves were deep green with a tip necrosis. The oldest leaves had a whitish-yellow color with a well-defined necrotic margin and the tips of oldest leaves curl downward. On the mature leaves, a patchy greenish-yellow color with some dark brown necrosis occurred on the tip. Cuttings fertilized with K at 29 $mg \cdot L^{-1}$ had a more downward growing habit than K at 234 to 59 $mg \cdot L^{-1}$, but were similar to K at 59 $mg \cdot L^{-1}$ in appearance, but upper growth was a brighter greenish-yellow. Cuttings from stock plants that received no K produced cuttings that were compact and had pointed and twisted young leaves with extremely narrow tips. These young leaves expressed a reddish-brown necrosis. The young leaves were glossy and needle-like, while the recently mature leaves were dark green and glossy

with a faint interveinal chlorosis. A tight compact rosette-like shoot apex was observed because lower foliage had abscised. The youngest and young leaves were more upright in habit than any other treatment.

Based on yield, foliar descriptions, and tissue concentrations of the stock plants 3 and 6 WAP, stock plants of strawflower should be fertilized with K concentrations ≥ 117 $mg \cdot L^{-1}$. Fertilizing with 1N:1.1K (N at 217 $mg \cdot L^{-1}$ and K at 234 $mg \cdot L^{-1}$) or 2N:1K (N at 217 $mg \cdot L^{-1}$ and K at 117 $mg \cdot L^{-1}$) ratios produced the maximum number of cuttings with medium green foliage 6 WAP. Also, foliar symptoms in cuttings fertilized with K at 117 to 234 $mg \cdot L^{-1}$ were restricted to lower leaf chlorosis with tip necrosis during propagation. Although Ca and Mg tissue concentrations were lower in plants fertilized with K at 117 and 234 $mg \cdot L^{-1}$ compared to K at 59 $mg \cdot L^{-1}$, there were less foliar symptoms in cuttings from the former cuttings, suggesting no stresses of Ca and Mg.

Three WAS cutting performance. Cuttings harvested 3 and 6 WAP were evaluated on 12 Feb. and 5 Mar. The week x K interaction was not significant, therefore the data were pooled by K concentration (Table 5.6). Rooting quality and root weight were significant, but not consistent with K concentration. Rooting performance of cuttings were similar from plants fertilized with K at 0 and 234 $mg \cdot L^{-1}$ may be attributed to similar tissue concentrations of N and Zn and increased levels of P and B in K-deficient cuttings. These nutrients were all important in successful rooting of strawflower (Gibson et al., 2003). Shoot dry weight increased while the root:shoot ratio decreased with increasing K (Fig. 5.4). These results agree with the Thornley model (Wilson, 1988) which states that the root:shoot ratio decreases when nutrients are not deficient in plants.

Four WAS cutting performance. Cuttings harvested 3 and 6 WAP were evaluated on 19 Feb. and 12 Mar. The week x K interaction was not significant, therefore the data were pooled by K concentration (Table 5.7). Shoot dry weight was smaller with K at 0 $mg \cdot L^{-1}$ than K at 29 to 234 $mg \cdot L^{-1}$. There were significant differences among K treatments for root dry weight, root:shoot ratio, and height, however trends in growth were not detected. Similar root:shoot ratios, root dry weights, and heights between certain treatments may be the result of remobilization of nutrients within cuttings. Good and Tukey (1967) reported that macronutrients were redistributed from mature parts of cuttings of chrysanthemum to the new growth.

A similar root area and root length occurred among the K treatments, but cuttings harvested 3 WAP had a larger root area (15.2 cm^2) versus cuttings harvested 6 WAP (9.5 cm^2) (data not shown). A similar trend occurred with root length, as cuttings harvested 3 WAP produced longer roots (180.0 cm) than 6 WAP (145.9 cm) (data not shown). Cutting root growth and development decreased as the age of stock plants of strawflower increased. For many ornamental plants, there is a negative correlation with rooting and increased age of the stock plant (Hackett, 1988).

Based on the cutting rooting performance results, there was no benefit in restricting K to stock plants because cuttings had smaller shoot dry weights with severe foliar deficiency symptoms. While fertilizing with K at 29 $mg \cdot L^{-1}$ may produce similar rooting results to higher concentrations of K, stock plants should be fertilized with K at 117 to 234 $mg \cdot L^{-1}$ to avoid deficiency symptoms appearing in the upper cutting foliage.

Harvest 3

Stock plant descriptions. Nine WAP (5 Mar.) stock plants fertilized with K at 117 to 234 $mg \cdot L^{-1}$ had medium to light green young leaves with deep green mature leaves, whereas stock plants fertilized with K at 0 to 59 $mg \cdot L^{-1}$ expressed interveinal chlorosis on recently mature leaves. Stock plants receiving no K exhibited narrow, undulating, and glossy young leaves with mottled and necrotic mature leaves

Tissue analysis. Nine WAP, N, P, S, B, Cu, Mn, and Zn tissue levels were higher for the 0 $mg \cdot L^{-1}$ K treatment than the 29 to 234 $mg \cdot L^{-1}$ K treatments, while Fe tissue levels were similar between the 0 $mg \cdot L^{-1}$ K and the 234 $mg \cdot L^{-1}$ K treatment (Table 5.8). As the concentration of K increased from 0 to 234 $mg \cdot L^{-1}$, K tissue concentrations also increased from 0.63 to 6.90% (Fig. 5.1), and Ca tissue concentrations were highest with K at 29 $mg \cdot L^{-1}$ and then declined (Table 5.8). Mg level reached a peak of 0.36% with K at 29 $mg \cdot L^{-1}$, then decreased to 0.31% in tissue from stock plants fertilized with K at 59 to 234 $mg \cdot L^{-1}$.

Stock plant performance. Nine WAP, stock plants fertilized with K at 29 to 234 $mg \cdot L^{-1}$ produced more cuttings than K at 0 $mg \cdot L^{-1}$ (Figure 5.2). As the concentration of K increased, shoot dry weight also increased (Fig. 5.5). Based on regression analysis, the lowest K concentration to achieve maximum yield and shoot dry weight would be K at 32 $mg \cdot L^{-1}$ and 39 $mg \cdot L^{-1}$, respectively. Stock plants fertilized with K at 29 to 234 $mg \cdot L^{-1}$ had a larger root dry weight (9.09 g) than 0 $mg \cdot L^{-1}$ K (5.36 g) at $P \leq 0.001$, and a smaller root:shoot ratio (0.31) than 0 $mg \cdot L^{-1}$ K (0.46) at $P \leq 0.001$.

Harvest 3 cutting descriptions. Cuttings harvested from stock plants fertilized with K at 117 to 234 $mg \cdot L^{-1}$ had medium green young leaves and dark green youngest

leaves Upon fertilization with KNO_3, cuttings developed a medium green color on young and recently mature leaves, while the oldest lower leaves remained greenish yellow with some pale yellow patches. Cuttings harvested from stock plants fertilized with K at 29 to 59 $mg \cdot L^{-1}$ had dark green youngest leaves with distinct interveinal chlorosis observed on the young and recently mature leaves. Upon fertilization with KNO_3, the recently mature leaves expressed an interveinal chlorosis while the mature leaves had tip chlorosis. Cuttings from plants fertilized with K at 0 $mg \cdot L^{-1}$ had dark green youngest leaves and young leaves that were narrow at the petiole, wider at the blade, then pointed at the tip. Young leaves also expressed an interveinal chlorosis. After fertilizing with KNO_3, cuttings had dark green upper growth, expressed no sign of interveinal chlorosis, and had narrower leaves when compared to other treatments.

Two WAS cutting performance. Cutting performance differences were observed 11 WAP with the 0 $mg \cdot L^{-1}$ K cuttings having a poorer rooting quality, smaller shoot and root dry weight, larger root:shoot ratio, and a smaller height than cuttings harvested from stock plants fertilized with K at 29 to 234 $mg \cdot L^{-1}$ (Table 5.9). Differences did not occur among plants treated with K at 29 to 234 $mg \cdot L^{-1}$.

Three WAS Cutting Performance. After applying KNO_3, all cuttings at 12 WAP were similar in rooting quality (3.14), but cuttings from 0 $mg \cdot L^{-1}$ K-fertilized plants had 50% smaller shoot dry weights and 55% smaller heights than cuttings from stock plants fertilized with K at 29 to 234 $mg \cdot L^{-1}$ (Table 5.10).

Based on results from harvest 3, stock plants of strawflower could be fertilized with K at 39 $mg \cdot L^{-1}$ because of similar yield and rooting to K at 117 to 234 $mg \cdot L^{-1}$, however nutrient deficiency symptoms were expressed, demonstrating the importance of

higher concentrations of K applied to stock plants. Stock plants should be fertilized with K at 117 to 234 $mg \cdot L^{-1}$ to avoid deficiency symptoms appearing in the upper cutting foliage. Even upon fertilization with KNO_3, lower leaf chlorosis was present on cuttings from stock plants fertilized with K at 117 to 234 $mg \cdot L^{-1}$. Mobile nutrients such as N, P, K, and Mg should be applied 8 DAS when root initials emerge from the cutting base and can absorb nutrients from the propagation substrate. Height control was not achieved with K concentrations ≥ 29 $mg \cdot L^{-1}$ and ≤ 234 $mg \cdot L^{-1}$ K

Conclusion

Deficiency symptoms appeared on stock plants fertilized with K at 59 $mg \cdot L^{-1}$ and less with necrosis on mature leaf tips and interveinal chlorosis on recently mature leaves, however tissue concentrations were above the minimum critical level of 3.55% K determined by Gibson et al. (2003). Totally eliminating K to stock plants resulted in higher P and Zn levels than with K at 29 to 234 $mg \cdot L^{-1}$ during the second harvest. This may explain why rooting was similar among all K treatments because low P and Zn concentrations in cutting tissue have been reported to have negative effects on rooting (Gibson et al., 2003). While the threshold level of K at 32 $mg \cdot L^{-1}$ achieved maximum yield, cuttings removed from stock plants rooted the same as those from stock plants fertilized with K at 59 to 234 $mg \cdot L^{-1}$. Stock plants should be fertilized with K concentrations ≥ 117 $mg \cdot L^{-1}$ because cuttings developed chlorosis on the mature leaf margins with K at 29 to 59 $mg \cdot L^{-1}$, while lower leaf necrosis and interveinal chlorosis on youngest leaves were observed on cuttings from stock plants not treated with K. Height control was not improved with lower K concentrations applied to the stock plants, except

for K at 0 $mg \cdot L^{-1}$ which produced poorly rooted cuttings. A smaller shoot dry weight and larger root:shoot ratio with 0 $mg \cdot L^{-1}$ K cuttings supports the Thornley model (Wilson, 1988), however 0 $mg \cdot L^{-1}$ K cutttings exhibited severe interveinal chlorosis and lower leaf necrosis. In summary, stock plants of strawflower can be fertilized at 1N:1.1K (N at 217 $mg \cdot L^{-1}$ and K at 234 $mg \cdot L^{-1}$) or 2N:1K (N at 217 $mg \cdot L^{-1}$ and K at 117 $mg \cdot L^{-1}$) ratios because upper cutting foliage did not exhibit deficiency symptoms and optimal cutting yield and rooting occurred.

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Table 5.1. Nutrient stock solutions used. The following concentrates were prepared in deionized water and used in making the final nutrient solutions. All stock solutions were stored in a cool, darkened place.

Stock solution	Salt	Concn ($g \cdot L^{-1}$)
A	KNO_3	101.10
B	$Ca(NO_3)_2 \cdot 4H_2O$	188.10
C	KH_2PO_4	136.09
D	$MgSO_4 \cdot 7H_2O$	246.48
E	$NaNO_3$	84.99
F	$NH_4H_2PO_4$	137.99
G	FeEDTA (Sequestrine)	40.0
H	$MnCl_2 \cdot 4H_2O$	197.91
I	$ZnCl_2$	136.28
J	$CuCl_2 \cdot 2H_2O$	170.48
K	H_3BO_3	61.83
L	$Na_2 2MoO_4 \cdot 2H_2O$	241.95

Table 5.2. Volume of nutrient stock solutions (ml) (from Table 5.1) added to prepare the final nutrient solutions of 113 L.

Stock solution	Nutrient solution (K, $mg \cdot L^{-1}$) 234	117	59	29	0
A	621.5	282.5	113.0	28.25	0.0
B	565.0	565.0	565.0	565.0	565.0
C	56.5	56.5	56.5	56.5	0.0
D	226.0	226.0	226.0	226.0	226.0
E	0.0	339.0	508.5	539.3	621.5
F	0.0	0.0	0.0	0.0	56.5
G	113.0	113.0	113.0	113.0	113.0
H	101.7	101.7	101.7	101.7	101.7
I	16.9	16.9	16.9	16.9	16.9
J	16.9	16.9	16.9	16.9	16.9
K	50.8	50.8	50.8	50.8	50.8
L	11.3	11.3	11.3	11.3	11.3

Table 5.3. The calculated nutrient concentration of the final nutrient solutions (macronutrients in $mg \cdot L^{-1}$ and micronutrients in μM) used for stock plant nutrient fertilization rates.

	Nutrient solution treatments (K, $mg \cdot L^{-1}$)				
Element	234	117	59	29	0
	in $mg \cdot L^{-1}$				
NO_3-N	217.11	217.11	217.11	217.11	217.11
P	15.49	15.49	15.49	15.49	15.49
K	234.59	117.29	58.67	29.32	0.0
Ca	140.07	140.07	140.07	140.07	140.07
Mg	48.64	48.64	48.64	48.64	48.64
S	64.14	64.14	64.14	64.14	64.14
	in μM				
Fe	72.0	72.0	72.0	72.0	72.0
B	45.0	45.0	45.0	45.0	45.0
Mn	9.0	9.0	9.0	9.0	9.0
Zn	1.5	1.5	1.5	1.5	1.5
Cu	1.5	1.5	1.5	1.5	1.5
Mo	0.1	0.1	0.1	0.1	0.1

Table 5.4. Elemental concentrations of P, Ca, Mg, S, B, Cu, Fe, and Mn 3 weeks after potting in stock plants of 'Florabella Pink' strawflower fertilized at different concentrations of K (Harvest 1).

Potassium concn ($mg \cdot L^{-1}$)	P (%)	Ca (%)	Mg (%)	S (%)	B ($mg \cdot kg^{-1}$)	Cu ($mg \cdot kg^{-1}$)	Fe ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)
0	0.97	1.60	0.35	0.35	49.4	10.5	61.9	234.3
29	0.76	1.88	0.37	0.25	35.8	8.6	76.9	187. 7
59	0.87	1.97	0.37	0.26	43.4	8.5	72.2	195.7
117	0.82	1.57	0.30	0.25	38.1	8.5	82.4	206.7
234	0.67	1.61	0.31	0.24	31.0	8.9	81.1	184.7
Significance[Z]	**	***	**	**	*	**	*	**
LSD ($\propto$ 0.05)	0.12	0.16	0.04	0.06	9.9	0.9	12.7	23.5

[Z] *, **; Significant at $P \leq 0.05$ or 0.01, respectively.

Table 5.5. Elemental concentrations of P, Ca, Mg, S, B, Cu, Fe, Mn, and Zn 6 weeks after potting in stock plants of 'Florabella Pink' strawflower fertilized at different concentrations of K (Harvest 2).

Potassium concn ($mg \cdot L^{-1}$)	P (%)	Ca (%)	Mg (%)	S (%)	B ($mg \cdot kg^{-1}$)	Cu ($mg \cdot kg^{-1}$)	Fe ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)	Zn ($mg \cdot kg^{-1}$)
0	0.91	1.57	0.27	0.40	67.7	16.7	74.3	362.7	83.4
29	0.70	1.70	0.29	0.25	43.1	8.9	71.1	227.0	57.9
59	0.65	1.74	0.29	0.27	40.3	9.9	75.8	221.7	54.8
117	0.67	1.42	0.25	0.28	37.5	9.9	81.1	213.7	42.4
234	0.62	1.46	0.25	0.26	41.0	10.4	88.8	219.7	46.3
Significance[Z]	***	**	**	***	***	***	*	**	*
LSD ($\propto$ 0.05)	0.10	0.16	0.03	0.04	8.4	2.4	10.2	60.4	25.5

[Z] *, **, ***; Significant at $P \leq$ 0.05, 0.01, or 0.001, respectively.

Table 5.6. Rooting performance effects 3 weeks after sticking from K fertilization on stock plants of 'Florabella Pink' strawflower harvested 3 and 6 weeks after potting.

Treatment	Rooting quality	Root weight (g)
0	2.86	0.029
29	2.49	0.027
59	3.16	0.035
117	2.66	0.031
234	3.16	0.031
Significance[z]	***	*
LSD	0.44	0.005

[z] *, ***; Significant at $P \leq 0.05$ or $P \leq 0.001$, respectively.

Table 5.7. Cutting performance effects 4 weeks after sticking from K fertilization on stock plants of 'Florabella Pink' strawflower harvested 3 and 6 weeks after potting.

Treatment	Shoot weight (g)	Root weight (g)	Root to shoot ratio	Height (cm)
0	0.139	0.041	0.317	6.3
29	0.206	0.050	0.245	6.4
59	0.195	0.050	0.263	6.8
117	0.203	0.057	0.300	5.9
234	0.204	0.050	0.258	6.7
Significance[z]	***	*	***	**
LSD	0.030	0.010	0.038	0.6

[z] *, **, ***; Significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$, respectively.

Table 5.8. Elemental concentrations of N, P, Ca, Mg, S, B, Cu, Fe, Mn, and Zn 9 weeks after potting in stock plants of 'Florabella Pink' strawflower fertilized at different concentrations of K (Harvest 3).

Potassium concn ($mg \cdot L^{-1}$)	N (%)	P (%)	Ca (%)	Mg (%)	S (%)	B ($mg \cdot kg^{-1}$)	Cu ($mg \cdot kg^{-1}$)	Fe ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)	Zn ($mg \cdot kg^{-1}$)
0	7.16	0.84	1.22	0.25	0.40	81.1	20.4	94.2	445.0	117.5
29	6.75	0.64	1.76	0.36	0.30	42.9	9.1	87.7	194.7	39.9
59	6.86	0.61	1.74	0.30	0.27	42.9	9.7	85.5	193.0	44.8
117	6.78	0.68	1.75	0.30	0.28	42.0	9.2	86.1	193.3	47.7
234	6.65	0.66	1.64	0.32	0.30	48.2	9.5	108.7	176.3	55.8
Significance[Z]	*	*	**	**	***	***	***	*	***	**
LSD ($\propto$ 0.05)	0.30	0.12	0.24	0.05	0.03	9.6	1.9	15.2	53.7	38.6

[Z] *, **, ***; Significant at $P \leq$ 0.05, 0.01, or 0.001, respectively.

Table 5.9. Cutting performance effects 11 weeks after potting from K fertilization on stock plants of 'Florabella Pink' strawflower harvested nine weeks after potting.

Treatment	Rooting quality	Shoot dry weight (g)	Root dry weight (g)	Root:shoot ratio	Height (cm)
0	1.75	0.077	0.022	0.342	4.2
29	3.21	0.266.	0.042	0.159	6.6
59	3.21	0.243	0.039	0.163	6.4
117	3.17	0.267	0.043	0.171	6.6
234	3.08	0.245	0.039	0.162	6.5
Significance[z]	***	***	***	***	***
LSD	0.70	0.051	0.008	0.051	0.6

[z] ***; Significant at $P \leq 0.001$.

Table 5.10. Cutting performance effects 12 weeks after potting from K fertilization on stock plants of 'Florabella Pink' strawflower harvested nine weeks after potting.

Treatment	Shoot dry weight (g)	Height (cm)
0	0.158	2.5
29	0.314	4.9
59	0.311	4.6
117	0.289	3.7
234	0.348	4.9
Significance[z]	***	***
LSD	0.060	0.8

[z] ***; Significant at $P \leq$ 0.001.

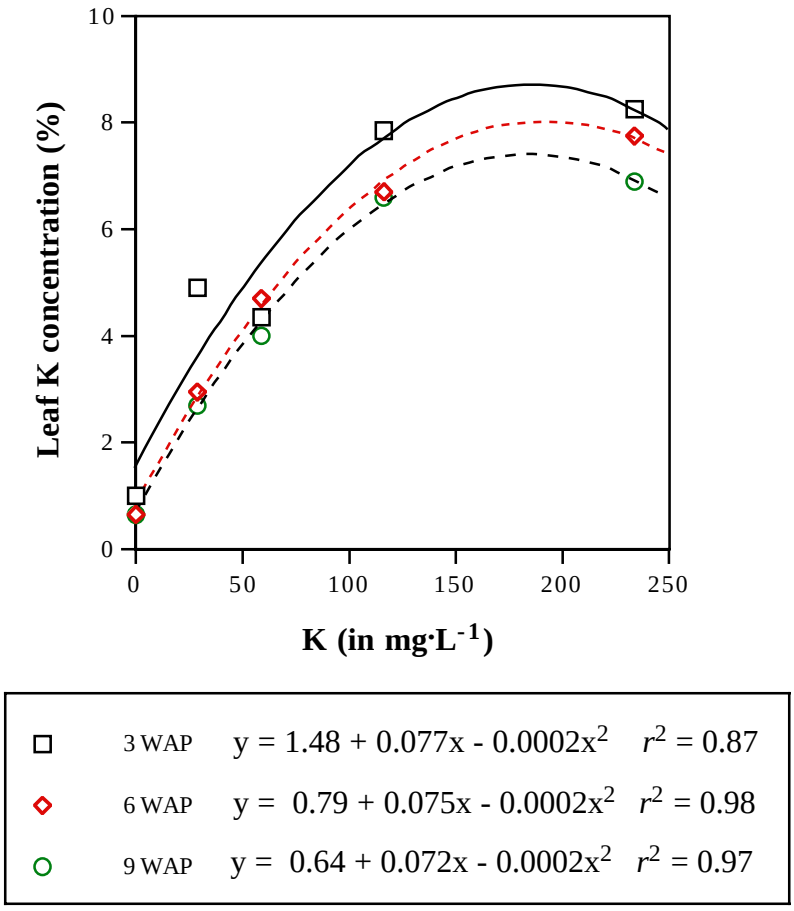
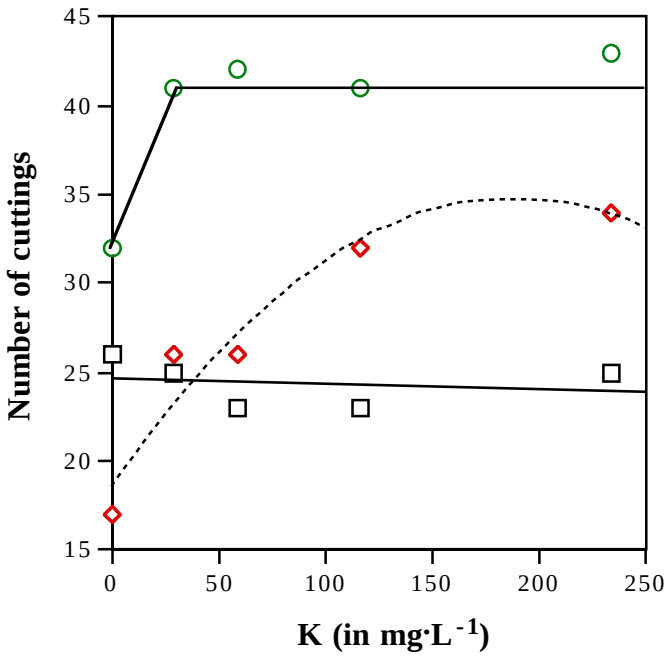


Fig. 5.1. Effect of K concentration on leaf K concentration of stock plants of 'Florabella Pink' strawflower. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=3). ***; Significant at $P \leq 0.001$; L = linear, Q = quadratic. 3 weeks after potting (WAP): L***, Q***; 6 WAP: L*** Q***; 9 WAP: L*** Q***.



□	3 WAP	NS
◇	6 WAP	y = 18.2 + 0.181x - 0.0004x^2 r^2 = 0.49
○	9 WAP	y = 32.0 + 0.301x X_0 = 32; r^2 = 0.25

Fig. 5.2. Effect of K concentration on yield of stock plants of 'Florabella Pink' strawflower. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=9). *, ***; Significant at $P \leq$ 0.05 or 0.001, respectively, or NS = not significant; L = linear, Q = quadratic, LP = linear plateau, X_o = joinpoint. 3 weeks after potting (WAP): L^{NS}, Q^{NS}; 6 WAP: L*** Q***; 9 WAP: L* Q* LP*.

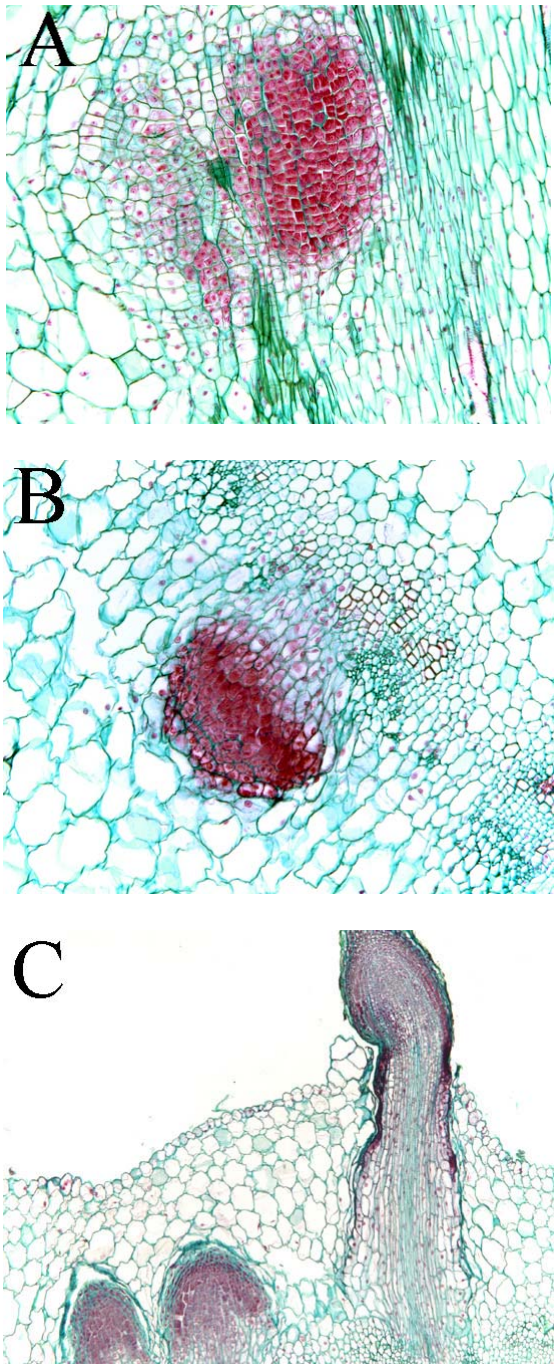


Fig. 5.3. Root primordia development in cuttings of ‘Florabella Pink’ strawflower harvested (A) 4, (B) 6, and (C) 8 days after sticking (DAS).

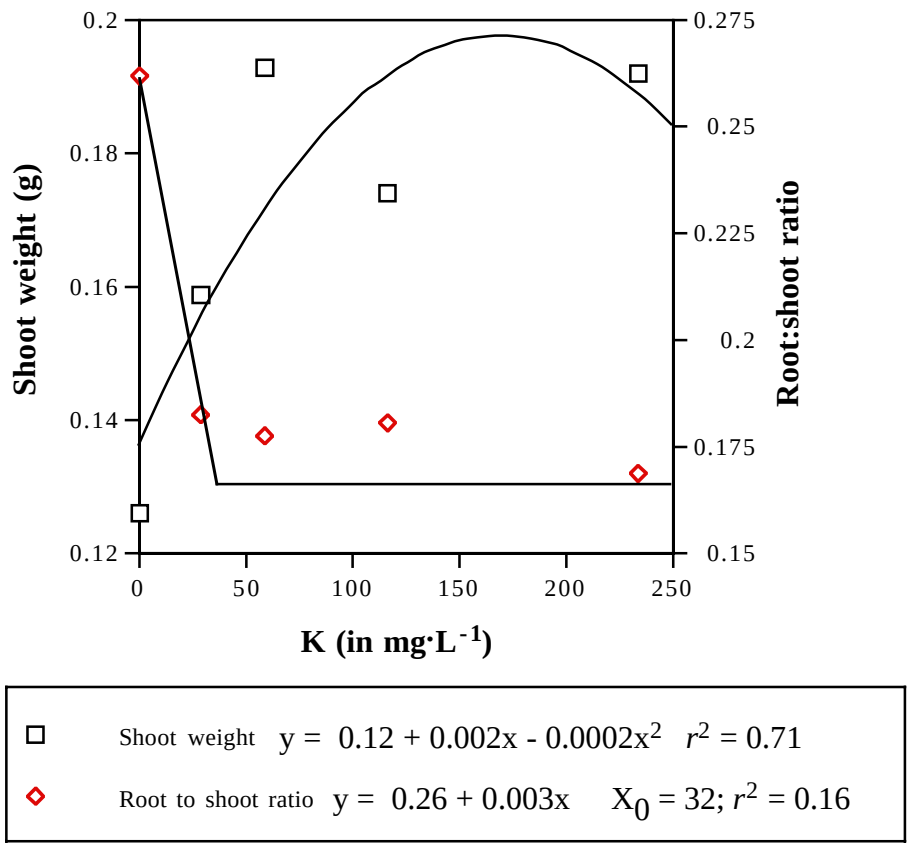


Fig. 5.4. Shoot weight and root:shoot ratio effects 3 weeks after sticking (WAS) from K fertilization on stock plants 'Florabella Pink' strawflower harvested 3 and 6 weeks after potting (WAP). Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=10). ***; Significant at $P \leq 0.001$. L = linear, Q = quadratic, LP = linear plateau, X_o = joinpoint. Shoot weight: L*** Q*** C***. Root to shoot ratio: L*** Q*** LP***.

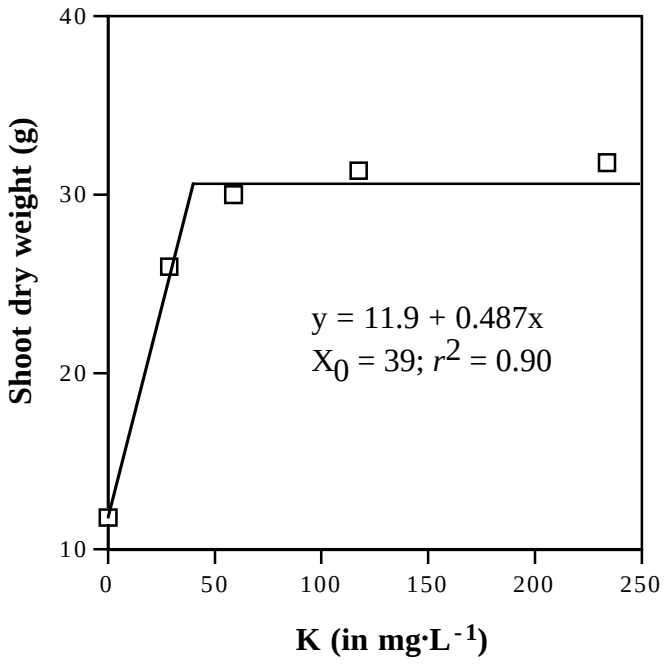


Fig. 5.5. Effect of K concentration on shoot dry weight of stock plants of 'Florabella Pink' strawflower 9 weeks after potting. Regression lines were generated from means of the treatments, and symbols are means of the treatments (n=5). ***; Significant at $P \leq$ 0.001 L = linear, Q = quadratic, LP = linear plateau, X_o = joinpoint. L***, Q***; LP***.