

ABSTRACT

Title of dissertation: **FACTORS AFFECTING MEDIA pH AND
NUTRIENT UPTAKE IN GERANIUMS**

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Consumer demand has prompted an increase in geranium breeding efforts to produce new cultivars each season. It is hypothesized that the breeding for unique morphological traits has inadvertently resulted in changing the plant's ability to competitively take up nutrients. Under certain conditions, nutrient uptake of these novelty cultivars is less efficient, possibly caused by the influence of the geranium itself. Information collected from the container media is a good indicator of the container nutritional status and can be used as a diagnostic tool for early identification of nutritional problems and prevent plant loss. Severe nutrient deficiencies and toxicities have been associated with plants fertigated with low alkalinity water, suggesting that an unsteady pH in the rhizosphere coupled with low buffering capacity of irrigation water may cause preferential nutrient uptake. Maintaining a media pH that optimizes nutrient solubility while preventing interactions or precipitation is the goal for ensuring proper plant nutrition. Three experiments were performed to address the

following objectives: 1.) Evaluate the effects of the geranium cultivar and class on the container media. 2.) Determine if media type affects nutrient availability and uptake by geraniums. 3.) Identify if preferential nutrient uptake occurs in response to changing pH and water alkalinity levels in the container media.

Results indicate that a significant reduction in media pH occurs for zonal and ivy geraniums during a specific stage of growth and that the effects of pH and water alkalinity on nutrient uptake are highly specific to the nutrient tested and the media type. Significant interactions between water alkalinity and pH contributed to preferential uptake of several of the tested nutrients especially at low water alkalinities Overall, the differences in uptake were in most cases specific to cultivar, the stage of growth and nutrient tested and should be considered when determining optimal fertility requirements for specific geranium cultivars.

**FACTORS AFFECTING MEDIA pH AND NUTRIENT
UPTAKE IN GERANIUMS**

By

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
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DEDICATION

This work is dedicated to my family and friends who have given me so much love and support over the last few years. I would especially like to thank my husband John and our baby boy, William, who have made the end of this process the most enjoyable. I can't put into words how lucky I am to have you both in my life. Also, a special thanks to my advisor and mentor, Dr. Marla McIntosh for whose support both personal and professional has helped me grow into the person I am today.

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INTRODUCTION

The floriculture industry is very unique in that it was founded by three principle groups; the growers, the academic researchers, and the trade industry. The growers, as the practitioners, are the most closely involved with production of the flowering plants and are responsible for propagating, growing and finishing the crop. The academic community, the researchers, teachers, and extension educators are involved with developing the science needed for successful production and disseminating this information to the growers. Floricultural research ranges from investigating methods of commercial production and improving cultural practices to the study of fundamental plant processes at the cellular and molecular level. The third main group, the trade community, focuses on the distribution and marketing of horticultural products. They are the link to all the groups by incorporating innovations of new research to the growers and providing feedback to the scientific community regarding areas needing further study.

The consumer also plays an integral role in shaping the floriculture industry by dictating popular trends through demand and spending patterns. New cultivars of home and garden crops are introduced each season to maintain consumer interest. Cultivars are often selected to produce a certain petal color, leaf shape, size or bloom time that is novel and specific to the current trends in home gardening and landscape design.

In order for the floriculture industry to thrive it must be proactive and develop the best methods of growing plants, manufacturing superior fertilizers and distributing quality products by making frequent adjustments to meet consumer demand. The constant introduction of new cultivars requires the commercial grower to continually customize cultural practices based on changing requirements of changing genotypes. Some new cultivars have been bred to be more tolerant to varying cultural practices, while other cultivars have been shown to be more susceptible to nutrient deficiencies and toxicities. The most important environmental factors impacting commercial floriculture production are pH, nutrient availability and water quality.

Water use in the greenhouse production of flowering plants has been the focus of much concern and research over the last decade (Beirnbaum, 1992). With the advent of nutrient management regulations for nurseries and greenhouses, the timing and the amount of water and nutrients that plants receive has become a high priority. Irrigation and fertilization practices that reduce water and nutrient loss and ensure nutrient availability in the media promote environmentally sound cultural practices (Ku and Hershey, 1992). Yet, it is economically important to the grower to maximize growing area and production cycles while producing high quality plants.

Managing the pH of the irrigation water and growing media often requires considerable time for formulation and testing. Acceptable media pH ranges vary by plant type, media, and fertilizer source and can be affected by water source (well or

municipal) and pipe construction. The relative acidity or basicity of the media solution directly affects which nutrients are available in the plant root zone. Maintaining a media pH that optimizes nutrient solubility while preventing interactions or precipitation is the goal for ensuring proper plant nutrition. Most growers chose their fertilizer formulas and nutrient sources to compliment the existing pH requirements of the water source, media type and crop. This information is based on grower experience or tradition and does not take into account the large amount of variation that can exist from location to location. It would be beneficial to introduce a database or computer modeling system that incorporates the cultural factors specific to the growing facility. From this system, precise nutrient recommendations could be made to incorporate appropriate nutrient management practices while ensuring proper nutrient availability to maintain plant health.

LITERATURE REVIEW

History of the geranium

Geraniums are popular greenhouse and home-landscaping plants. To date, there are over 280 natural species identified, most originating from the Capetown region of South Africa, plus many more hybrid cultivars that have been introduced in the United States and in the United Kingdom (Taylor, 1998; Fonteno, 1992). The family *Geraniaceae* consists of five genera, including *Pelargonium*, the common geranium. Of the *Pelargoniums*, the major groups of cultivated geranium plants are *Pelargonium x horticum* (Zonal), *Pelargonium pelatum* (Regal), *Pelargonium domesticum* (Ivy), and the scented geraniums.

The most popular and widely cultivated group is *Pelargonium x horticum*, the 'Zonal' classification. It is a hybrid plant within the subgenus *Ciconium* (meaning woody, succulent stems) that resulted from years of out-crossing in the wild with native species such as *P. zonale*, *P. inquinans*, *P. scandens* and *P. frutetorum* (Fonteno, 1992). Zonals were first grown as a cultivated crop in the United Kingdom and have fibrous, delicate root systems and foliage that is characterized by a banded pattern on its leaves. Each leaf is covered by soft hairs and the 'zone' of color is red pigment within the leaf that can range in thickness from a thin line up to two-thirds of each leaf face (Taylor, 1998). In 2001, the demand for bloom color varied greatly among growers and markets with an overall mix of 45% red, 30% salmon, 15% pink and 10% white (USDA, 2001).

The second major group of the geraniums is *Pelargonium pelatum*; members of the subgenus *Dibrachya*, classified as the ‘Ivy’ group. Ivy geraniums have been selectively bred for their unique leaf shape resembling English ivy and a particular trailing habit suitable for hanging basket production.

The third major group of the geraniums is *Pelargonium domesticum*; members of the subgenus *Pelargonium*, classified as the ‘Regal’ group. The regal geraniums are considered to be the most beautiful of the geraniums with unique large leaves and oversized single and double blooms in a large array of colors and blends. Due to problems associated with breeding, cultivation and flower initiation, these plants are grown much less than the other two classes (Fonteno, 1992).

The scented geraniums are a collection of many cultivars of *Pelargoniums* that have been bred to highlight specific scents. These cultivars are often descendants of wild geraniums of unknown pedigree due to out-crossing. These cultivars are commonly named by scent such as “apple-scented” or “lemon-scented”. Scented cultivars are grown to a much smaller extent than the other three groups and are mostly considered a novelty or herb plant used for medicinal purposes (Grieg, 1991).

New cultivars from all four major groups are introduced each season into the horticultural market and are most frequently bred to increase the palette of bloom color and size as well as leaf color, shape and habit. However, bloom color in the commercial market has been limited with only two cultivars of a yellow shade and no true blue shades (Taylor, 1998; USDA 2001).

Plant diseases are another major consideration for successful geranium production. Most geraniums are susceptible to diseases such as bacterial stem rot and leaf spot caused by *Xanthomonas pelargonii*. Culture indexing techniques are used by many breeders to ensure virus-free stock lines and produce healthy cuttings (Oglevee, 2004; Fonteno 1992). New cultivars are subjected to rigorous trials before introduction to the consumer market to identify and remedy potential susceptibility to disease or sensitivity to nutritional imbalances or variation due to pH. Consumer preferences for flower color, leaf variegation and price for *Pelargonium x horticum* are also primary considerations for release and marketing new cultivars. Beche et al., (1999) found that most consumers purchased geraniums based on flower color, followed by leaf variegation and least important was price.

The geranium effect

Most horticulturists develop nutrient management plans for ornamental plants based on three main factors: water quality, container media status and nutrient concentrations of recently matured plant tissue. Nutrient availability, deficiencies, and toxicities are determined from laboratory analyses of plant tissue and growing media. Research involving careful monitoring of the media pH and increased understanding of how pH can cause gradients of nutrient uptake would improve nutrient management recommendations and practices.

Commercial growers of geraniums have noticed that several common problems associated with geranium production are cultivar and ‘class’ specific (personal communication. H. Lang; 2003). Geranium production companies such as

Fischer USA, Ball Seed Company, and Oglevee Incorporated generate detailed production manuals on a yearly basis in order to ensure produce quality finished plants. With the introduction of new cultivars every year, current information is vital to the success of the commercial grower. Included in this information are propagation instructions (Light, temperature, day-length), and suggested pH, EC and fertility guidelines. These guidelines that are very broad and do not consider irrigation water quality or media type that the grower uses in production.

Some plants grown in the field such as bean, pea, and corn can affect their own root substrate pH (Nelson and Haung, 2003; Nye, 1984). Geraniums and other greenhouse grown ornamentals are most commonly grown in containers that can only hold a small amount of medium, therefore the supply of nutrients and water is limited in comparison to plants grown in the field (Ku, 1994). The availability and concentration of certain nutrient species (NO_3^- , NH_4^+ , and sparingly soluble P) can affect which ions are excreted by a plants roots (Marschner, 1996). If the plant preferentially takes up a anion, the plant will normally excrete an anion (HCO_3^-) to maintain electrical neutrality around the roots. Conversely, if the plant preferentially takes up an cation, the plant will normally excrete a cation (H^+) to maintain electrical neutrality in the root zone (Nye, 1984). My dissertation addresses the hypothesis that the geranium cultivar, itself, is an additional factor to be considered in making appropriate nutrient recommendations and therefore must be considered as a 4th major factor when addressing geranium plant nutrition along with tissue, media and water analysis.

These four factors become issues when abnormalities arise in the normal course of geranium production that are specific to a class or cultivar. In the mid 1990's, certain varieties of zonal geraniums exhibit a leaf abnormality now referred to as 'leaf cupping'. Initially, growers thought the leaf-cupping symptoms were a new characteristic of leaf shape introduced as a new cultivar within the zonal class and not a production problem. Leaf cupping involves newly formed leaf tissue becoming puckered, rubbery and cupped upward thereby reducing the tissues ability to expand and the overall plant size. Once the problem becomes severe, all new leaf tissue develops severe necrotic lesions starting at the leaf margins that eventually render the plant unmarketable. Presently, leaf-cupping has been documented in several greenhouses across the U.S. and world-wide (Fisher Inc. 2004; Ball Seed Co, 2004; Oglevee, 2004) but has only been observed in specific "sensitive" cultivars under conditions of low alkalinity irrigation water. Previous attempts to duplicate these symptoms in a scientific, replicated experiment have been unsuccessful (Peters, 2002; Nelson and Lang. 2002 (unpublished); Bergage et al., 2001 (unpublished)). However, leaf-cupping can be prevented from occurring and mildly affected plants can be salvaged via in-house or laboratory media pH testing, the addition of pre-plant limestone or the application of potassium bicarbonate or flowable lime at first sign of puckering (Fisher et al., 2001).

Nutrient effects on geranium growth

Nitrogen. Nitrogen is an essential plant macronutrient required for growth and development. For most horticultural crops, growers use an ammonium ($\text{NH}_4\text{-N}$) nitrogen source to stimulate lush vegetative growth including greater leaf expansion and stem internode length during the early stages of plant development. As the plant grows and reaches the final two weeks of the production cycle growers are preparing the plants for sale and switch to a nitrate ($\text{NO}_3\text{-N}$) nitrogen source to ‘harden’ the plant and produce more compact growth (Nelson, 1996). Generally, dry plant tissue contains between 2% and 4% N depending on species and growth habit. (Mengle and Kirkby, 1979). Research comparing the effects of $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ fertilization on geraniums has determined that higher concentrations of $\text{NO}_3\text{-N}$ are preferable to $\text{NH}_4\text{-N}$ as the N fertilizer source. Ammonium nitrogen in excess can be toxic to plant growth mainly due to the effects of high concentrations of the NH_4 ion and the damage it can cause to the plants root system (Mengle and Kirkby, 1979). Zonal geraniums fertilized with N that was more than 60% $\text{NO}_3\text{-N}$ were larger, healthier, and greener than plants grown with greater than 25% $\text{NH}_4\text{-N}$ (Biamonte, 1993; Nelson, 1996). In contrast to other ornamentals, recently rooted zonal and ivy geranium cultivars do not grow well when initially fertilized with higher levels of $\text{NH}_4\text{-N}$ (Mengle and Kirkby, 1979; Biamonte 1993; Ball Redbook, 2003). ‘Red Elite’ (zonal) *pelargonium x horticum* seedlings fertilized on a constant feed basis with a $\text{NH}_4\text{-N}$ based fertilizer produced lower quality geraniums especially when grown in cooler temperatures and lower light conditions (Biamonte et al., 1993).

This suggests that pH affects the N concentration in the media and subsequent plant uptake. Generally, $\text{NH}_4\text{-N}$ uptake decreases as the pH of the media decreases with maximum uptake at pH 6.8. The converse is true for $\text{NO}_3\text{-N}$ uptake in that $\text{NO}_3\text{-N}$ uptake decreases as the pH rises. In a high pH solution OH^- ions predominate and competitively suppress the plant's ability to take up NO_3^- (Mengle and Kirkby, 1979). Similar studies conducted on N accumulation and uptake in hybrid impatiens (*Impatiens wallerana*) test the effects of N-form on media pH (Agro and Biernbaum, 1997). They found a linear relationship between higher N tissue concentration and a reduced media pH. It is their opinion that media pH does not affect N uptake, but rather the form of N taken up by the plant that causes the media pH to change. Although Agro and Biernbaum (1997) suggest that these findings could be used for other bedding plants and geraniums, Cox et al. (1985) found no significant differences due to N form for seed geranium performance. 'Jackpot' geraniums fertilized with NH_4^+ based fertilizer versus a NO_3^- based fertilizer did not differ significantly for dry mass when grown at 200 mg L^{-1} rate.

Based on this previous research and years of trial and error by growers it is common to recommend a combination of NH_4^+ and NO_3^- fertilizer sources to satisfy N requirements for geraniums. In the future, recommendations should be based on the specific cultivar grown, media type, optimal pH range and initial irrigation water quality (J.R. Peters Laboratory, 2004). In most cases, these four factors are considered and analyzed in making a N-source recommendation and therefore no general rule applies for N fertilization for geranium production.

Phosphorous. Phosphorus is often considered a macronutrient of luxury consumption for most geranium cultivars. (personal communication, Ron Adams Ball Seed Inc, 2004; Ball Redbook, 2003; Bethke, 1993). P is required by plants as the major energy rich bond of adenosine triphosphate (ATP) that supplies most of the energy for active processes of plant metabolism. P is actively taken up by the roots and is very mobile in the plant. It is usually converted into organic compounds immediately after it crosses the cell wall. Phosphorus in the media is anionic, existing as H_2PO_4^- or HPO_4^{2-} and its solubility is dependent on the media pH. Because media pH is positively correlated to anionic uptake, N source in most fertigation programs affects media pH, which can subsequently affect P solubility. For soil solution, at pH 7.22, $[\text{H}_2\text{PO}_4^-] = [\text{HPO}_4^{2-}]$, at pH > 7.22, $[\text{HPO}_4^{2-}] > [\text{H}_2\text{PO}_4^-]$ and at pH < 7.22 $[\text{H}_2\text{PO}_4^-] < [\text{HPO}_4^{2-}]$ (Marschner, 1995). At low pH, phosphate forms sparingly soluble precipitates with Al^{3+} and Fe^{3+} . As the solution pH increases to neutral, P ions form similar complexes with Ca^{2+} and Mg^{2+} (Marschner, 1995).

General phosphorus recommendations for geraniums currently suggest that 20 to 50 mg L^{-1} P be injected into the irrigation water as a constant feed to maintain optimal growth rates (Biamonte et al. 1993). However, most plants only require 5-10 mg L^{-1} of phosphorous to provide healthy growth and most geranium cultivars are able to take up adequate amounts of P regardless of the media mix (Whipker et al., 2003).

Phosphorus phytotoxicity has been found to occur in geraniums when P was applied in excess of 200 mg L⁻¹ on a constant feed basis (Payne, 1975), Payne theorized that P availability is often underestimated, especially in high water alkalinity environments, because P sources, including phosphoric acid used to lower media pH, and pre-plant incorporated nutrient charges containing granular forms of P are not considered in determining P application rates. In soilless media based on sphagnum peat moss, P phytotoxicity could also occur because peat does not fix P as it would to a mineral soil and has low concentrations of natural Fe and Al. Therefore, if the soilless media is acidic, P is very soluble and available for plant uptake. Symptoms of excess P include reduced plant yield, impaired uptake of Cu, B, and Zn and increased uptake of Mn, and Mo (Whipker and Hammer, 1994). The effects of P-related stress caused by high P levels was studied on many bedding plants including cultivars of *Pelargonium* (Baas et al., 1995) in an ebb and flow irrigation system. Their results indicated that high P levels reduced plant yield. Also, the number of lateral side shoots and blooms were greatly decreased.

P can affect growth habit of ornamental crops. It has been suggested that limiting P by reducing the P rate during constant feed irrigation could effectively produce compact vegetative growth without growth regulators (Whipker et al., 2003; Baas et al. 1995).

Potassium. K is a macronutrient essential for plant growth, development and water retention of plant tissues. K is a mobile element with most uptake occurring during

the vegetative growth stage. It is taken up in the K^+ ion form and can readily move through the plant from older to newer tissues to ensure developing tissue has an adequate K supply. All types of geraniums have been found to take up K in excess without causing any physiological damage or stress to the plant (Biamonte, 1993). The optimal range for K concentration in the media of geraniums is 150- 250 $mg\ kg^{-1}$, for leaf tissue the range varies depending on class (2.6-3.5 % for zonal; 2.8- 4.7 % for ivy; 1.1-3.1% for regal) (Whipker, 2003). Media K deficiency symptoms are not common and occur when K concentrations are very limited or complexed with other nutrients (Whipker, 1998). Symptoms of K foliar deficiency include necrotic spots around the lower leaf edges and weak, pliable stems. Potassium toxicity is also rare and causes a reduction in the uptake of other nutrients such as Ca, Mg, Mn and Zn. By using a balanced fertilizer formula with a K:Ca:Mg ratio of 4:2:1, K imbalances will not occur for most cultivars of geraniums (Whipker, 2003).

Calcium. Calcium is classified as a secondary macronutrient because it is required in lower concentrations than the primary macronutrients (N,P,K) but greater concentrations than the micronutrients (Fe, Mn, B, Cu, Zn, Mo). Calcium is essential for the strengthening of plant cells and tissues, proper expansion of leaves and is most commonly stored in the plants cell walls (Marschner, 1996; White, 1993). Calcium is generally not mobile in the plant and is not actively transported between tissues. It moves with water through the plant and is translocated from the root system via transpiration. Recommended Ca foliar concentrations for

geraniums vary according to commercial classification (1.4 - 2.0 % for zonal, 0.9 - 1.4% for ivy and 1.2 – 2.6% for regal). Symptoms of Ca foliar deficiency are expressed as the blackening and eventual death of the meristematic points and roots. Excess Ca can inhibit the uptake of other nutrients such as K, Mg and B (Whipker, 2003) yet, Ca foliar toxicity in geraniums is rare because Ca ions at high concentrations do not negatively affect *Pelargonium* growth (Mikesell, 1992). Zonal geraniums have displayed preferential uptake of specific nutrients from the media, particularly calcium, regardless of the surrounding nutrient competition (Fonteno and Adams, 2003; Nelson and Haung, 2003). The ability of a plant to selectively take up certain nutrients and increase uptake under various conditions has been suggested for Ca in a soilless media (Fonteno and Adams, 2003) and other nutrients in a soil environment (Marschner, 1996). Mikesell (1992) performed a study that determined the effects of calcium's presence or absence to *Pelargonium pelatum* (ivy) vegetative and reproductive development. She found that in the absence of Ca, *Pelargonium pelatum* grown in nutrient solutions resulted in plants with lower overall plant weights, reduced leaf size and leaf number per plant and the complete absence of adventitious roots. It is her theory that Ca not only is necessary for good root growth, it also plays a role in deterring excessive uptake of other minerals in the rhizosphere. She concludes that Ca can influence overall plant growth, root development, media pH and is important for cation exchange in the root zone.

Most ornamentals require between 50-100 mg L⁻¹ Ca as a constant feed rate incorporated in a balanced fertilizer program. In some areas, this level is naturally supplied by the irrigation water due to high Ca parent material soils. Conversely, areas which have low alkalinity can have minimal available Ca in the irrigation water and therefore Ca must be supplied through the fertilizer. When the pH of the irrigation water is less than 6.2 and the amount of soluble carbonates in the water is minimized (less than 70 mg L⁻¹ soluble carbonates) calcium can be reduced to deficient levels. When this occurs the available Ca in the media decreases especially when there is no pre-plant incorporation of a limestone amendment (Whipker, 1998). Based on a pre-plant media and water quality test, initial Ca concentrations are evaluated and it is often recommended that a supplement of Ca be added to the media as calcitic or dolomitic limestone. This type of addition can greatly affect the amount of available Ca at the time of transplant and is very dependent on the characteristics of the media components and the limestone. Some factors that can affect Ca availability include: grade of material, incorporation rate and surface area. A study by van Iersel at University of Georgia found that Ca and Mg were affected by media composition. Increasing the proportions of peat and perlite while decreasing the proportion of pine bark, significantly increased Ca concentration in the leaf tissue (1999).

Magnesium. Mg is a secondary macronutrient essential for enzyme activation in plant metabolism, it is involved with organic acids such as malate and citrate and

most importantly it is the center of the chlorophyll molecule. It is required in lesser amounts than Ca^{2+} and K^+ , but its availability can be affected by competition from other cations in the media thereby causing deficiency in the tissues (Mengel and Kirkby, 1979). The recommended leaf concentration for Mg in geraniums varies according to cultivar (0.2 -0.4 % for zonal; 0.2-0.6 for ivy; 0.3- 0.9 % for regal) (Whipker, 2003). Magnesium deficiency is common in geraniums and is characterized by interveinal chlorosis on both the newly formed tissues and the older leaves (Bethke, 1993). A Mg deficiency can be avoided by a pre-plant media addition of dolomitic limestone as a Mg supplement and to adjust pH (Fisher, 2003). Mg toxicity is rare in most cultivars of geraniums. Just as geraniums are tolerant of high levels of available P and K, they are also able to take up and tolerate higher concentrations of Mg than most other ornamentals (Bethke, 1993). Balanced commercial fertilizer formulas provide small amounts of Mg and Ca as secondary soluble nutrients. Therefore, for most ornamentals, a combination of a natural supply of Mg in the water source and the soluble additions of Mg in the fertilizer provide the required Mg for adequate growth (Nelson, 1996).

Iron. Fe is a micronutrient essential for plant metabolism. Its major function is in enzyme systems including catalase and peroxidase with the majority of Fe stored as the protein phytoferritin. Current research has found that specific cultivars of geraniums are very susceptible to iron and manganese toxicity especially when grown at a media pH, below 4.5 (Fisher and Argo, 2003; Whipker 2003; Bachman

and Miller 1995; Biamonte 1993). The recommended optimal range for foliar iron in geraniums is specific to cultivar and classification (110-580 mg kg⁻¹ for zonal; 115-270 mg kg⁻¹ for ivy; 120-225 mg kg⁻¹ for regal) (Whipker, 2003; Biamonte 1993). For media, the recommended iron concentrations are between 0.3 and 3.0 mg kg⁻¹ based on results using a saturated paste extractable method (Biamonte, 1993). Many conditions in the media can contribute to iron deficiency in the plant tissues even if media tests suggest high media Fe. These conditions include: high pH (forms insoluble Fe-oxides), high concentrations of soluble carbonates (can raise pH and cause a iron reduction to be suppressed), excessive lime application, over fertilization (especially with P,Mn, Cu, or Zn), and over-watering (poor aeration). Iron deficiency symptoms begin with interveinal chlorosis of the youngest growth where there are dark green veins and a lighter green leaf face. This can progress so that the newest tissues are completely chlorotic and eventually meristematic death when the conditions are severe (Nelson, 1996).

Iron toxicity can be common in geraniums especially in low pH conditions and with cultivars that are classified as “Fe-efficient” cultivars. Fe efficient cultivars have the ability to translocate large concentrations of Fe and thereby can become severely damaged due to high foliar Fe concentrations. Iron toxicity symptoms in geranium tissues include necrotic speckling on the older growth (lower leaves) and/or reduced uptake of Mn leading to Mn foliar deficiency in the leaves. Most commonly, iron toxicity occurs when the pH of the media becomes too acidic. It is recognized as a serious problem for geranium production. Fisher and Agro

(2001) have devised a 10 step program to manage Fe and Mn nutrition for geraniums and other ornamentals that are susceptible to excess Fe uptake. They recommend monitoring and maintaining prescribed media pH and irrigation water alkalinity levels to prevent Fe-Mn toxicity including cultivars that are identified as 'sensitive' to excessive micronutrient uptake. This program has been readily accepted and is currently used by most commercial geranium growers.

Problems with iron nutrition in ornamentals were initially recognized in the 1980's. Subsequently, research conducted on iron uptake in bedding plants has found that Fe toxicity causes loss of marketable plant material in marigolds, new guinea impatiens, vinca, vegetable plugs and geraniums (Biernbaum et al., 1987; Vetanovetz and Kraus, 1989; Albano and Miller, 1996; Albano and Miller, 1998; Fisher and Argo, 2001). Bachman and Miller (1992) investigated the interactions between iron and manganese in zonal geraniums. Rooted cuttings grown in a soilless peat-based media were exposed to increasing concentrations of iron-chelate (FeDTPA) as a soluble supplement. Results indicated that increasing supplemental Fe caused increased Fe foliar concentrations but decreased Mn foliar concentrations. The first symptoms of toxic Fe tissue concentrations were marginal and interveinal chlorosis resembling Mn deficiency. As more Fe was taken up, leaf edges began to turn down and become covered with necrotic spots. However, Bachman and Miller cautioned that these symptoms may vary among cultivars of geraniums as seen in studies conducted with different cultivars of marigolds.

Manganese. Mn is a micronutrient essential for plant growth and is involved as a cofactor in many enzymatic processes similar to the Mg^{2+} . Mn is absorbed as Mn^{++} and is available from most fertilizer formulas as manganese sulfate ($MnSO_4 \cdot H_2O$) or manganese chelate Mn-EDTA. It is not a mobile element, yet it is preferentially translocated to meristematic tissues for proper growth. Therefore, meristematic tissues are usually the most Mn-rich. The recommended optimal range for manganese in the leaf tissue of geraniums varies according to cultivar (270-325 $mg\ kg^{-1}$ for zonal; 40-175 $mg\ kg^{-1}$ for ivy; 115-475 $mg\ kg^{-1}$ for regal) (Whipker, 2003). For media concentrations, it is recommended that Mn levels be within 0.2- 3.0 $mg\ kg^{-1}$ based on results using a saturated paste extractable method (Biamonte, 1993). Geraniums are highly susceptible to both Mn toxicity and deficiency depending on water type, pH and media composition, and Fe concentration. Foliar symptoms of Mn deficiency are displayed as interveinal chlorosis of the newer leaves which eventually results in necrotic lesions on the leaves due to reduced cell volume and shrunken tissues and cell walls (Mengle and Kirkby, 1979).

Excessive uptake of Fe, as explained in previous section, has been shown to induce Mn foliar deficiency for zonal, ivy and regal geraniums (Agro and Fisher, 2003a). Mn deficiencies often decrease photosynthetic activity and reduce transpiration rates. Although Mn deficiency looks similar to an iron deficiency at the beginning stage of deficiency, Mn deficient tissues do not turn white due to total loss of chlorophyll. (Biamonte, 1993). Iron and manganese have an antagonistic relationship and an elevated concentration of one ion can induce a deficiency of the

other ion. Handrek (1997) found that certain cultivars of *Pelargonium x horticum* exhibited Mn foliar toxicity when Mn media concentrations were only 26 mg kg⁻¹, which is within the acceptable Mn range for zonal geraniums. On further analysis, it was found that the pine bark media used in the experiment was extremely low in total iron, which caused acidification of the media around the root zone. The resulting pH decrease caused an increase in Mn availability leading to an increased uptake in the geranium leaves.

Plant uptake of Mn can increase in low pH media or media that is low in Ca (Marschner, 1996). For most plants, including geraniums, a media low in calcium carbonate concentration can increase Mn availability resulting in increased uptake of Mn in the newer growth (Biamonte et al, 1993). In a soil based system, Mn can exist in many oxidation states as Mn-oxides. Many factors can contribute to increased Mn uptake including: a decrease in pH, organic matter content, microbial activity and soil moisture (Marschner, 1996; Godo and Reisenauer, 1980; Mengel and Kirkby, 1979).

Boron. B is a micronutrient essential for early tissue development and is required for germination and growth of pollen. The recommended optimal range for boron concentration in the leaf tissue of geraniums varies according to cultivar (40-50 mg kg⁻¹ for zonal; 30-280 mg kg⁻¹ for ivy; 15-45 mg kg⁻¹ for regal) (Whipker, 2003). As with most micronutrients, boron is not actively translocated through the plant tissues, therefore a B foliar deficiency is exhibited in the newer leaves first. The

concentration range at which boron is classified as deficient depends on the cultivar and class. However, McFadden (1970) showed that most boron deficiency symptoms start to present when B foliar levels are below 27 mg kg^{-1} .

Boron in media is readily available under recommended levels of pH and water alkalinity for a standard soilless media. When media is custom blended, B can become limiting depending on organic matter content of the media, the addition of clay minerals, the presence of Fe and Al oxides, and carbonates in the water source (Xu et al. 2001). In a soil-added custom blend media, B can become complexed rendering it unavailable in the media thereby causing foliar deficiency symptoms.

Boron toxicity in the geranium tissues is displayed as leaf tip yellowing followed by marginal chlorosis and eventually necrotic speckling of the older leaves. Often the leaves look as if they have been 'scorched' and drop prematurely. The range for boron toxicity is very narrow, however, the plasticity of these limits especially with the new cultivars has not been reported in the scientific literature and further study is needed to better understand the role of boron levels in geranium tissues. Several other horticultural crop species are extremely sensitive to B toxicity including peaches, grapes and figs. When growing these plants, even the naturally occurring B in the water source may be too high concentration of B and cause toxicity.

Copper / Zinc / Molybdenum. These micronutrients are essential for plant growth and development. Because most micronutrient are required in very small amounts, copper, zinc, and molybdenum are rarely reported as deficient in the growing media or plant tissue for geraniums (Biamonte, 1993). Overuse of supplemental micronutrients can cause micronutrient foliar toxicities especially when multiple applications of soluble trace elements are used to address other micronutrient issues (Biamonte, 1993; Whipker, 2003).

Copper is essential for both protein and carbohydrate metabolism in the plant. It is absorbed as Cu^{++} from the media or as the Cu-chelated form Cu-EDTA as supplied by the fertilizer formula. Like Fe, it is highly concentrated in the chloroplasts and even though it is not mobile, it can be translocated from older to newer tissues on plant demand. Recommended concentrations of copper in the media are approximately 0.2 mg kg^{-1} (Whipker, 2003) or between $0.001 - 0.5 \text{ mg kg}^{-1}$ depending on cultivar (Biamonte, 1993). The recommended range for foliar concentrations of copper for most geranium cultivars is between $5 - 13 \text{ mg kg}^{-1}$. However, concentrations outside of this range can be tolerated by some cultivars without foliar damage symptoms. Cu toxicity is more common than Cu deficiency for geraniums. When Cu is in excess it can displace other metal ions (especially Fe) thereby causing leaf chlorosis superficially resembling Fe deficiency.

Zinc is essential in N-metabolism and many enzyme systems resembling the activities of Mn and Mg. Zinc is taken up as Zn^{++} and is relatively immobile in the plant. It is supplied from commercial fertilizers as the Zn-chelated form Zn-EDTA

and foliar Zn deficiency is rare for most greenhouse crops. However, Zn toxicity can be caused by over-supplementation or galvanized pipes used for irrigation lines. Zn toxicity can cause a reduction in root growth reduced leaf size and chlorosis. In addition, high levels of Zn can depress plant uptake of Fe and P. Recommended concentrations for zinc in the media are approximately 0.4 mg kg^{-1} (Whipker, 2003) or between $0.3 - 3.0 \text{ mg kg}^{-1}$ depending on cultivar (Biamonte, 1993). The recommended range for foliar zinc concentrations for most geranium cultivars is between $50-55 \text{ mg kg}^{-1}$ however concentrations outside of this range can be tolerated by some cultivars without signs of foliar damage.

Molybdenum is an essential for plant metabolism as a component of nitrogenase and nitrate reductase necessary for NO_3^- reduction. It is taken up as MoO_4^- from either ammonium molybdate $(\text{NH}_4)\text{MoO}_4$ or sodium molybdate $\text{Na}_2\text{MoO}_4 \cdot 2 \text{H}_2\text{O}$ from the fertilizer formula. Recommended concentrations of molybdenum in the media are approximately between $0.01 - 1.0 \text{ mg kg}^{-1}$ depending on cultivar. Foliar molybdenum concentrations recommended range for most ornamental plants is between $0.2 - 5.0 \text{ mg kg}^{-1}$ however there are no set recommended standards for geraniums (Biamonte, 1993). Foliar deficiency symptoms begin in the middle to older leaves and resemble N deficiency in that overall plant size is reduced, leaves become yellow and pale and eventually dry up.

PH

A pH is the relative concentration of hydrogen and hydroxyl ions in solution and defined by Sorenson in 1909 (Kramer and Peterson, 1990; Bloom, 2000) as the

negative log (base 10) of the hydrogen ion activity. Most container grown plants grow well over a wide range of pH levels (Nelson & Huang, 2003). A general recommended pH range for soilless media is between 5.4 – 6.8 for greenhouse crops and between 5.6 - 6.2 for geraniums (Whipker et al. 2003).

Extremes in pH result in nutrient deficiencies and toxicities in the plant tissue due to changes in the solubility and absorption of certain nutrients. For greenhouse production of tomatoes, chrysanthemums, poinsettias, carnations, and geraniums (Kramer and Peterson, 1990; Argo and Biernbaum, 1996), high media pH is reduced by injecting a small amount of concentrated acid (HNO_3 , H_2SO_4 , H_3PO_4) into the fertigation line (Biamonte, 1993), resulting in improved productivity and quality of growth. At the other extreme, low media pH is corrected by adding lime to the media with calcitic limestone (CaCO_3), dolomitic limestone (MgCO_3) or a combination of calcium or magnesium hydroxides $\text{Ca}(\text{OH})_2$, and $\text{Mg}(\text{OH})_2$. To correct for low pH in the media, the amount of lime needed to reach this level depends on media characteristics and the lime particle size, surface area, incorporation rate and water quality (Argo and Biernbaum, 1996; Sheldrake; 1980). A recommended initial media pH for most ornamentals is 6.0 (Argo and Biernbaum 1996; Nelson, 1991; Fonteno and Adams; 2003).

As noted in a previous section, horticultural crops can be seriously affected by Fe-Mn toxicities. Research conducted at the University of New Hampshire by Dr. Paul Fisher and colleagues suggests that the best way to reduce the loss of plants due to damage done by Fe-Mn toxicity is to prevent it by managing media pH. By

studying iron-efficient plants such as geraniums, marigolds and lisianthus, factors have been identified helping the grower to target a an optimum media pH range (Fisher, 2001). Keeping media pH within a targeted range through diligent monitoring can prevent micronutrient toxicities. Media pH tends to decline due to insufficient lime application pre-plant, overuse of a fertilizer formula that is high in NH_4^+ -N, low water alkalinity (less than 40 mg L^{-1} soluble carbonates) or over acidification of the irrigation water. Fisher has also suggested that geraniums may interact with the media and reduce the media pH (Fisher et al., 2001).

In order to determine a way to rapidly increase media pH and reduce foliar damage of crops, Fisher (2001) evaluated the media pH after applying flowable limestone and potassium bicarbonate, amendments commonly used to raise media pH for geraniums and other micronutrient sensitive crops. Both of these amendments raised media pH to targeted levels when applied at the rate of four quarts to 100 gallons for flowable lime and 2 pounds per 100 gallons for potassium bicarbonate. It was also recommended that, for geraniums, using a fertilizer formula that is highly nitrate-based (e.g. 13-2-13) could also correct most cases of low media pH, but this effect is more gradual in its actions (Fisher, 2001).

Argo and Biernbaum (1996) have conducted experiments to determine how lime, irrigation water and water soluble fertilizer affect root-medium pH and nutrient uptake for impatiens. The experiment included a 2 x 4 x 3 factorial design using 2 types of lime, 4 irrigation water sources varying in alkalinity and 3 water soluble fertilizer formulas. Plants were sampled at 4, 8, 12 and 17 weeks of the production

cycle and analyzed for foliar nutrient uptake, media pH, media EC. It was found that plant growth was not affected by the treatment factors, yet lime source and irrigation water alkalinity did affect root zone pH after the week 4 sampling date with the maximum range of pH (4.5- 8.5) occurring at week 8. They suggest that there are interactions between lime source, water soluble fertilizer and alkalinity that affect root medium pH for impatiens and conclude that further research should be conducted on specific nutrient uptake for these plants (1996).

Argo and Biernbaum (1997) conducted additional experiments with impatiens to examine how media type can influence media pH and nutrient uptake. A 6 x 3 factorial experiment was designed with 6 different media types and 3 nutrient solution combinations. They found that plant growth was affected by media type and fertilizer treatment and media pH ranged according to the CEC, amount of lime and percent media components. Little or no interactions between these factors was found at the earliest sampling date, yet at the later sampling dates, interactions between media type and nutrient solutions significantly affected root zone pH.

Argo and Biernbaum's research with impatiens recognized the need for fertility and nutrient management plans to be designed for impatiens based on target pH zones. Factors such as water soluble fertilizer formula, media type, and water alkalinity were determined to be important for recommending fertility programs for impatiens. To date, there have been no parallel controlled studies performed for geraniums and, geraniums are a much different crop than impatiens when grown in a

commercial setting. Water alkalinity and pH management are essential to ensuring a quality crop and therefore this was part of the basis of my hypothesis for this dissertation research.

Managing pH for geranium production

Most growers monitor the pH of the media and irrigation water by a combination of in-house and scheduled laboratory testing in order maintain a pH range specific to the crop and to prevent nutritional toxicities or deficiencies from reducing the plant quality or causing plant mortality.

The pour through (PT) extraction method is widely used by nurserymen and greenhouse operators to monitor their crop's nutrient status. As part of a regular nutrient maintenance program, it can be used to effectively obtain a complete nutrient analysis of the soil solution (Wright, 1986). The PT technique for monitoring and maintaining nutrient levels of the soil solution of greenhouse crops was first introduced by Dr. Robert Wright at Virginia Tech University in 1986. The PT procedure is a simple and economic in-house test to determine nutrient concentration and availability in the soil solution around the root zone that includes four steps. First, each container is elevated to promote good drainage and collect the leachate from the center and bottom holes of the pot. Second, a pre-determined amount of distilled water is applied to a 'field-moist' pot so that approximately 25-50 mL of leachate can be collected for analysis. It is important that the moisture conditions are consistent from pot to pot and at each separate extraction time if results are to be compared. Third, the leachate is transferred and stored in a suitable

plastic or glass container for future pH, EC and nutrient analyses either on-site or at a professional laboratory. Fourth, samples must be kept refrigerated or frozen until analysis in order to maintain nutrient integrity in solution.

Handreck et al. (1994) used two potted plant species (Hebe 'Inspiration' and Petunia 'Stereo Red') grown in different media types to compare the PT extract results to a standard method of media analysis, the saturated media extract (SME) method and found that the PT extraction technique resulted in higher (0.53) pH readings when compared to the laboratory determined SME. These results suggest that new ranges should be identified for the accurate representation of pH and EC when the PT extraction method is used instead of the standards set by SME interpretation charts for most ornamental species.

Alkalinity

The properties of irrigation water are greatly affected by geographic location and water source (Kramer and Peterson, 1990). Minor differences in bedrock formation and parent soil type can cause major differences in the elemental content of the water. Therefore, there exists much variation in the mineral content of the water running through most irrigation lines of greenhouses across the country and the world. Most important to the production of horticultural crops is the natural variation in water alkalinity and the consequences on nutritional status of container crops.

Water alkalinity is defined as the concentration of total soluble carbonates in a solution (Kramer and Peterson, 1990; Kuehny and Morales, 1998). The soluble

carbonates are the relative species of carbonates (CO_3^{2-}), bicarbonates (HCO_3^-) and carbonic acid (H_2CO_3) while other chemical species contributing to water alkalinity include dissolved hydroxides, ammonia, borates, organic bases, phosphates and silicates (Ludwig, 1985; Whipker et al. 1996). Higher concentrations of all of these materials in solution can raise the pH of the growing media to levels that reduce micronutrient uptake for most plant species (Reed, 1996). Removal of hydrogen ions from the media solution by bicarbonate ions increases the media pH (Kuehny and Morales, 1998). Therefore, the alkalinity of the irrigation water is considered a main component in the buffering ability of the solution and media.

Alkalinity is a concept that is often confused with pH for most commercial growers. Alkalinity, also referred to as the “acid-buffering capacity”, is a measure of the amount of acid needed to lower the pH below a certain level (Argo and Fisher, 2003). Alkalinity is not ion specific, rather it is a measurement of the concentration of a group of ions. It can be calculated using a test kit that adds small amounts of dilute acid to your water sample until there is a color change specific to a certain pH level. Conversely, pH is ion specific and is measured as the negative log of the concentration of H^+ ions in the solution.

Studies have been conducted to identify the variation in nutrient content of irrigation water across the United States. Ludwig and Peterson (1984) monitored nutrient concentrations from water sources across the U.S. and found that water alkalinity levels ranged between 2 and 575 mg CaCO_3 /liter with an average of 147 mg CaCO_3 /liter. Argo and Fisher (2003a) found that the median pH of irrigation

water in the United States 7.1 and the median alkalinity concentration was 130 mg CaCO₃/liter.

Water alkalinity, pH and nutrient content of the irrigation water are of critical importance in determining the suitability of a water source to be used to irrigate ornamental crops. Irrigation water should be monitored and carefully evaluated in order to calculate the total nutrients either occurring naturally or through supplementation with fertilizers. Miscalculation of the initial water quality can cause such damage and plant loss to a crop that the average loss per grower was over 50% loss of saleable plant material (Kuehny and Morales, 1998). Irrigation water that is highly alkaline (greater than 250 mg CaCO₃/ liter) has been shown to slowly increase the pH of the growing media over time (Whipker and Hammer, 1994; Kuehny and Morales, 1998). Toxicity due to high alkalinity and the resulting high media pH include reduced plant yield, chlorosis and in severe cases lower leaf necrosis along the leaf margins. Toxicity symptoms are caused by interactions of bicarbonates with other nutrients within the plant tissue as well as in the rhizosphere (Hageman and Hartman, 1941; Kramer and Peterson, 1990). To reduce the content of soluble carbonates in high alkalinity irrigation water, a small amount of phosphoric acid is injected into the irrigation lines. The phosphoric acid neutralizes available bicarbonate ions and lowers substrate pH to a level that is more suitable for proper root and plant growth (Whipker and Hammer, 1994).

Fertilizers

The fertilizer formula most commonly used to produce geraniums delivers 20% N - 4.4 % P - 16.6% K - 0.15% Mg - 0.1 % Fe as (FeEDTA) - 0.56% Mn - 0.2% B - 0.16% Zn - 0.1% Cu - 0.1% Mo at each fertigation (J.R. Peters Inc, 2004). Based on the considerations regarding N described in a previous sections, N is supplied as 60% nitrate-N and 40% ammonium-N. This geranium fertilizer formula was developed for heavy-feeding ornamentals grown in peat-based soilless media and provides enhanced concentrations of available chelated micronutrients similar to the “Peat-Lite™” formula of 20 N-10 P-20 K. In most greenhouses, the pH and water alkalinity can fluctuate widely in the irrigation water and can limit the solubility of micronutrients in the media. Peat-Lite™ formulations contain higher concentrations of chelated micronutrients to prevent precipitation of these nutrients in the media that could reduce the availability to the plant (Bachman and Miller, 1995).

The selection of a water-soluble fertilizer formula is based on two main considerations: the percentage of nutrients that the formula will provide the crop; and the ability of the formula to maintain a favorable pH. Fertilizers containing NH_4^+ as the main source of N can cause a decrease in media pH due to the release of H^+ ions during root uptake and during the conversion of NH_4^+ to NO_3^- through the process of nitrification. Examples of these types of formulas are: Peters Acid Special™ 21-7-7 (100% NH_4^+ producing 780 kg acidity/ 1000 kg) Peters Peat-Lite Special™ 20-10-20 (40% NH_4^+ producing 210 kg acidity/ 1000 kg) and Peters

General Purpose™ 20-20-20 (72% NH_4^+ producing 300 kg acidity/ 1000 kg).

Conversely, fertilizers that contain NO_3^- as the main source of N can increase the media pH due to the release of OH^- and HCO_3^- around the roots to balance nutrient uptake. These fertilizers that are low in NH_4^+ -N are considered 'basic' or 'neutral' formulas. Examples of these types of formulas are: Jack's Professional LX™ 15-5-15 (28% NH_4^+ producing 68 kg basicity/ 1000 kg) and Peters Dark Weather Special™ 15-0-15 (13% NH_4^+ producing 210 kg basicity/ 1000 kg) (Argo and Biernbaum; 1996).

The goal of most commercial greenhouse growers is to produce the maximum number of high quality plants in a relatively short production cycle. Efficient use of fertilizer maximizes the plant growth rate and utilizes the optimum ratio of macro and micronutrient fertilizers to minimize environmental and economic costs. Research investigating nutrient uptake at specific physiological stage of plant growth and development could be used to develop more effective fertility programs based on accurately assessing nutrient uptake patterns in order to reduce nutrient losses. These types of studies have been conducted with poinsettias (Whipker and Hammer, 1997) but have not been published for geraniums.

Currently, most growers use a soluble fertilizer formula injected directly into there irrigation lines in order to provide the geranium with nutrients on a constant-feed basis. Also, some growers for reasons previously discussed, supplement with additional Ca and Mg usually as a pre-plant addition of limestone or by using a fertilizer formula with higher Ca:Mg ratio. It is also common for growers to

supplement with a mixture of soluble trace elements at least one time during the crop cycle in order to provide the geraniums with an extra boost of micronutrients.

It is important for commercial growers to assess geranium fertility needs on the basis of many factors including media type, irrigation water quality and crop grown, it would be beneficial for fertilizer manufacturers to customize fertilizer formulations and programs to account for these factors in a manner that is simple and understandable for the growers to use. Controlled studies have been conducted to address various nutritional issues for impatiens (Argo and Biernbaum 1996, 1997), marigolds (Albano and Miller, 1998) and other ornamentals container crops (Fisher et al. 2001) in order to produce high quality plants. The research reported on in this dissertation will add another factor into this equation by exploring nutritional and fertility management of specific cultivars of geraniums.

The Influence of Media type

The implementation of fully automated irrigation systems required changes in the growing media for most container-grown plants to add materials that allowed for fast and thorough draining in order to avoid over-watering and high moisture levels (Biernbaum, 1992). Media used as a growing substrate for horticultural crops that is composed of some materials that are not soil is termed “soilless” media. Yet technically, this media can be classified within the Histisol soil taxonomic group because it is mainly (50% or greater) composed of peat and bark based materials. These “man-made Histisols” are largely organic based and participate in pH-dependent cation exchange reactions. Depending on the pH of the media, the

materials can vary widely in nutrient holding and nutrient exchange capacities.

Therefore, since these reactions in the media are much like most reactions in typical soils, some soil scientists do not consider these to be “soilless” growing media (Dr. Martin Rabenhorst, 2003; personal communication).

The availability of nutrients in media is a major concern when developing a growing media for a commercial crop. The common components of “soilless” root media include peat, bark, and vermiculite, which affect nutrient availability and perlite, polystyrene and rock wool, which ensure good drainage by increasing aeration and water-holding capacity, but do not have a nutrient holding capacity (Biernbaum, 1992; Argo and Biernbaum 1996; Nelson; 1991). Peat, bark and vermiculite have high cation holding capacities and can readily exchange available nutrients between the uptake site on the roots and the soil solution (Marschner, 1995).

One of the first soilless mixes was developed by Boodley and Shel Drake in 1972 at Cornell University and named “Cornell Peat-Lite A™”. This mix and several subsequent mixes contain 50% peat, usually as sphagnum peat moss, but also could be primarily reed sedge (Bunt, 1988; Nelson 1991). Peat, being the main component of most mixes, contributes the most to the cation exchange capacity of the media by influencing the pH and nutrient exchange in the root zone. Peat particles have readily exchangeable H⁺ ions held to the outside of organic functional groups (Bunt, 1988; Argo and Biernbaum, 1996; Marschner, 1996). Cations exchange along the peat surface with the available protons (Brady and Weil; 1999;

Marschner, 1995; Bloom, 2000). As the pH of the media solution increases from acidic to basic, the amount of H⁺ ions bound to the peat decreases and the amount of cations (mostly divalent) increases, thereby greatly increasing the CEC (cation exchange capacity) of the media. An early study (Helling et al., 1964) reported an increase of over 140 meq/ liter of CEC as the pH of a peat-based media (over 50%) increased from 3.5 to 8.0. This illustrates the influence of the pH of a peat and bark based media on nutrient availability and nitrification rates (Argo and Biernbaum; 1997). Since the exchange sites on the peat favor binding of divalent cations (Ca²⁺, Mg²⁺) these nutrients are less available to the plant while most monovalent cations (NH₄⁺, K⁺, Na⁺) remain soluble in the soil solution (Bunt, 1988; Marschner, 1995; Argo and Biernbaum, 1996).

Some growers have suggested that adding wetting agents to a peat-based media increases not only the water-holding capacity but also the capacity for the nutrients to exchange in the media solution. However, Biernbaum and his colleagues from Michigan State University conducted an experiment to test this theory and found that wetting agents did not increase nutrient exchange capacities under normal watering conditions (Biernbaum, 1992). Also, because of the high salt content of most fertilizer sources, the true water holding ability of most of the wetting agents could be greatly decreased in a well-drained substrate.

Many growers custom blend their own media specifically for the crops they are growing. Most geranium growers in the northern United States use a peat-based media with a soil and limestone amendment in order to increase the media's initial

pH and nutrient holding capacity (Argo and Biernbaum, 1997). Other commercially grown potted plants like the African marigold also require a higher substrate pH and commonly use these types of supplements (Albano and Miller, 1998). Although it is commonly thought that most of the media's CEC comes from the peat component, on a per volume basis, the addition of a mineral soil component to the mix can increase the effective CEC of the mix in excess of 40% (80 meq CEC for mix with mainly peat component vs. 140 meq CEC for a mix with peat plus a mineral soil addition) soil (Lucas, 1982; Argo and Biernbaum 1997). The inherent low bulk density of peat caused it to have overall lower cation exchange than the mineral soil even though the mineral soil had the capacity to hold less cations per unit.

Research had been conducted on growing geraniums in a standard soilless mix with the addition of a municipal waste compost (MWC) as a media addition. Ribeiro et al (2000) tested the hypothesis that MWC improved the media physical characteristics. They proposed that a MWC addition would lower the media's bulk density, increase water-holding capacity and supply the necessary nutrients for growth. Increasing increments of MWC were added to the media (10% -50%) and plant growth, EC and media nutrient content were assessed. Geraniums (*Pelargonium x horticum*) grown in media containing greater than 16.5% MWC had reduced yields and higher micronutrient levels in both the media and plant tissue. Ribeiro and his colleagues suggested that the negative results were caused by salinity stress of the geraniums and do not recommend using a MWC at a rate higher than 10% for a field addition. Other research has been conducted using geraniums

and other bedding plants grown in media amended with other materials such as: media with fish-waste compost addition (Hummel et al, 2000); media with humic components (Newman and Follett, 1989); media with rubber containing substrates (Evans and Harkess, 1997). This research investigated the effects of improving the physical characteristics of growing media by new amendments to the standard soilless media for growing geraniums.

Partially because of the wide variability that exists when growers custom blend their own media, there has been no research investigating the differences between the physical and nutrient exchanging characteristics of a standard geranium media and a custom blend media. Variable conditions at each greenhouse facility ranging from different soil types to different lime sources complicate development of standardized “custom field soil” blends of media. However, research is needed to address the differences in buffering capacity, cation exchange and nutrient solubility that exist between the two media types.

Water management and fertigation methods

Concerns about nutrient runoff from greenhouses have promoted a surge of research related to reducing nutrient losses during the production of container grown plants. In commercial plant production, the earliest methods for providing water and nutrients to plants were accomplished by “top irrigation”. This method was very labor intensive and resulted in widespread inconsistency in growth rate and heterogeneity in plant quality (Baas et al, 1995). The invention of the “injector” led

to the creation of the first fertigation system that employed the idea of “constant feeding”. This automated system was a way to distribute small levels of nutrients with each watering thereby greatly influencing how water and nutrients were managed and delivered to the crop. Systems were designed as early as 1960 that allowed for large amounts of water to be directed to each plant’s root zone. Thin plastic drip tubes and overhead sprayers provided water on demand and were used as the first irrigation systems for greenhouses. These systems are very inefficient and in the case of overhead irrigation often resulted in over 50% of the water and nutrients applied lost as runoff. Even though these systems have been improved over the years to provide a more uniform application of water and soluble fertilizer, nutrient loss is still an important concern (Biernbaum, 1992).

The introduction of the ebb-and flow irrigation system added greater control to avoid nutrient losses from commercial bedding plant and pot plant production. The optimum leaching fraction should be the smallest leaching fraction needed to maintain proper plant health (Biernbaum and Fonteno, 1989). By adjusting the rate of fertilizer along with the amount of water applied to each pot, the amount of nutrients lost and overall runoff from the facility are decreased. Ku and Hershey (1992) found that geraniums preferred a leaching fraction greater than 0.4. Lower leaching fractions resulted in a reduction of overall plant yield possibly due to the geranium’s inability to tolerate salts accumulating in the media over time. However, this conclusion does not support the theory that geraniums are salt tolerant (see next section).

Geraniums tolerance to salt and the importance of electrical conductivity

Geraniums are considered to be tolerant of high levels of potassium and magnesium. Therefore many nutritional recommendations for geraniums include supplementation with higher levels of these two macronutrients in order to prevent any deficiency in the media due to complexing with other ions (Fisher Inc., 2003). Feeding recommendations for most types of geraniums include nitrogen rates that are between 200 – 350 mg L⁻¹ N. Geraniums are classified as “heavy feeders” and require higher N rates on a constant feed basis to supply the fast rate of vegetative and reproductive growth during the short production cycle (Biamonte, 1993; White 1993).

Media salinity is quantified by the electrical conductivity (EC) of the saturated media extract. As the media EC increases, the ability for the plant to take up water decreases. High salt levels in the media cause water stress in plants due to the toxic effects of the salt ions. The result is a reduction in overall plant growth. Hartman et al. (1988) were the first research group to extensively study the effects of electrical conductivity research on the growth of greenhouse crops including geraniums. Subsequently, more extensive research found that media salinity at levels greater than 100 mg/L caused leaf edge burn, upward curling of leaves and reduced flower numbers for impatiens and pansies but not for geraniums (Kuehny and Morales, 1998).

Geraniums are referred to as “salt tolerant” (White, 1993) and compared to other ornamental plants, geraniums can tolerate higher media salinity levels without

experiencing a reduction in overall plant yield that is often seen in other ornamental crops (Ball Seed Co., 2004; Kuehny and Morales, 1998). However, its tolerance is cultivar specific (Ball Seed Co., 2004). For most ornamentals grown in containers, the maximum recommended EC level is 1.5 mS/cm and for plugs and propagation the maximum recommended EC level is 0.75 mS/cm (Argo and Fisher, 2003). For geraniums, when the media EC exceeds 2.0 mS/cm, leaching with distilled water for one irrigation cycle is recommended (Ball Seed Co., 2004). However, Baas et al. (1995; 1992) tested geraniums tolerance to salt accumulation in the media when using an ebb and flow irrigation system found that *Pelargonium* tolerated high levels (up to 7.5 mS/cm) of salt in the media and produced quality plants without the use of growth regulators. At higher EC levels (13.5 mS/cm), there was a 43% reduction in leaf width and a 50% reduction in total number of terminal cuttings produced. However, these symptoms could probably be avoided if leaching were scheduled based on media testing to prevent uncontrolled salt accumulation throughout the crop cycle.

CHAPTER 1: VARIATION IN MEDIA pH AND ELECTRICAL CONDUCTIVITY IN GERANIUMS

ABSTRACT

Pour-through extraction can provide data indicating geranium container nutrient status for growers to diagnose nutritional problems and prevent plant loss. The objective of this study was to examine changes in growing media pH and electrical conductivity during the production cycle of ten cultivars from each of the three geranium classes. Thirty cultivars of geraniums were grown in pots using standard commercial greenhouse production guidelines for 12 weeks. Pour-through extractions were performed every five days and media pH and electrical conductivity were determined on the collected leachate. While there was a significant reduction in media pH for zonal and ivy geraniums 36 days after transplanting plugs, only one regal cultivar exhibited a decrease in pH during the production cycle. Statistically significant differences for mean media pH and electrical conductivity were also observed among cultivars within each class at several sampling dates. The results of this study indicates that zonal, ivy, and one regal cultivars media pH decreases rapidly from day 21 to day 36 and then returns to initial levels by day 46. Because of the importance of media pH to nutrient uptake,

this study allows for a better understanding of nutritional problems that are linked to pH that frequently occur at the stage of growth. It also suggests that fertigation rates should be adjusted by cultivar and growth stage to address this pH variation.

INTRODUCTION

Geraniums are popular annuals grown as potted plants and hanging baskets and home landscape plants. Their variations in plant size, leaf and flower color, growing habit and bloom type make them adaptable in many home landscape designs. Geraniums cultivars are grouped into classes (zonal, ivy and regal) based on their taxonomy and morphology. The zonal class, *Pelargonium x horticum* has a unique banded leaf pattern and is adapted to many environments. Zonals vary in flower and leaf color and grow best in a media with a pH between 5.8 and 6.3 and a soluble salt level that is maintained between 1.5 mS/cm and 2.5 mS/cm (Whipker, 2003). Drawbacks of growing zonal geraniums include sensitivity to micronutrient levels, stem and internode elongation due to fluxing temperatures, and the required use of growth regulators to ensure compact vegetative growth. Advantages of growing zonal geraniums include tolerance to high soluble salts in the media, tolerance to high temperatures, and tolerance of high light and low water conditions. Overall, zonal geraniums are the class most suitable for the hobbyist gardener because these plants can thrive under variable conditions.

The ivy class of geraniums, *Pelargonium pelatum*, possesses a leaf shape similar to English ivy, a growth habit that is compact with trailing vegetative leads, and unique flower styles. The recommended optimum media pH for ivy geraniums is between 5.5 and 6.0 and a soluble salt level between 1.0 mS/cm and 2.0 mS/cm (Whipker, 2003). Although ivy geraniums are difficult to transplant and root and are sensitive to over-watering, their sales have been increasing because their trailing

habit is uniquely suitable for hanging basket production. Ivy geraniums are produced as a “specialty” ornamental which has increasing consumer demand.

The regal class of geranium, *Pelargonium domesticum*, have unique flower color combinations, oversize blooms, and uniquely serrated leaf shape and leaf size. Even though they have been grown for many decades, regal geraniums are new to consumers and more growers are producing a greater percentage of these types per year. Regal geraniums grow best at a media pH between 5.5 and 6.0, and a media soluble salt level between 1.5 mS/cm and 2.5 mS/cm (Whipker, 2003). The regal class of geranium is considered the most difficult type to produce (Ball Redbook, 2003) because they require cooler temperatures and a longer production time than the other geraniums classes. They are thought of as a novelty crop and are produced in fewer numbers than the other classes. When growing regal geraniums, some growers have reported problems that resemble micronutrient toxicity that could occur if the pH of the media decreases during the production cycle (H.Lang personal communication 2003; George Sheldrake personal communication, 2003). This production problem has only been reported over the last few growing seasons and may be linked to the type of fertility problems associated with the newer cultivars. Regal geraniums, unlike the zonal and ivy geraniums, are sensitive to drought and require a uniformly moist media throughout the production cycle. However, the production difficulties of the newer cultivars are offset by a higher selling price because they are considered unique and attractive.

A new production problem has recently been observed among some newly introduced cultivars of zonal geraniums. This problem, referred to as 'leaf cupping', involves newly formed leaf tissue becoming puckered, rubbery and cupped upward thereby reducing the leaf tissue's ability to expand and the overall plant size (personal communication. H. Lang; Fischer Inc. 2004). "Leaf cupping" has only been observed in specific zonal cultivars that appear to be "sensitive" to low alkalinity irrigation water but it has been suggested that it could occur in the other classes of geraniums grown under specific conditions. The cultivars that are affected most severely have dark leaves and dark colored flowers, dark reds and dark purples (Ball Seed Co. 2002; Fisher USA. 2001). Although, it is not certain when "leaf cupping" initiates, the growing media pH of severely affected plants tends to be at least one unit below the normal recommended range. Thus, to correct this abnormality, it has been recommended to apply flowable lime or potassium bicarbonate during production or pre-mix a coarser grade limestone in combination with fine grade limestone at the beginning of production. This lime treatment should maintain a consistent media pH over a longer period of time. However, there have been no scientific reports of studies that have confirmed the role of water alkalinity, media pH and cultivar in producing leaf cupping symptoms. There has also been no verification that the cupping is related to micronutrient toxicity as suggested. Monitoring the growing media pH could be a useful tool to determine the cause of leaf cupping and subsequently be used as a diagnostic indicator for growers to prevent this disfiguring problem.

The objective of this study was to determine and compare the growing media pH and EC levels of 30 geranium cultivars from three geranium classes (zonal, ivy and regal) over the course of a production cycle. The results of this study will provide basic information related to geranium nutrition because of the major influence of pH and EC on nutrient uptake. This information will increase the understanding of the nutritional requirements of geranium and improve the recommendations for fertility programs of geraniums. Currently, fertility is based on the macro and micronutrient concentrations of geranium tissue, media and the greenhouse water quality. If the geranium cultivar also affects its own environment around the root media and the effects vary over time, this should also be considered as a major factor when addressing fertility issues. Also, if the leaf cupping is observed during the study, monitoring the pH and EC would provide scientific evidence that “leaf cupping” is related to changing pH and EC in the root media. This would provide evidence that the variability in pH at certain stages of growth affects nutrient availability leading to unbalanced nutrient uptake by the geranium roots as a potential cause of these symptoms.

MATERIALS AND METHODS

This experiment studied ten cultivars selected from each of the three most commonly grown geranium classes: the hybrid species, *Pelargonium x horticum* (Zonal), *Pelargonium pelatum* (Ivy) and *Pelargonium domesticum* (Regal).

Cultivars were selected based on factors including: leaf and flower color, growth habit, sensitivity to micronutrient imbalances, sensitivity to pH levels, salt tolerance, consumer preference and plants grown per year (Oglevee, Inc 2003) (Table 1).

Fourteen day old, rooted cuttings (25 of each cultivar) were shipped in size 7 plug trays (Jiffy Inc.) in a peat-based media. Cuttings were taken from virus free stock plants at a plug production center for Oglevee Incorporated in Connellsville, PA. Three cuttings of each cultivar were selected for the study, based on uniformity of height, root condition and plant appearance at the time of transplant. Plants were grown in 6-inch (15 cm) diameter plastic pots and fertigated by an automated system using drip tubes (1 per pot). Plants were fertilized with a combination of two formulas as needed over the course of the 12 week study with a rate set to deliver 250 mg L⁻¹ of N from either Jacks Professional Peat-Lite Special™ (20-10-20) or Jacks Professional Cal-Mag™ (15-5-15) (J.R.Peters, Inc, Fogelsville, PA).

The experiment was a randomized complete block design with three blocks and one plant per cultivar per block at the University of Maryland new research greenhouse complex. Plants were spaced pot-to-pot for 14 days and then extended to 6 inches (15 cm) on center per square foot area. For the first two weeks, temperature was maintained at 22° C (72 °F) during the day and 18 ° C (65 °F)

during the night. After two weeks, temperature was lowered to 20° C (68 °F) during the day and 14 ° C (56 °F) during the night with similar day period length for the remainder of the experiment. The day-length was extended to 14 hours during the winter months with additional lighting providing 350 $\mu\text{mol m}^{-2} \text{s}^{-1}$ of photosynthetically active radiation at plant height.

The growing media was a commercial blend of 78% sphagnum peat moss and 22% perlite on a bulk basis (Sunshine Mix #1™, SunGro Inc.). Pots were filled with media to 3 cm below the top of the pot, the media was tamped into the pots to remove air pockets and leached with 1000 mL of de-ionized water to remove impurities or contaminants before transplant. All pots received a preventative drench of ‘Root Shield™’ with the soil fungus active ingredient *Trichoderma harzianum* T-22 (BioWorks. Inc., Geneva NY) to protect against root rot fungi such as *Rhizoctonia sp.* and *Pythium sp.*. Pot media was allowed to return to field moisture conditions (approx 24 hours) before the selected plugs were transplanted to begin the experiment.

Fourteen days after transplanting (DAT), plants showed good establishment of root growth and received 500 ppm of the growth regulator, Florel™, active ingredient Ethephon (Monterey Inc., Fresno, CA) as a foliar spray (48 hour REI) to increase branching, delay flowering and promote more compact growth. At each fertigation event, plants were thoroughly soaked and then allowed to dry out to the point just before wilting to condition the plants, promote root growth, and maximize nutrient uptake.

Growing media pH and electrical conductivity were assessed over the course of the 74 day study using the pour-through technique (Robert Wright, 1986). At each collection date 200 mL of distilled water was poured onto each pot, allowed to drain for 15 minutes, and collected from an eight inch saucer. Twenty-five milliliters of the leachate solution was collected in a sterile plastic vial (Wheaton Inc.) and refrigerated at 10 °C for approximately 5 days until pH and EC were measured. The experiment began on October 31, 2003. The initial pour-through was conducted prior to the transplant of the rooted cuttings. Pour-throughs were collected every five days until the termination of the experiment on January 12, 2004 providing 14 sampling dates. Due to wet conditions, data from one sampling date were not included in the analyses.

Leachate pH and electrical conductivity were determined by measuring the extract recovered from pour-through with pH and EC meters. Measurement difference between replicates were within 0.2 pH units for all samples. The EC meter measures soluble salts and is important for commercial horticulture production because it is used to diagnose potential salinity problems.

Statistical analyses of the data were conducted using the SAS (Version 6.0). Statistical significance of the pH and EC data were determined using PROC GLM, the analysis of variance tests. The pH and EC cultivar means were compared at each sampling date using LSD (least significant difference) values at $P=.05$.

Table 1. Geranium Cultivars and Criteria Used For Including in Experiment 1

<i>Pelargonium x horticum</i>	<i>Pelargonium pelatum</i>	<i>Pelargonium domesticum</i>
Zonals	Ivies	Regals
Kim ^{1,2,3}	Nicole ^{1,2}	Royalty White ^{3,8}
Fox ⁶	Global Merlot ^{2,3,7}	Camelot ^{2,7,8}
Evening Glow ^{2,7,8}	Global deep lilac ^{4,5,8}	Bravo ^{2,3}
Sassy Dark Red ^{4,5,8}	Global Red ^{6,8}	Maiden Deep Lavender ⁷
Patriot Cherry Rose ^{4,7}	Global Salmon Rose ^{1,3}	Debutante ^{2,6}
North Star ^{4,5}	Global Ruby Red ^{1,7,8}	Daper Burgundy ^{2,4,5}
Pink ⁸	Global Purple ^{1,3}	Imperial ^{1,2,3}
Peaches ^{1,8}	Sybil Holmes ^{4,5,7}	Elegant Purple Bicolor ^{2,7}
Melody Blue ^{2,5,7}	Red Sybil ⁶	Baroness ^{2,6,8}
Shocking Violet ^{2,7}	Beauty of Eastbourne ^{4,5,7}	Elegant Rose Bicolor ^{2,3,7}

1. leaf color
2. flower color
3. growth habit
4. sensitivity to micronutrients
5. sensitivity to pH
6. salt tolerance
7. consumer preference (new)
8. level of production

RESULTS & DISCUSSION

Zonal geraniums

The pH of the solution collected from the containers of the zonal geraniums was significantly different ($p < 0.01$) between cultivars within a particular date and there were also significant differences ($p < 0.01$) between the sampling dates.

The pH means of the zonal cultivars at each sampling date are displayed in figure 1. During the 12 week production cycle, the root media pH decreased sharply during the period 21 to 36 DAT and then rapidly returned to the initial levels by day 46. The initial mean media pH of 6.3 declined to a low of 4.8 and then increased to an average final pH of 6.4. Twenty one DAT, the mean pH values for 'Fox' and 'Patriot Cherry Rose' were 6.1, while the mean pH values for 'Kim' and 'Pink' had dropped to 5.4 (Table 2, Figure 1). Certain dates were identified as pivotal points in the production cycle and the means comparison and statistical significance are displayed in Table 2.

In addition to pH, electrical conductivity (EC) was measured on the media leachate for the ten zonal cultivars. The EC means were significantly different ($p < 0.01$) due to cultivar within a sampling date. Differences between EC means of cultivars ($p < 0.01$) were also significant between sampling dates (Table 3). Means were calculated and compared between cultivars for each sampling date and between sampling dates and are represented graphically in Figure 1.

Initially there was a dramatic increase in EC that would coincide with the initiation of the automated constant feed fertigation system as a mechanism to

supply water and nutrients to the plants. A second increase in EC was observed between 25 and 40 DAT where a maximum EC for all cultivars was observed. For some cultivars, EC increased more than one full unit of soluble salts during the experiment. In comparing the pH and EC data, it is evident that there is an inverse relationship between pH and EC at 36 DAT. At this sampling date, the pH of the leachate was at a minimum while the EC of the leachate was at its maximum (Table 3, Figure 2).

Table 2. pH Means at Selected Sampling Dates for 10 Zonal Geranium Cultivars.

Cultivar	-----pH-----				
	Day 1 Oct.31	Day 21 Nov. 20	Day 36 Dec. 5	Day 46 Dec. 15	Day 74 Jan. 12
Evening Glow	6.26 b	6.09 ab	4.98 b	5.85 a	6.38 b
Fox	6.31 ab	6.05 b	5.16 a	5.86 a	6.49 a
Kim	6.40 a	5.90 bc	5.21 a	5.53 bc	6.44 ab
Melody Blue	6.36 a	6.15 a	5.03 ab	5.44 c	6.42 ab
North Star	6.29 b	6.09 ab	5.13 a	5.65 b	6.42 ab
Patriot Cherry Rose	6.31 ab	6.15 a	5.12 a	5.54 b	6.59 a
Peaches	6.35 a	6.21 a	4.87 c	5.67 b	6.53 a
Pink	6.39 a	6.21 a	4.98 b	5.56 b	6.49 a
Sassy Dark Red	6.23 b	5.80 bc	5.22 a	5.81 a	6.39 b
Shocking Violet	6.44 a	6.13 a	4.81 c	5.90 a	6.54 a
LSD within a date (p=.05)	0.15	0.14	0.15	0.15	0.13

Table 3. Electrical Conductivity Means at Selected Sampling Dates for 10 Zonal Geranium Cultivars.

Cultivar	-----Electrical Conductivity-----				
	<u>Day 1</u> Oct.31	<u>Day 21</u> Nov. 20	<u>Day 36</u> Dec. 5	<u>Day 46</u> Dec. 15	<u>Day 74</u> Jan. 12
Evening Glow	1.96 a	3.01a	2.93 a	3.67 a	3.05 ab
Fox	2.11 a	3.00 a	2.92 a	3.71 a	3.09 a
Kim	1.85 ab	3.00 a	2.93 a	3.76 a	3.14 a
Melody Blue	1.63 b	2.95 b	2.87 ab	3.71 a	3.09 a
North Star	2.31 a	2.97 ab	2.89 ab	3.69 a	3.08 a
Patriot Cherry Rose	1.83 a	2.98 ab	2.90 a	3.72 a	3.11 a
Peaches	1.72 b	3.07 a	2.99 a	3.69 a	3.08 a
Pink	2.17 a	3.03 a	2.95 a	3.56 a	2.95 b
Sassy Dark Red	1.72 b	3.06 a	2.98 a	3.63 a	2.97 ab
Shocking Violet	2.13 a	3.00 a	2.93 a	3.71 a	2.96 ab
LSD within a date (p=0.05)	0.43	0.11	0.11	0.92	0.90

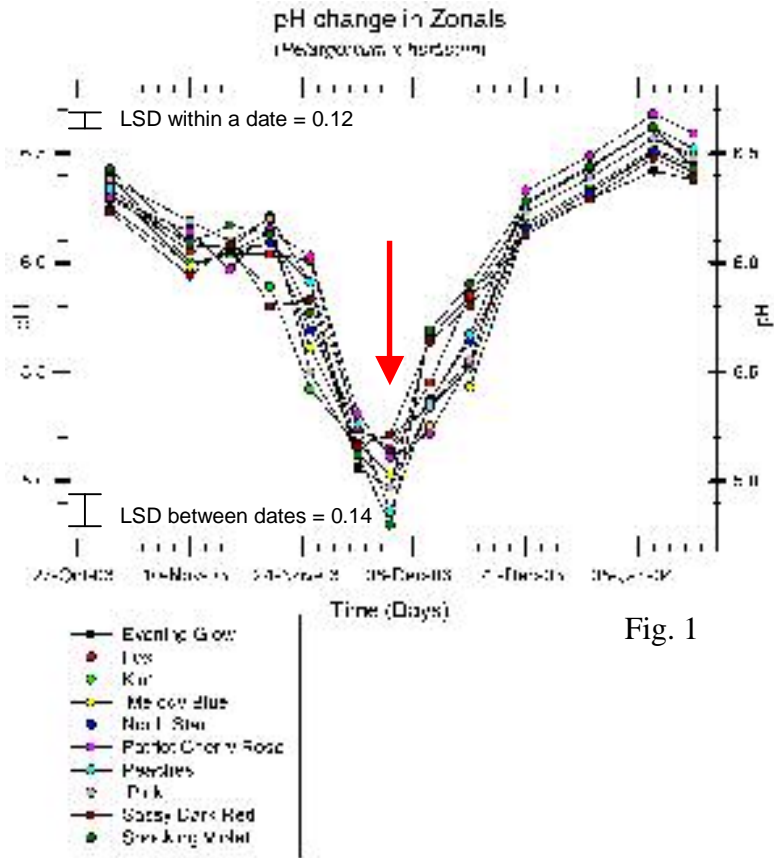


Fig. 1

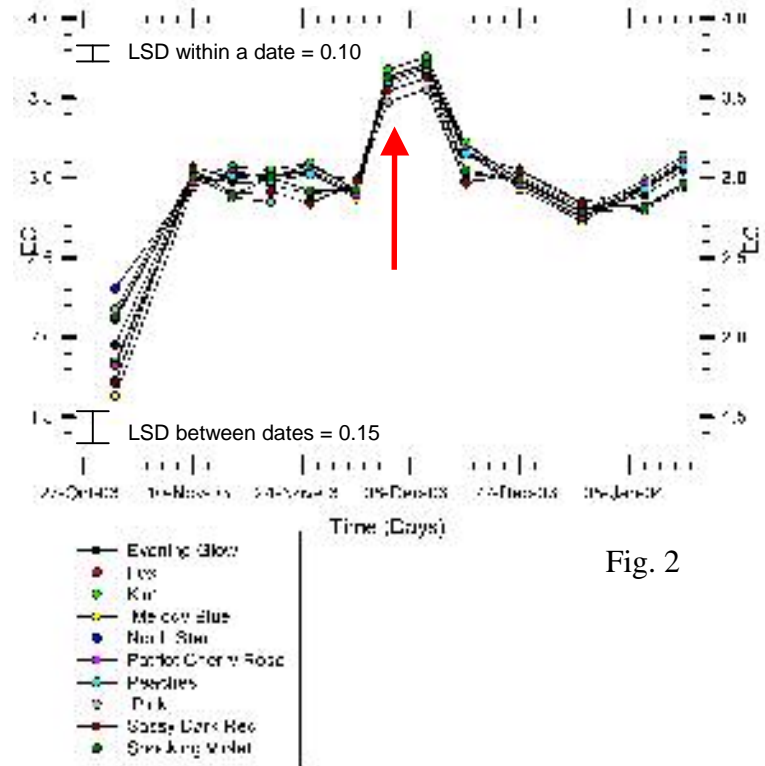


Fig. 2

Figures 1 and 2: Media pH and Electrical Conductivity Means of Zonal Geraniums as Measured by Pour-Through Extraction. Red Arrow Indicates 36 Days of Growth from Transplant.

Ivy geraniums

The pH of the solutions collected from the containers of ivy geraniums were significantly different ($p < 0.01$) between cultivars within a particular date and there were also significant differences ($p < 0.01$) between the sampling dates (Table 4). Mean pH of a cultivar at a particular sampling date and between sampling dates and are represented graphically in Figure 3.

Ivy geraniums exhibited a pattern of pH variation similar to the zonal geraniums. A general decrease in media pH was observed over the first few weeks of production followed by a gradual increase back to the initial pH levels by experimental harvest. Media pH decreased dramatically 21 DAT and at that sampling date, there were significant differences between cultivars (Table 3, Figure 3). The media pH decreased from an average initial pH of 6.0 DAT, to an average pH of 5.2 at 21 DAT, with the lowest average pH at 36 DAT. The mean pH's of 'Global Salmon Rose' and 'Nicole' displayed the largest decrease in pH during this period. The mean pH decreased from 6.1 to 5.2 for Global Salmon Rose and from 6.2 to 5.2 for Nicole (Table 4, Figure 3). After 36 DAT, mean media pH increased for all cultivars reaching a maximum mean pH 74 DAT.

The overall pH decrease for ivy geraniums was not as dramatic as the decrease observed in zonal geraniums. The lowest media pH measured for an ivy cultivar was 5.2 for the Global Salmon Rose compared to the lowest pH for a zonal cultivar was 4.8 for the Shocking Violet cultivar. Recommended media pH for production is lower for ivy geraniums (recommended pH range 5.5-6.0) than for

zonal geraniums (recommended pH range 5.8- 6.3). The selected sampling dates that were identified as pivotal points in the production cycle and the cultivar means and LSD values are presented in Table 4

EC was also measured from the same leachate collected from the container media by the pour-through extraction process. The results for the ivy cultivars were very similar to the zonal cultivars for EC. The mean EC's for the media of the ivy cultivars were also significantly different ($p < 0.01$) between cultivars within a sampling date as well significant differences ($p < 0.01$) between sampling dates (Table 5). Similar to the zonal cultivars, at 36 DAT, the media EC of the ivy cultivars also increased while the media pH decreased. Mean EC values of the ivy cultivars for each sampling date and between sampling dates and are represented graphically in Figure 4 and for selected dates (Table 5).

Table 4. pH Means at Selected Sampling Dates for 10 Ivy Geranium Cultivars.

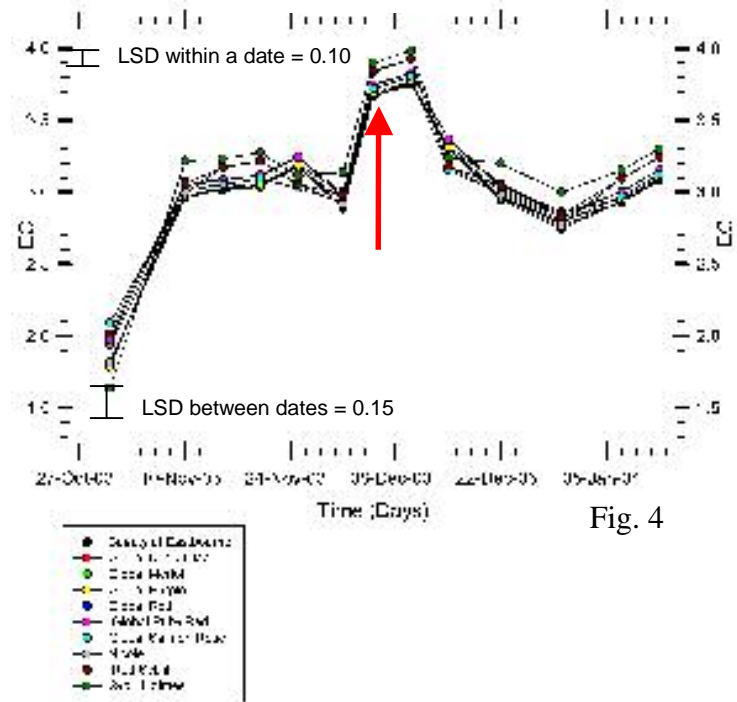
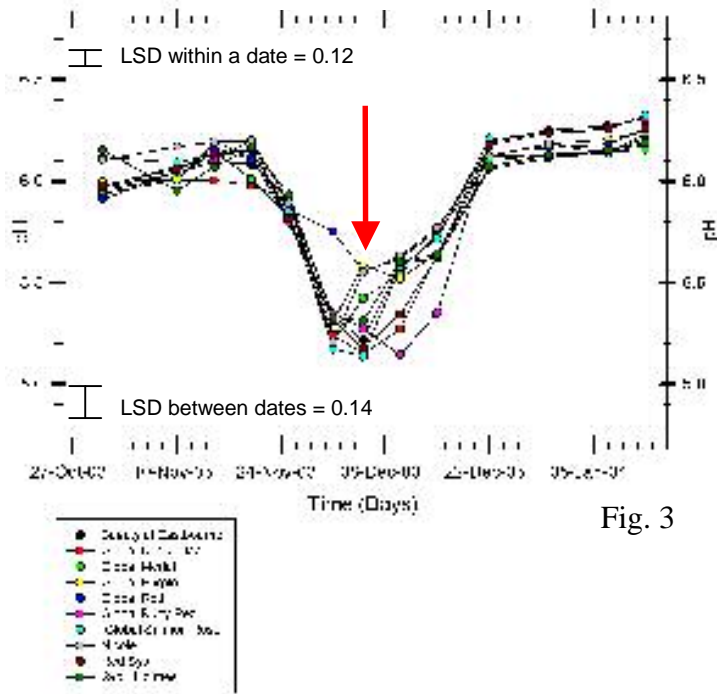
Cultivar	-----pH-----				
	<u>Day 1</u> Oct.31	<u>Day 21</u> Nov. 20	<u>Day 36</u> Dec. 5	<u>Day 46</u> Dec. 15	<u>Day 74</u> Jan. 12
Beauty of Eastbourne	5.97 b	6.04 ab	5.33 b	5.59 a	6.21 a
Global Deep Lilac	5.94 bc	6.01 b	5.24 bc	5.27 b	6.18 ab
Global Merlot	5.96 b	6.02 b	5.21 bc	5.54 a	6.16 ab
Global Purple	6.00 b	6.01 b	5.31 bc	5.52 a	6.24 a
Global Red	5.91 bc	6.05 ab	5.74 a	5.62 a	6.26 a
Global Ruby Red	5.97 b	6.07 ab	5.35 b	5.14 c	6.31 a
Global Salmon Rose	6.12 a	6.09 ab	5.17 c	5.58 a	6.33 a
Nicole	6.10 ab	6.17 a	5.21 bc	5.63 a	6.24 a
Red Sybil	5.98 b	6.06 ab	5.31 b	5.34 ab	6.26 a
Sybil Holmes	6.15 a	5.95 b	5.33 b	5.60 a	6.19 ab
LSD	0.14	0.14	0.14	0.15	0.14

Statistical significance using LSD(0.05) within a date calculated using the ANOVA procedure of the SAS

Table 5. Electrical Conductivity Means at Selected Sampling Dates for 10 Ivy Geranium Cultivars.

Cultivar	-----EC-----				
	<u>Day 1</u> Oct.31	<u>Day 21</u> Nov. 20	<u>Day 36</u> Dec. 5	<u>Day 46</u> Dec. 15	<u>Day 74</u> Jan. 12
Beauty of Eastbourne	1.82 a	2.96 b	2.89 b	3.76 a	3.09 b
Global Deep Lilac	1.80 a	3.02 b	2.95 b	3.75 a	3.08 b
Global Merlot	1.94 a	2.98 b	2.90 bc	3.76 a	3.09 b
Global Purple	1.78 a	3.08 ab	3.00 b	3.77 a	3.10 b
Global Red	1.99 a	3.04 ab	2.97 b	3.83 a	3.16 ab
Global Ruby Red	1.97 a	3.07 ab	2.99 b	3.83 a	3.15 ab
Global Salmon Rose	2.09 a	3.01 b	2.93 b	3.80 a	3.12 ab
Nicole	1.81 a	2.99 ab	2.92 b	3.93 a	3.25 a
Red Sybil	2.02 a	3.06 ab	2.98 b	3.92 a	3.24 a
Sybil Holmes	1.64 a	3.22 a	3.14 a	3.98 a	3.30 a
LSD	0.43	0.11	0.11	0.92 a	0.09

Statistical significance using LSD(0.05) within a date calculated using the ANOVA procedure of the SAS



Figures 3 and 4: : Media pH and Electrical Conductivity Means of Ivy Geraniums as Measured by Pour-Through Extraction. Red Arrow Indicates 36 Days of Growth from Transplant

Regal geraniums

The pH collected from the media leachate of the regal geraniums was significantly different ($p < 0.01$) between cultivars within some dates and there were significant differences ($p < 0.01$) between some sampling dates but not all of them (Table 6). Means were calculated and compared between cultivars within and between sampling dates and are represented graphically in Figure 5.

All cultivars of regal geraniums except for 'Baroness' were within the recommended pH range for optimal regal geranium growth (5.5- 6.0) throughout the 74 day production cycle. Although some pH differences were significant among cultivars and dates, plant growth did not appear affected during any stage of production. 'Baroness' was an exception and the leachate collected from the media dramatically decreased in pH after 15 DAT. At 36 DAT, media pH continued to decrease reaching its lowest value of 5.1 after which leachate pH increased over the next 10 days and by 53 DAT the pH was no longer significantly different from the other regal cultivars. The pH means for the regal cultivars for the selected sampling dates are presented in Table 6.

Before designing this experiment, based on grower reports, it was hypothesized that regal cultivars could decrease the media pH. In my experiment, only one regal cultivar produced a pH reduction. However, other regal cultivars that were not included in my experiment may cause a decrease in media pH since the ten cultivars selected represent a small sample of regal geraniums from one production company (Oglevee, Inc.). It would be beneficial to further investigate

this trend within the regal geranium class and test its effects if any on nutrient uptake.

Electrical conductivity was also measured on the media leachate for the ten regal cultivars. There were significant differences ($p < 0.01$) due to cultivar within a sampling date as well significant differences ($p < 0.01$) between sampling dates (Table 3). Means were calculated and compared between cultivars for each sampling date and between sampling dates and are represented graphically in Figure 6. Unlike pH in the media, EC trends over time for regal cultivars responded almost identically to zonal and ivy cultivars and the variation of the electrical conductivity similar patterns over the production cycle.

Table 6. pH Means at Selected Sampling Dates for 10 Regal Geranium Cultivars.

Cultivar	-----pH-----				
	<u>Day 1</u> Oct.31	<u>Day 21</u> Nov. 20	<u>Day 36</u> Dec. 5	<u>Day 46</u> Dec. 15	<u>Day 74</u> Jan. 12
Baroness	6.35 a	5.99 c	5.11 c	5.23 c	6.30 ab
Bravo	6.27 ab	6.25 a	6.43 a	6.17 a	6.36 a
Camelot	6.24 ab	6.21 a	6.44 a	6.17 a	6.33 ab
Daper Burgundy	6.32 a	6.28 a	6.51 a	6.24 a	6.38 a
Debutante	6.42 a	6.31 a	6.37 a	6.10 ab	6.37 a
Elegant Purple Bicolor	6.41 a	6.15 ab	6.33 ab	6.08 ab	6.21 b
Elegant Rose Bicolor	6.39 a	6.16 ab	6.29 ab	6.04 ab	6.22 b
Imperial	6.31 a	6.26 a	6.37 a	6.11 a	6.38 a
Maiden Deep Lavender	6.31 a	6.23 a	6.31 ab	6.08 ab	6.34 a
Royalty White	6.32 a	6.17 ab	6.27 ab	6.00 b	6.29 ab
LSD	0.13	0.13	0.14	0.15	0.14

Statistical significance using LSD(0.05) within a date calculated using the ANOVA procedure of the SAS

Table 7. Electrical Conductivity Means at Selected Sampling Dates for 10 Regal Geranium Cultivars.

Cultivar	-----EC-----				
	<u>Day 1</u> Oct.31	<u>Day 21</u> Nov. 20	<u>Day 36</u> Dec. 5	<u>Day 46</u> Dec. 15	<u>Day 74</u> Jan. 12
Baroness	1.77 a	3.14 ab	3.07 ab	3.91 a	3.27 a
Bravo	1.81 a	3.23 a	3.15 a	3.78 a	3.16 b
Camelot	1.88 a	3.05 b	2.98 b	3.71 a	3.09 b
Daper Burgundy	1.79 a	3.02 b	2.95 b	3.77 a	3.15 b
Debutante	1.77 a	3.04 b	2.97 b	3.80 a	3.18 ab
Elegant Purple Bicolor	1.64 ab	3.24 a	3.16 a	3.81 a	3.15 b
Elegant Rose Bicolor	1.89 a	3.24 a	3.17 a	3.73 a	3.07 bc
Imperial	2.06 a	3.25 a	3.17 a	3.81 a	3.15 b
Maiden Deep Lavender	1.55 b	3.29 a	3.22 a	3.71 a	3.05 bc
Royalty White	1.6 ab	3.09 b	3.01 ab	3.71 a	3.06 bc
LSD	0.43	0.11	0.11	0.92	0.09

Statistical significance using LSD(0.05) within a date calculated using the ANOVA procedure of the SAS

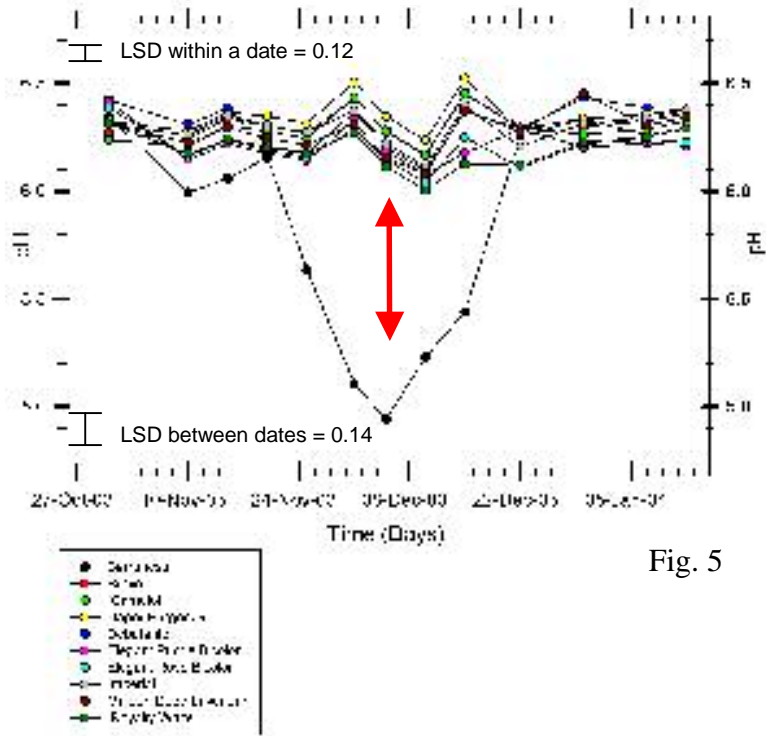


Fig. 5

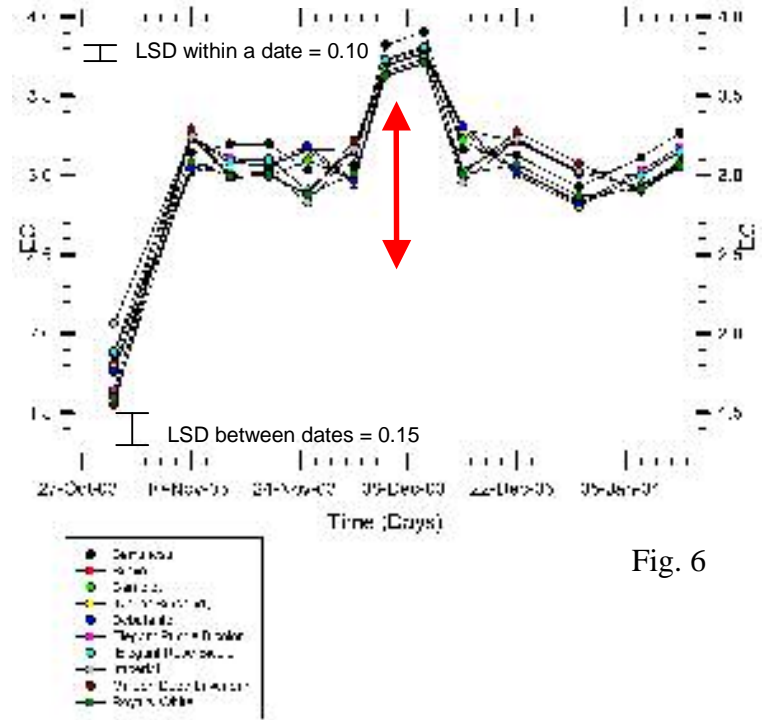


Fig. 6

Figures 5 and 6: : Media pH and Electrical Conductivity Means of Regal Geraniums as Measured by Pour-Through Extraction. Red Arrow Indicates 36 Days of Growth from Transplant

Difference among geranium classes

The mean media pH of the three geranium classes showed different trends over time while the mean electrical conductivity of the geranium classes were strikingly similar. Figure 7 graphically displays the media pH means over time for the three geranium classes. Except for the initial sampling date, the mean media pH of the regal geraniums was significantly different pattern than the ivy and zonal classes (Figure 7). Between 21 and 46 DAT, the mean media pH of the ivy and zonal geraniums rapidly decreased to almost one full pH unit lower than the regal class mean media pH. At the experiment's conclusion, the mean media pH of the zonal geraniums was significantly higher than the means of the ivy and regal classes. However, at the end of the experiment all class means were within the normal recommended range for media pH for their specific class.

The mean EC values of the three geranium classes were not significantly different within sampling dates (Figure 8) However, there were significant differences for EC measurements between means at different stage of growth. An initial increase in EC was expected with the initiation of the constant-feed fertigation, but after this increase it was expected that EC levels would stabilize. However, there was a significant increase in media EC that coincided with the decrease in pH for the ivy and zonal geranium. Often when there is an increase in EC it is due to an increase in fertilizer application rate causing the excess salts to accumulate in the media, but since the fertigation rate was constant throughout the production cycle, this probably did not the cause the significant increase in EC.

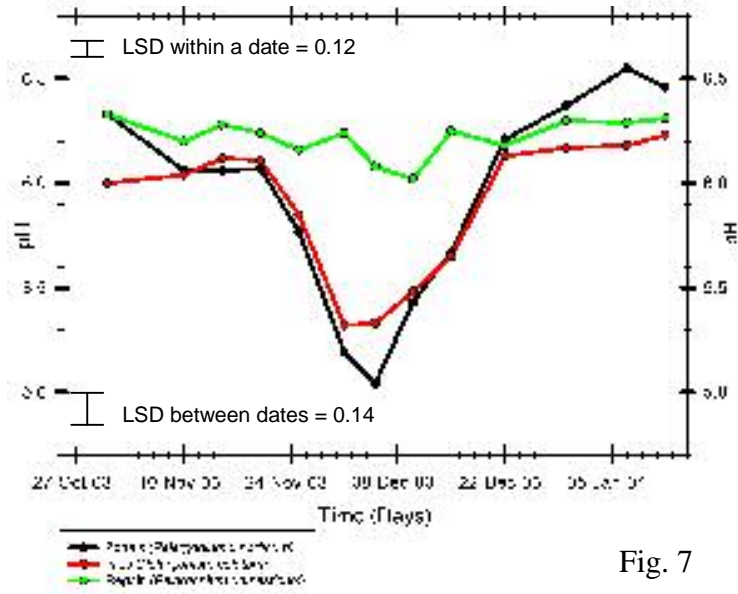


Fig. 7

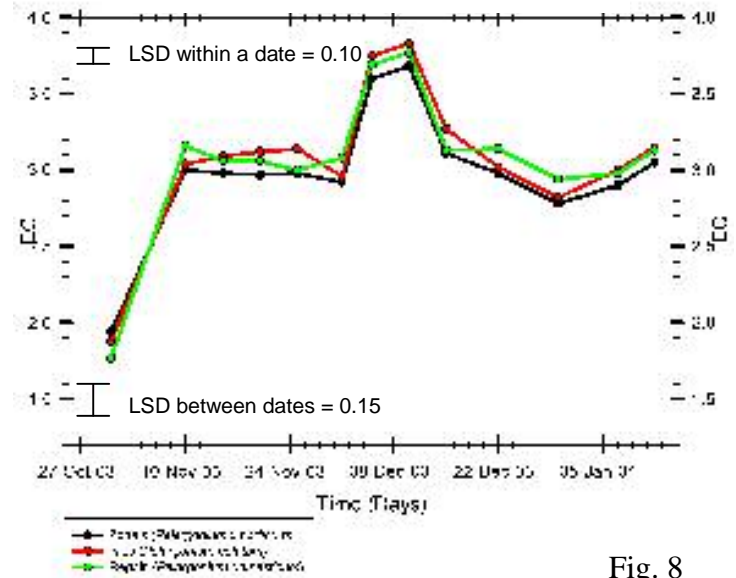


Fig. 8

Figures 7 and 8: Variation in media pH and electrical conductivity of the three classifications of geraniums as measured by pour-through extraction over a 12 week production cycle.

DISCUSSION

This study was designed to evaluate and compare the growing media pH and EC levels of 30 geranium cultivars from three geranium classes (zonal, ivy and regal) over the course of a production cycle. The pour-thorough technique provided an accurate representation of the media pH and EC variability. Analysis of the data allowed us to compare the differences between each geranium class over time and also the differences of the cultivars within each class. Results provided basic information related to geranium nutrition because of the major influence of pH and EC on nutrient uptake. This information is useful in understanding the basic nutritional requirements of geranium and can be used to improve the recommendations for fertility programs of geraniums. Currently, fertility is based on the macro and micronutrient concentrations of geranium tissue, media and the greenhouse water quality. The pH data from this study showed that the geranium cultivar affects its own environment around the root media. These effects vary over time with changes in pH occurring at similar times in both the zonal and ivy geraniums and one cultivar of the regal class.

Nelson and Haung in 2003 studied how several varieties of horticultural grown crops could affect their own media pH. Seedlings were grown in a nutrient solution environment on germination paper until the plants reached the two leaf stage. The initial pH of the paper was recorded and over a period of several hours the researchers measured the change in pH of the paper around the root. Seedling geraniums, new guinea impatiens and lisianthis demonstrated a decrease in pH while

vinca and petunia increased in pH over the period tested. This was the first information on a plants ability to cause a pH shift around the root zone. There were many drawbacks to these findings including the short period of time tested, the age of the plants, the nutrient solution environment and the method of pH determination on the pH paper.

Differences in the media pH at specific stages of growth should be considered as a major factor when addressing fertility issues of ivy and zonal geraniums. In addition, further testing of all existing and new cultivars should be conducted in order to identify the plants that are more susceptible to large media pH shifts. It has been well documented that a decrease in pH can cause an increase in micronutrient uptake for most horticultural crops (Fisher and Argo, 2001; Marschner 1995). Geraniums can take up high concentrations of Fe and Mn under acidic media conditions leading to excessive foliar damage due to chlorosis and necrosis (Fisher and Argo, 2001; Bachman and Miller, 1995; Biamonte, 1990). However, geraniums in production are termed “heavy- feeders”; in order to produce large plants quickly, geraniums often receive higher concentrations of soluble fertilizer on a daily basis in comparison to other horticultural crops (Fonteno, 1992; White, 1993). A supplemental drench of a complete soluble micronutrient package such as S.T.E.M. is also applied at least once during a production cycle. One of the goals of most greenhouse nutrient management plans is to implement best management practices that reduce nutrient input and loss (Biernbaum and Fonteno, 1989). The pH data

acquired in this study can be used to adjust fertilizer levels with pH in order to reduce excess uptake or nutrient loss.

The leaf cupping was not observed during the study, therefore we were unable to determine if monitoring the pH and EC could provide scientific evidence that “leaf cupping” is related to changing pH and EC in the root media. There was evidence that the variability in pH at certain stages of growth affects nutrient availability leading to unbalanced nutrient uptake by the geranium roots. Further study with new cultivar and subsequent leaf tissue and root nutrient concentration needs to be conducted in order to determine the potential causes of these symptoms.

CHAPTER 1: CONCLUSION

The objective of this study was to monitor the pH and EC levels of media in order to determine whether there were differences in media pH and EC among 30 geranium cultivars from three geranium classes (zonal, ivy and regal) and determine when the differences occurred during the production cycle. The data were intended to provide basic information related to geranium nutrition relating the major influence of pH and EC on nutrient uptake. This information can be used to improve nutritional recommendations for fertility programs for geraniums.

Currently, fertility assessment is based on the macronutrient and micronutrient concentrations of geranium tissue, their growing media, and the greenhouse water quality. This experiment addressed the question of whether geraniums should be considered as a 4th factor when determining the appropriate amendments for optimizing container media nutritional status. The mean media pH and EC over time varied among the geranium commercial classes and stage of plant growth indicating that nutritional recommendations should consider these factors. Within the zonal and ivy geranium classes, all of the cultivars followed similar patterns of pH and EC variation at similar stages of growth over the production cycle. In contrast, except for Baroness, the regal cultivars studied did not cause pH variation in the media. The media of pots containing zonal geraniums have the most variable pH of the three geraniums classes.

Therefore, this experiment confirms that geraniums have the ability to affect their media environment and should improve the understanding of nutrient availability in the media or unbalanced nutrient uptake by the geranium roots.

General pH recommendations for geraniums should be revised and replaced by more specific ranges that consider the geranium class, cultivar, and stage of growth.

CHAPTER 2: CULTURAL FACTORS THAT AFFECT
NUTRIENT UPTAKE AND BALANCE IN *PELARGONIUM x*
HORTICUM

ABSTRACT

The standard indicators of container-plant nutritional status are elemental concentrations of the plant tissue, growing media and irrigation water. However, there are no published studies investigating the effects and their interactions of these factors on geranium growth. In addition, geraniums fertigated with low alkalinity water have been associated with severe nutrient deficiencies and toxicities suggesting that an unsteady media pH coupled with low buffering capacity of irrigation water may cause preferential nutrient uptake.

The objective of this greenhouse study was to investigate the effects of water alkalinity, pH, and micronutrient fertilization on the growth and nutrient uptake of the zonal geranium ‘Cardinal’ grown in soilless and soil-added media. Results indicated that the effects of pH, water alkalinity, media type and their interactions on nutrient uptake by Cardinal are highly dependent on the nutrient tested. Determining

the effects of pH and water alkalinity on nutrient availability and uptake in different media types provide a scientific basis to improve geranium fertility programs, plant health and avoid loss of plant sales.

INTRODUCTION

The common bedding plant, geranium, has been a staple in most homeowners gardening palette for decades. This hardy plant tolerates high levels of direct sunlight, water stress due to over and under watering, and adapts to many different container shapes and sizes. Consumer demand for new and novel cultivars has prompted an increase in geranium breeding efforts. Unfortunately, some of the newer cultivars appear to be “sensitive” to low or high nutrient concentrations in the growing media or plant tissues (Healy, 2001; Lang 2002). It has been hypothesized that breeding for unique morphological traits has inadvertently resulted in decreasing the plant’s ability to competitively take up nutrients, possibly a result of the geranium actively changing the chemistry of the root media (Nelson and Haung, 2003).

Most horticulturists base their recommendations for fertilization of ornamental plants on three main factors: water quality, container media status and the nutrient concentrations of recently matured plant tissue. Nutrient availability, deficiency, toxicity and competition is usually determined from laboratory analyses and used to evaluate the plant’s nutrient status.

Irrigation water alkalinity and pH must be carefully monitored in any greenhouse operation to ensure the production of quality finished plants. Understanding nutrient relationships and determining nutrient ranges for healthy plants will help ensure proper crop fertility management. In addition, media type

which differs among growers can affect nutrient uptake by altering nutrient availability in the media especially when a custom mix is introduced (Biernbaum, 1992). These factors and their interactions with fertilizer and micronutrient sources can present difficulties for the identification and correction of problems associated with the production of vigorous geranium plants. Understanding these interactions can benefit both the grower and the fertilizer manufacturer if the result is improving and customizing fertility regimes and formulations to eliminate nutritional deficiencies and toxicities that produce substandard plants and by reducing nutrient losses.

The main objective of this second study was to determine how media pH, water alkalinity, media type and fertilizer micronutrient source affect nutrient uptake of a container grown cultivar of *Pelargonium x horticum* L.H. Bailey that is considered to be sensitive to nutrient imbalances. Understanding these relationships will provide the ability to optimize nutrient recommendations based on the pH, water alkalinity, cultivar, media type and micronutrient source particular to a grower or facility.

MATERIALS AND METHODS

‘Cardinal’ a zonal class geranium of the hybrid species, *Pelargonium x horticum* was selected for this study because it is sensitive to micronutrient imbalances over a broad range of pH levels (Healy, 2001). ‘Cardinal’, introduced in 1999, has become popular due to its dark leaves with distinct zonal bands and dark purple-red flowers.

Cuttings from virus free stock plants were grown in size 7 plug trays (Jiffy Inc TM) in a peat-based media at a plug production center for Ball Seed Company in Mexico. After 2 weeks, three hundred rooted cuttings were shipped to the University of Maryland. Seventy-two of the three hundred original plugs were selected for the study based on uniformity of height, root condition and plant appearance at the time of transplant. Each plant was grown in a separate Ebb-N-Flow watering system comprised of a standard geranium plastic pot (4.5 inch diameter) within a 6-inch diameter standard saucer. Plants were fertigated 22 times during the 56 day study with a rate set to deliver 250 mg L⁻¹ of N from Jack’s Professional Peat-Lite SpecialTM (J.R.Peters, Inc, Fogelsville, PA). The 60% nitrate-N and 40% ammonium-N formula delivered 20 N-4.4 P-16.6 K-0.15 Mg-0.1 Fe-0.56 Mn-0.2 B-0.16 Zn-0.1Cu-0.1 Mo at each fertigation.

The experiment was a 2 x 3 x 2 x 2 factorial with three replications in a completely randomized design. Pots were arranged in twelve rows of 6 plants per row on one wire mesh bench in the center of the glass house in section F-1 of the

University of Maryland greenhouses. Temperature was maintained at 21° C during the day and 15 ° C during the night. The day period was 16 hours due to the short daylight period during the winter months with additional lighting providing 350 $\mu\text{mol m}^{-2} \text{s}^{-1}$ of photosynthetically active radiation at plant height. Plants were selected, transplanted and initially watered with fertilizer-free water. The factors followed by their treatment consisted of: 1) media type (soilless and soil-added), 2) water alkalinity (low, medium and high), 3) media pH's (5.5 and 6.5), and 4) fertilizer micronutrient source: granular incorporated fertilizer (GIF) and soluble trace elements (STEM). Thus, the experiment contained 72 plants (experimental units) to result in 3 replications of four factors with 24 treatment combinations.

The cuttings were planted in pots containing a media mix that was soilless or with a soil addition. Both of these types of media are commonly used by geranium producers. The media with soil was a blend of 50% peat, 30% perlite and 20% clay loam soil. The soilless media was Metro-Mix 510™ (Scotts Co.) a standard soilless mix used in commercial production of geraniums and other flowering pot plants (Table 10).

Pots were filled with media to 3 cm below the top lip of the pot, the media was tamped into the pots to remove air pockets and each pot was leached with 1000 mL of de-ionized water to remove any impurities or contaminant before transplanting. Pot media was returned to field moisture conditions (approx 24 hours) before the selected plugs were transplanted to begin the experiment.

The irrigation water treatments differed in the alkalinity level measured as total soluble carbonates. The low alkalinity water was de-ionized water with a negligible (2.0 ± 0.5 ppm) soluble carbonates. The medium alkalinity water had 70 ± 0.5 ppm soluble carbonates and was obtained from a geranium production greenhouse in Pennsylvania that has natural alkalinity levels typical of greenhouse irrigation water of the region. Twelve 5 gallon buckets of water were transported from the site to the University of Maryland every ten days. The sealed buckets were stored in a shaded section of the greenhouse under dark cloth to restrict light. The high alkalinity water treatment used de-ionized water with NaHCO_3 (2.0 g) added to every 2 gallons of de-ionized water to produce 300 ± 0.5 ppm total soluble carbonates.

The media pH treatments were at the lower and upper limits of the recommended media pH range for zonal geranium growth (5.5 and 6.5) (Ball Seed Co., 2002). One milliliter of 3N H_2SO_4 was added to 2 gallons of water to produce a pH of the media solution of 5.5 ± 0.2 and eight grams of CaCO_3 was added to the growing media prior to transplant to produce the second pH treatment of 6.5 ± 0.2 . Weekly tests of the media solution pH for one plant from each of the twenty four treatments were conducted using a hand-held pH instrument.

The fertilizer micronutrient treatments were added twice during the study as STEM (J.R.Peters, Inc.) at the rate of 0.5 grams per gallon (150 mg L^{-1}) of irrigation water or GIF, UNI-MIX™ micronutrients (Scotts Co.) incorporated in to the media at 2 grams per pot (150 mg kg^{-1}) prior to seedling transplant.

On April 12, 2002 plants were cut at the base of the stem just above media contact, triple rinsed with deionized water and dried for 72 hours at 250° F in a large convection oven. Each plant was ground to a fine powder in a Wylie Mill to form a homogenous sample corresponding to a 40 intermediate mesh screen size. Ground tissue was then acid digested and analyzed for macronutrients (N, P, K, Ca, Mg) and micronutrients (Fe, Mn, B, Cu, Zn, Mo) by Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES).

On the harvest date, the roots were removed from the soilless media, and the media was then air dried for 72 hours. Each sample was extracted using the saturated paste extract method. By this process, the media is saturated with water, transferred to a ceramic funnel filter and using a partial vacuum, the liquid is removed and collected into a plastic beaker (Rhoades, 1982). The soil extracts were analyzed for the same macronutrients and micronutrients on the ICP-AES as the plant tissue. Extract solutions containing greater than 10,000 mg L⁻¹ (1.0% w/v, estimated from EC) were diluted since solutions this concentrated with salt were outside the internal range of the instrument and may cause instrument damage. Media pH was determined by measuring the extract recovered from saturated paste extraction with a pH meter. Replicates samples did not differ more than 0.2 pH units. Electrical conductivity was measured from the liquid collected during the saturated paste extraction using an electrical conductivity meter. A high conductance (reciprocal of resistance) signifies a higher concentration of salts in the solution and its units of measure are mmhos cm⁻¹ (U.S. Salinity Laboratory, 1954). Electrical

conductivity is important for commercial horticulture because it represents the quantity of charges (cations and anions) in the soil solution or in this case our extract (soil solution of a specific pot) (Table 9).

Statistical analyses of the data were conducted using the SAS GLM procedure version 6.0. Statistical significance due to the factor's main effects and their interactions on plant nutrient uptake and growth were determined using the analysis of variance procedure and F-tests. Means of all treatment combinations were compared using a Least Significant Difference (LSD) Procedure at $p = .05$.

Table 8. Factors and their Treatment Levels for Experiment 2

Treatment levels	Media	Water Alkalinity (mg·L ⁻¹ soluble carbonates)	pH	Micronutrient Source (150 mg·L ⁻¹)
1	Metro-Mix	Low: 0	5.5 (± 0.02):	Soluble: S.T.E.M.
2	Soil-added Mix	Medium: 70	6.5 (± 0.02):	Pre-Mix: GIF
3		High: 300		

Table 9. Initial Electrical Conductivity and pH of Irrigation water and fertigation solutions.

Water Source	Electrical Conductivity (dS m ⁻¹ at 25° C)	pH
Irrigation water	0.3	7.1
Fertilizer solution	1.9	5.9

Table 10. Characteristics of growing media used in greenhouse experiment.

Media	Ingredients (%)						Bulk Density lb/cu ft
	Peat	Pine bark	Vermiculite	Bark ash	Clay loam	perlite	
Standard Mix (Scotts Metro-Mix 510)	35	40	15	10	--	--	17.5
Custom Mix	50	--	--	--	20	30	21.2

RESULTS and DISCUSSION

The analysis of variance tables including sources of variation and F-values for the dry weights and leaf and media nutrient concentrations are presented in Table 11 through Table 15. For clarity of presentation and ease of discussion, F values were used as a measure of relative importance of each source of variation.

Dry Weight

Dry weights of the geraniums were significantly affected by water alkalinity and pH but not by media type or micronutrient source (Table 11). In general, plants grown at a pH of 6.5 weighed more than plants grown at a pH of 5.5. However, the significant interactions indicate that pH varied depending on media type and water alkalinity. Figure 9 graphically display these interactions.

For soilless media, increasing water alkalinity increased the dry weights for the low pH treatments and decreased the dry weights for the high pH treatments. Thus, increasing the amount of soluble carbonates caused a reduction in plant growth only at a pH of 6.5. The response to increasing soluble carbonates resulted in an increase in growth at the lower pH of 5.5.

For the soil-added media, the effects of water alkalinity did not show the same trends as in the soilless media. The plants receiving the medium alkalinity treatments tended to have the greatest dry weights regardless of the pH with no significant differences due to water alkalinity among plants grown at pH 6.5 using

GIF. Possibly, the soil addition added a buffering capacity component that the soilless media lacked and therefore dry weight decreases resulting from water alkalinity were not observed at the higher pH levels.

Plant dry weights ranged from 2.5 g/pot to 5.6 g/pot. The geraniums grown in the soil added media at pH of 6.5, 70 ppm alkalinity, receiving STEM had the highest average weights of 5.6 g/pot (Figure 9). Geraniums grown in soilless media at pH 6.5, receiving low water alkalinity treatments had similarly large dry weights averaging 5.1 g/pot (Figure 9). These results were similar to previous studies that have reported that adding soil materials (clay, silt) increased overall growth and yield for many greenhouse crops including geraniums (Ehert et al., 1998) and that M x W interactions affected overall yield for some bedding plants (Kuehny and Morales, 1998).

Table 11. Analyses of variance to determine significant effects of media, water alkalinity, fertilizer source and pH on total dry weight and macronutrient concentrations of *Pelargonium x horticum* 'Cardinal' leaf tissue.

ANOVA Source of variation	df	----- F value -----					
		Dry Weight	N	P	K	Ca	Mg
Media (M)	1	1.1	2.7	14.2 ***	121.0 ***	691.0 ***	399.0 ***
Water Alkalinity (W)	2	4.3 **	19.8 **	22.6 ***	49.4 ***	693.0 ***	159.0 ***
pH (PH)	1	62.5 ***	24.8 **	49.6 ***	0.8	211.0 ***	147.0 ***
Fertilizer Source (F)	1	0.0	1.2	5.2	1.4	0.0	0.6
M × W	2	8.4 **	2.8	1.5	1.3	15.5 ***	7.5**
M × PH	1	2.6	4.9	32.5***	3.5	17.6 **	1.4
M × F	1	1.5	0.1	1.3	0.4	4.4	2.0
W × PH	2	15.9 ***	9.2 **	6.8 **	19.1 ***	18.2 ***	44.9 ***
W × F	2	2.5	3.0	1.1	6.1	3.4	0.5
PH × F	1	3.4	0.1	0.7	16.2 ***	1.6	6.9*
M × W × F	2	0.6	2.5	0.7	1.1	1.2	2.1
M × W × PH	2	4.6*	18.2**	0.5	6.1**	0.2	8.5 **
M × PH × F	1	1.3	1.4	0.1	0.4	1.6	5.2
W × PH × F	2	0.3	1.0	1.5	2.3	0.1	4.5
M × W × PH × F	2	1.8	1.1	0.4	3.1	1.7	6.1

*. **,*** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

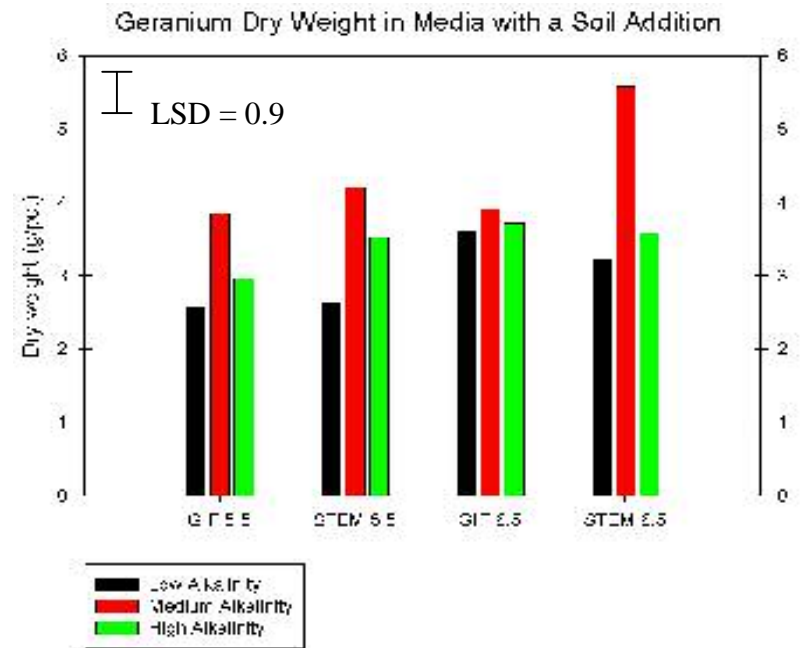
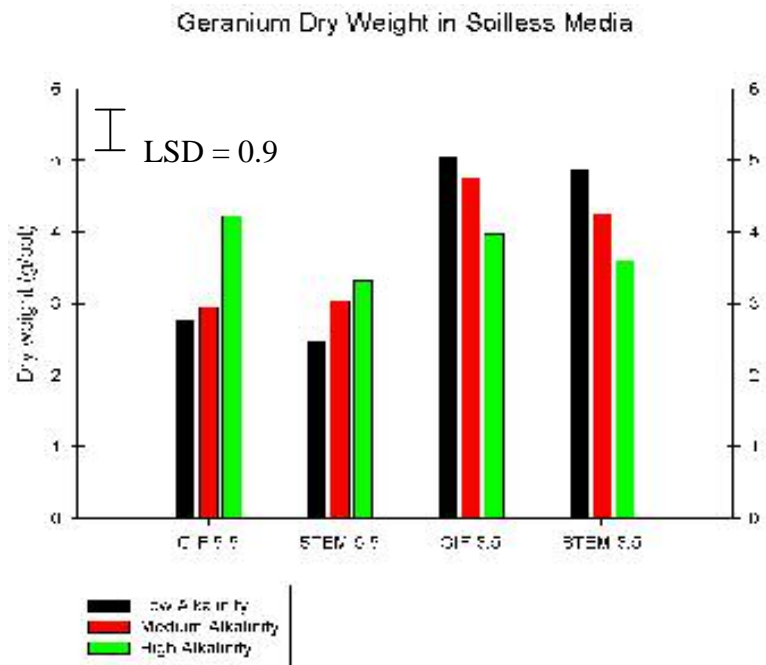


Figure 9 Mean dry weights of ‘Cardinal’ geraniums grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Nitrogen

Nitrate (NO₃) media concentration. Nitrate concentration in the geranium media was significantly affected by fertilizer micronutrient source, media type, pH and water alkalinity (Table 12). Media fertilized with STEM had significantly lower NO₃ concentrations compared to media fertilized with GIF. In addition, the NO₃ concentrations in the soilless media were significantly lower than the media with the soil addition (Figure 11). For pH 5.5, NO₃ concentrations were lower for the medium alkalinity treatments than for the high or low alkalinity treatments. Conversely, for pH 6.5, the NO₃ concentration in the media decreased possibly due to the natural buffering ability of the soil in the media.

Ammonium (NH₄) media concentration. NH₄ concentration in the geranium media was significantly affected by the main effects for pH and water alkalinity (Table 12). In general, increased concentration of NH₄ was observed at pH 5.5 and lower concentrations of NH₄ were observed when the pH was raised to 6.5 with the average NH₄ concentrations only 1.7 mg kg⁻¹ for the pH of 6.5 (Figure 12). In soilless media at pH 5.5, NH₄ concentrations decreased significantly as the amount of soluble carbonates increased. However, no significant differences were observed at pH 6.5. In soil-added media, no differences were seen between the low and medium alkalinity treatments, yet significant decreases were observed when the amount of soluble carbonates was raised to 300 mg L⁻¹. Overall, the effect of increasing water alkalinity was pH-dependent, in that, at a pH of 5.5, NH₄

concentrations were greatly reduced as the amount of soluble carbonates increased. Although the M X W X pH and other two-way interactions were significant, based on their F-values, they were less important than the main effect of media pH in determining NH₄ concentrations in the media.

Tissue concentration. The N concentration in the geranium leaves was significantly affected by the main effects for pH and water alkalinity along with a pH X W X M interactions. There were no significant effects due to fertilizer micronutrient source (Table 11). In general, slightly lower N tissue concentrations were observed in plants grown at a pH of 6.5 as compared to 5.5 for both media types (Figure 10). For most treatments, increases in water alkalinity reduced plant N uptake. In the soilless media, N was deficient for all geraniums grown at pH 5.5 receiving GIF and low or medium water alkalinity treatments. In contrast, geraniums grown in soil-added media were within the recommended range for N except for the STEM, pH 6.5 treatments and the GIF high alkalinity treatments. It is not clear why the two media types do not follow the same trends at pH 6.5 for soilless media but could be related to changes in N availability in each media type as pH dependent N reactions in the media take place.

Plant-media relationship. Fertilizer micronutrient source and media type significantly affected N-form and concentration in the growing media. However, pH and water alkalinity levels played equally important roles in determining N uptake into plant leaf tissues. NH₄-N based fertilizer produced lower quality geraniums especially when grown in cooler temperatures and lower light conditions

(Biamonte et al., 1993). In my study, the fertilizer formula used was calculated to deliver 250 ppm N, by using 15.5 oz of 20-10-20 Peat-Lite™. The formula was a blend of 60% NO₃-N and 40% NH₄-N and is recommended for most geraniums due to their preference for NO₃ uptake. The trends that were observed in my experiment were similar to previous studies of both a soilless media and a typical soil in regards to the pH dependent availability of NH₄⁺ (Marshner, 1996).

Geraniums are sensitive to higher concentrations of ammoniacal-N (NH₄-N) fertilizers. Therefore, it is recommended that most fertilizer programs have at least 75% of their N supplied as NO₃-N (Whipker, 1998). The availability and concentrations of these N forms are affected by and can affect the pH of the growing media.

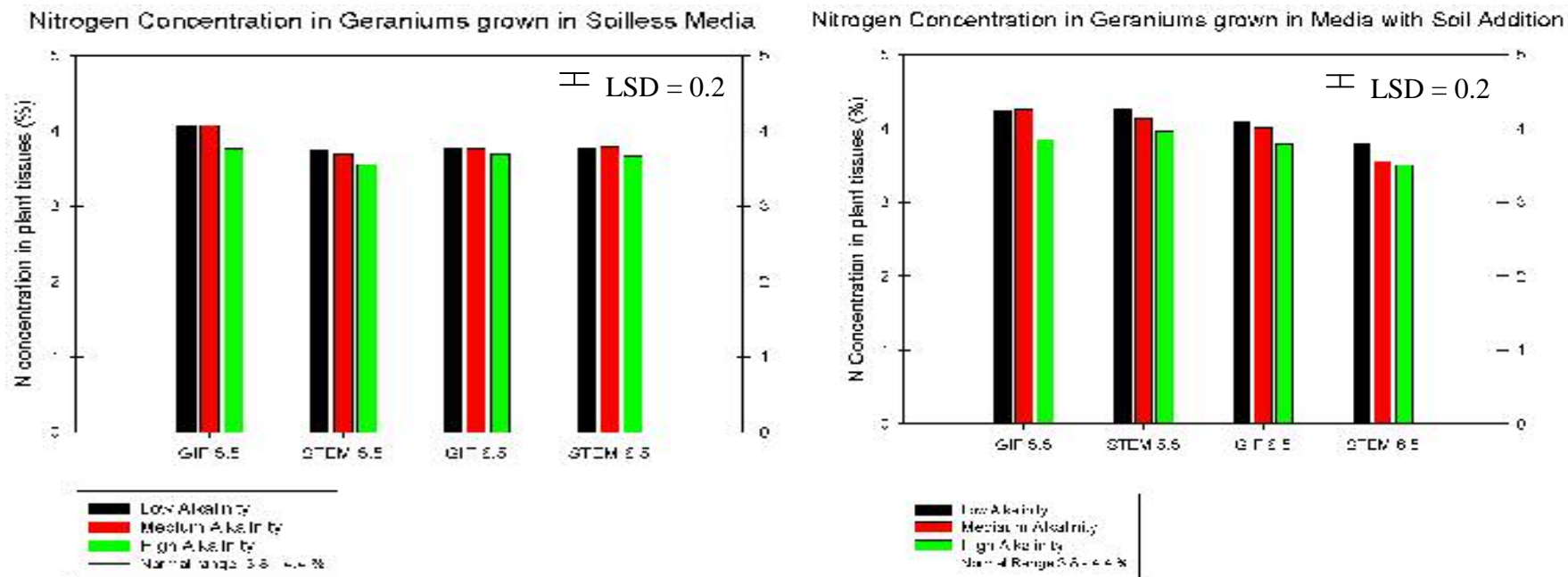


Figure 10: Mean tissue N concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

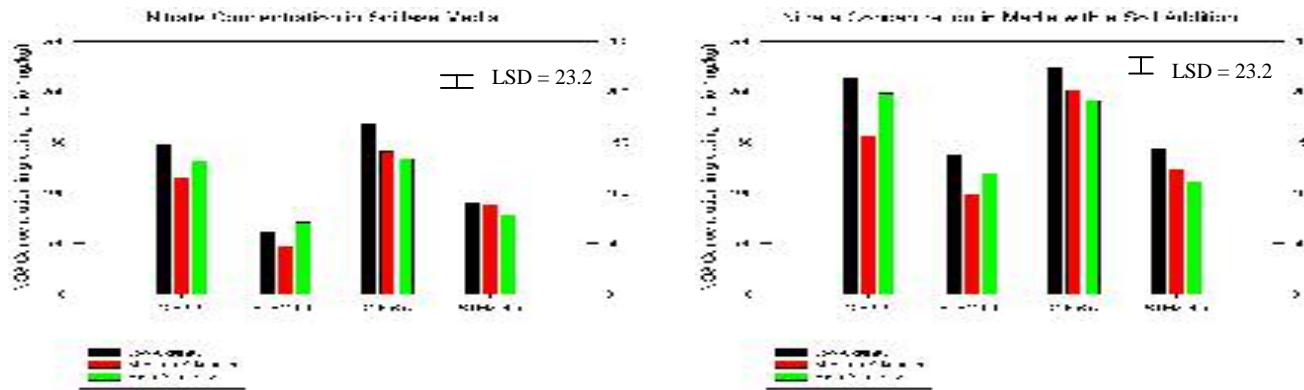


Figure 11: Mean media NO₃ concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

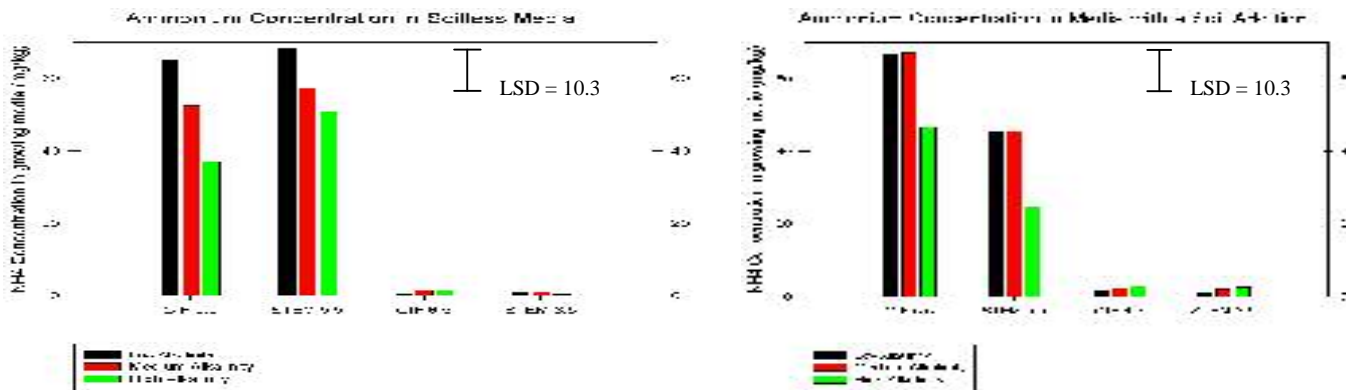


Figure 12: Mean media NH₄ concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Table 12. Analyses of variance to determine significant effects of media, water alkalinity, fertilizer source and pH on pH of media, electrical conductivity, macronutrient concentrations of *Pelargonium x horticum* ‘Cardinal’ growing media.

ANOVA		----- F value -----					
Source of variation	df	pH	EC	NO ₃	NH ₄	P	K
Media (M)	1	9.3 **	27.6 ***	242.0 ***	3.9	231.0***	367.0 ***
Water Alkalinity (W)	2	208.0 ***	3.8	14.7 ***	18.6 ***	3.4	102.0 ***
pH (PH)	1	2758.0 ***	310.0 ***	51.3 ***	1201.0***	195.0 ***	795.0 ***
Fertilizer Source (F)	1	0.3	108.0 ***	438.0 ***	6.5	91.2 ***	234.0 ***
M × W	2	11.1 **	16.8 ***	1.1	21.5 ***	3.1	18.8 ***
M × PH	1	15.7 ***	55.3 ***	0.1	3.7	2.6	57.1 ***
M × F	1	4.6 *	46.7 ***	17.0 ***	4.3	0.2	0.4
W × PH	2	19.3 ***	9.0 **	16.2 ***	19.6 ***	2.2	29.6 ***
W × F	2	5.0	2.4	5.3	0.2	0.4	5.8 *
PH × F	1	3.3	7.9 **	0.0	5.2	6.9 *	4.6 *
M × W × F	2	4.1	0.9	9.9 **	0.5	8.8 **	63.2 ***
M × W × PH	2	1.0	0.2	7.5 **	23.4***	3.9	12.1 **
M × PH × F	1	0.0	1.3	3.5	1.4	0.1	4.4
W × PH × F	2	3.6	1.1	4.4 *	0.4	0.3	1.2
M × W × PH × F	2	1.8	9.4 **	8.0 **	0.4	7.7 **	11.2 **

*, **, *** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

Phosphorus

Media concentration. Phosphorus concentration in the growing media of geraniums was significantly affected by media type, pH and fertilizer micronutrient source and there were significant interactions of these factors with water alkalinity (Table 12). In general, P concentration in the soilless media was approximately two times higher than the P concentration in the soil addition media. For both media types, the concentrations of P also doubled when the pH of the media was increased from 5.5 to 6.5 (Figure 13). The form of soluble (STEM) or granular (GIF) micronutrients significantly affected the concentration of P held in the media regardless of media type. Concentrations of P were significantly less in pots treated with STEM than those treated with GIF (Figure 13). This difference could have been due to interactions between P and micronutrients in the media that affected P availability. Regardless of treatment, P media concentrations were within the recommended range for P except the treatment with pH 5.5 and STEM added to the soil-added media.

Tissue concentration. Phosphorus concentrations in geranium leaves were significantly affected by the main effects for pH, media type and water alkalinity but not fertilizer micronutrient source (Table 11). For both media types and both pH levels, tissue P concentration decreased as the water alkalinity increased. However, there were also statistically significant but biologically small M X pH and W X pH interactions. The highest P concentration occurred in plant tissues at pH of 5.5 for

soilless media but at a pH of 6.5 for media with a soil addition (Figure 14). In addition, in both media types there was a decrease in P tissue concentration as the water alkalinity treatment increased where a maximum 0.2 % decrease was observed in the soil-added media at pH 5.5 as the soluble carbonates increased from 0 to 300 ppm using GIF.

Plant-media relationship. Significant main effects for pH and media type observed in the growing media were also seen in the leaf tissue. It is assumed that proper management of media pH and media composition is essential for maintaining adequate levels of P for plant growth. P availability is often governed by the other cations present in the soil solution that are available to form complexes. At a pH greater than 5.8, and in the presence of an abundance of Ca^{2+} ions, the phosphate ion forms strong complexes in the soil solution. This could account for the increase in P concentration in the media for both media types as the pH was raised from 5.5 to 6.5. Phosphorus becomes more available in a soilless media between pH 4.5 and 5.7, while in a soil-based media, phosphorus is most available between pH 6-8 (Marschner, 1996).

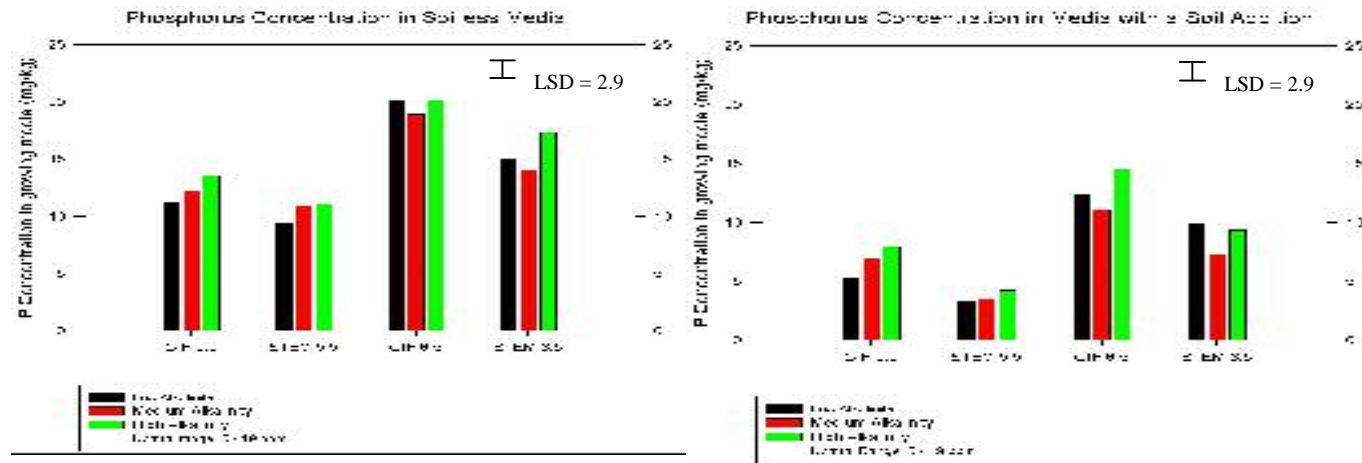


Figure 13: Mean media P concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

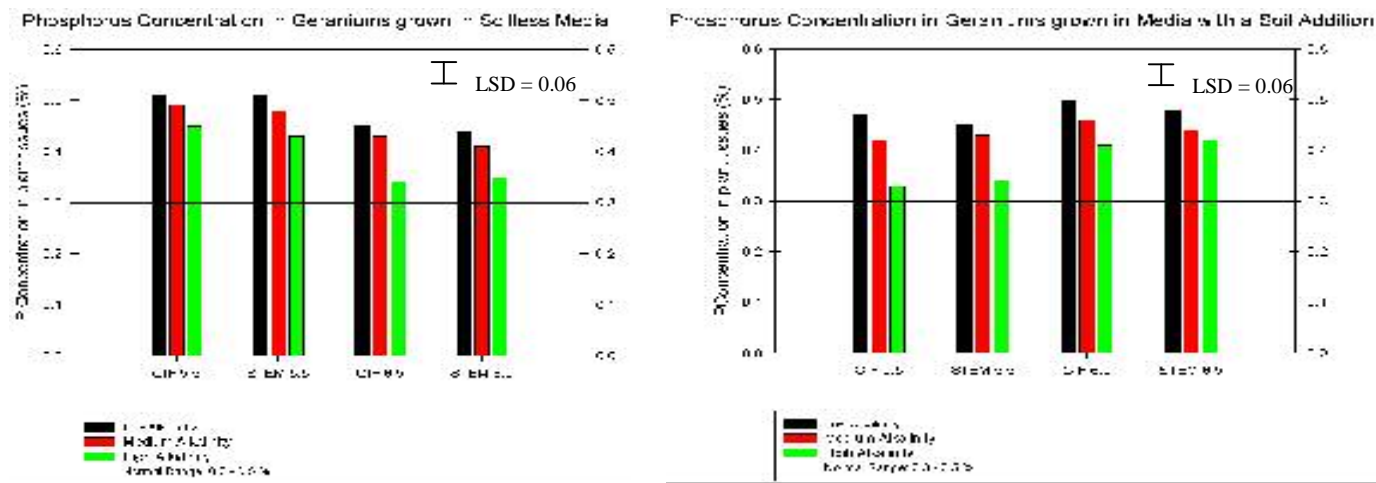


Figure 14: Mean tissue P concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Potassium

Media concentration. Potassium concentration in the growing media of geraniums was significantly affected by the main effects for pH, media type, fertilizer micronutrient source and water alkalinity (Table 12; Figure 15). In general, K concentrations were higher in soilless media with a low pH and fertilized with GIF. There were also significant two and three-way interactions, however, these interactions were of lesser magnitude than the main effects (Table 12). These results support current literature on the availability of K in different media types (Biamonte et al., 1993).

Tissue concentration. Potassium concentration in geranium leaf tissue was significantly affected by the main effects for media type and water alkalinity and interactions involving pH level and fertilizer micronutrient source. However, the main effects for pH level and fertilizer micronutrient source were not statistically significant (Table 11). Plants grown in soilless media had higher K concentrations in their tissues. The maximum tissue concentration for soilless media was 4.4 % while the maximum for media with soil added was 3.8 %. As the water alkalinity level increased, the amount of K taken up by the plant tissues decreased for all treatments (Figures 16). Slightly higher concentrations of K were found in plants that were supplied with GIF and no significant differences due to altering the pH. Several two way interactions were statistically significant but caused small changes in the magnitude of response. Overall, these results agree with current data on the tissue uptake of K for *Pelargonium x horticum*. Similar to the P leaf tissue

concentrations, all of the K leaf tissue concentration were within or exceeded the recommended range.

Plant-media relationship. The main effects for media type, water alkalinity and pH were significant for both media and tissue K concentration. K deficiency symptoms are not common and usually occur only if K concentrations are very limited or complexed with other nutrients (Whipker, 1998). When severe deficiency occurs, cells can elongate, necrotic spots appear in large blotches and the plants meristematic areas do not divide (Biamonte, 1993). Although some concentrations of K in the media were below the recommended levels, the plants were still able to translocate adequate amounts of K into the plant tissues to be within the recommended range to support plant growth.

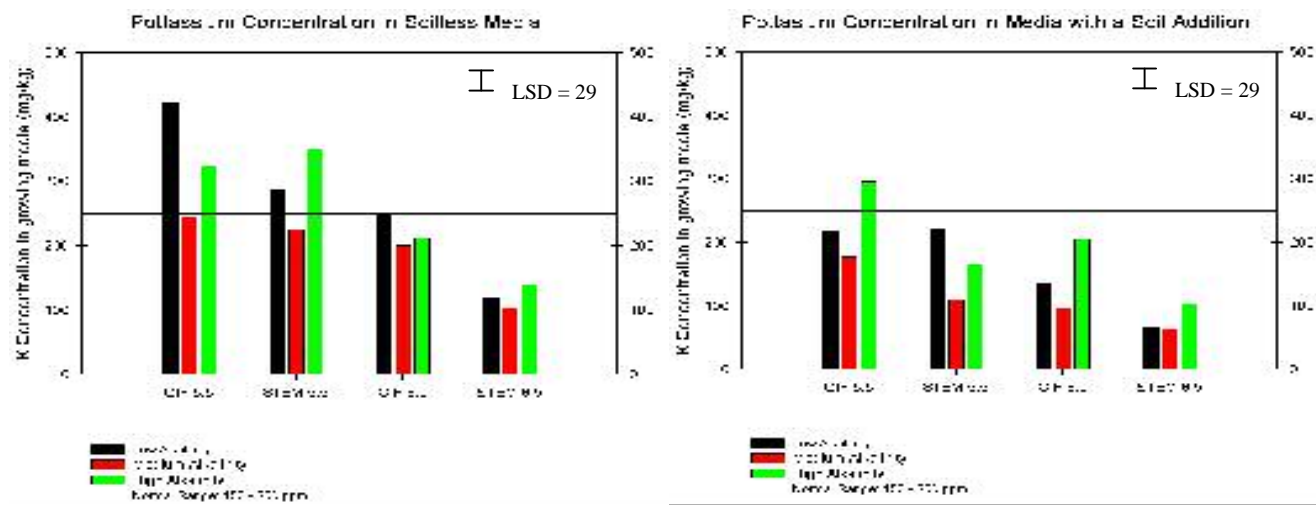


Figure 15: Mean media K concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

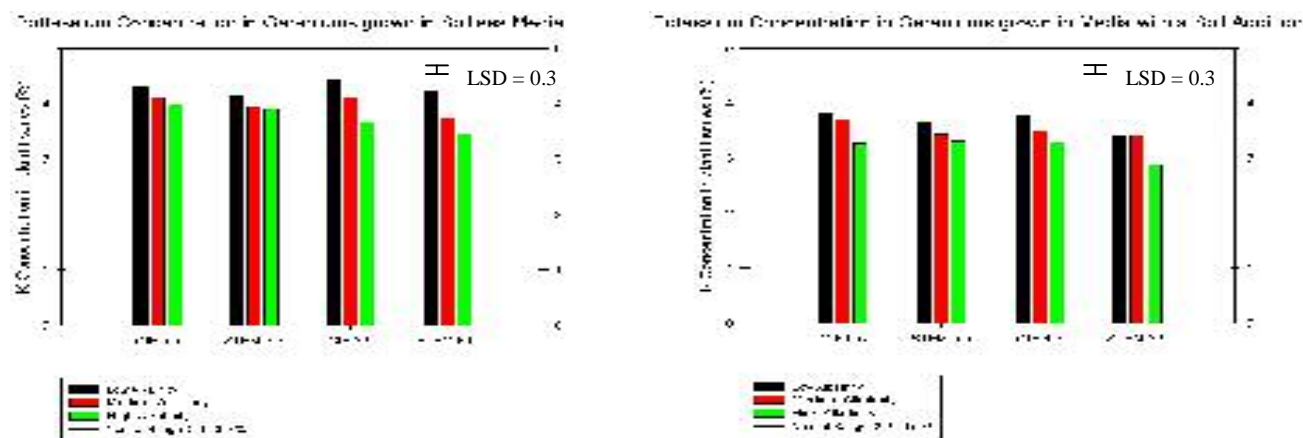


Figure 16: Mean tissue K concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Calcium

Media concentrations. Calcium concentration in the media was significantly affected by the main effects and interactions for water alkalinity, media type and pH. The fertilizer micronutrient source had no significant effects on calcium media concentrations (Table 12). Water alkalinity was the factor that had the largest effect on calcium concentration in the media. Increasing the amount of soluble carbonates in the irrigation water greatly increased the amount of available media Ca. For the high water alkalinity treatments, media calcium levels were twice the levels of the low alkalinity treatments. Sodium bicarbonate was used to increase water alkalinity without adding calcium to the media. The sodium form of carbonate was chosen in part because of geraniums high tolerance to salt concentrations in the plant media without causing much plant stress. For both media types, calcium concentrations at the high water alkalinity level were above the normal range for zonal geraniums. In soilless media, there were higher Ca levels at high alkalinity with a maximum concentration of 252.2 mg kg^{-1} Ca at pH 6.5, and fertilized with GIF. (Figure 17). And for the soil-added media the Ca concentrations in the media were over 100% greater than the normal recommended range at the high water alkalinity and high pH treatment for both fertilizer micronutrient sources.

Tissue concentration. Calcium concentration in the tissues of geraniums was significantly affected by the main effects and the two-way interactions for water alkalinity, media type and pH (Table 11). There were no significant effects due to fertilizer micronutrient source. Calcium tissue concentrations of the soilless media

were at levels considered to be deficient for all treatments. In soil-added media, deficiencies were observed at pH 5.5, except at the medium water alkalinity level. As the pH was increased to 6.5, the geraniums were within the recommended range (1.4 -2.0%) at all water alkalinity levels (Figure 18). In both media types, there were no significant differences due to increasing the water alkalinity from 0 to 70 ppm soluble carbonates. However, Ca uptake was significantly lower when the water alkalinity level was raised to 300 ppm soluble carbonates and decreased significantly to less than half of the recommended level for geraniums. Despite the low Ca levels, the plants did not show symptoms of Ca deficiency at time of harvest. The general trend, suggested by the significant pH main effect was that the concentration of Ca in the plant tissues increased as the pH level was raised from 5.5 to 6.5.

Plant-media relationship. In this study, at low and medium water alkalinity levels, less Ca was available in the media, yet plants were able to translocate more Ca to the tissues than at the higher alkalinity level that contained more than sufficient available calcium in the media. Adding a soil addition to a standard soilless media improves the buffering capacity to the soil, increases the soil's cation exchange capacity and allows for the media to hold more divalent Ca cations even at pH of 5.5. When pH drops below 6.2 and the amount of soluble carbonates in the water is minimized, the Ca concentration available for uptake is reduced (Whipker, 1998). Ca concentration can often influence and is directly involved in both the pH of the media solution and irrigation water alkalinity. Thus, it is important recognize

how these factors affect Ca uptake and are related to each other by significant 2-way and three-way interactions

Recommended Ca concentrations for a zonal geranium are between 1.4 and 2.0 % with most of the Ca stored in the plants cell walls (Marschner, 1996; White, 1993). It is essential for strengthening of the cell walls of plant tissues and proper expansion of leaves in geraniums. Researchers have suggested that zonal geraniums have the tendency to prefer to take up specific nutrients in the media regardless of competition (Fonteno and Adams, 2003; Nelson and Haung, 2003). This ability of a plant to select for certain nutrients and increase uptake under various conditions has been suggested for Ca in a soilless media (Fonteno and Adams, 2003) and other nutrients in a soil environment (Marschner, 1996).

The results from this study showed Ca concentrations in the leaf tissue were higher for plants grown in soil-added media. The composition of this media was largely based on peat and perlite with no pine bark component; therefore using a mix that has no pine bark component would be beneficial to the uptake of Ca in zonal geraniums, especially when grown in low water alkalinity conditions since it is often Ca deficient. The plants in my study, although technically Ca deficient, took up more Ca when grown in the soil-added media rather than a standard soilless mix with a pine bark additive. Also, they did not show signs of Ca deficiency at the apical meristems or root tips at harvest. A study by van Iersel at University of Georgia found that Ca and Mg were affected by media composition. Increasing the

proportions of peat and perlite while decreasing the proportion of pine bark, significantly increased Ca concentration in the leaf tissue (1999).

Ca deficiency in plant tissues at pH 5.5 as observed in these plants was expected, yet at the high water alkalinity levels ($>300 \text{ mg L}^{-1}$) the Ca in the media was above the normal concentration. Thus, increased media Ca did not result in increasing the concentration of Ca taken up in the leaf tissue. Ca uptake in plant tissues at 300 mg L^{-1} was highly deficient regardless of media type even though there was ample Ca available in the media at this treatment. Fertilization with K rates in excess of 200 mg L^{-1} can reduce Ca uptake into the plant tissues (Whipker, 2003). For this study, K fertilization rates were 100 mg L^{-1} constant feed and the K media concentrations did not correlate with the leaf tissue calcium concentrations and therefore, is probably not the cause for the reduced Ca uptake.

As the amount of soluble carbonates in the media increased so did the concentration of Ca in the media, yet less Ca was transferred to the shoots for both media types. This trend could be due to the pH-dependent reactions occurring between the peat, possible mineral component (12%) of the soil and the available cations. As the pH increased, more cations (mostly divalent, Ca^{2+} , Mg^{2+}) were exchanged for H^+ ions from the peat surface. These cations were held tightly to the exchange sites and consequently saturated the nutrient holding capacity of the peat (Argo and Biernbaum, 1996). The most soluble and available nutrients under these conditions are NH_4^+ , K^+ and Na^+ (Biamonte, 1993) giving the bound Ca limited availability and causing a decrease in Ca uptake. All Ca concentrations in the tissues

for the highest water alkalinity treatment were well below recommended levels, while Ca concentrations in the media for these treatments were well above the normal recommended levels. Plants grown in media with a soil addition took up more Ca even though these conditions existed therefore it is thought that the increased buffering capacity of the soil aided in keeping Ca available for uptake.

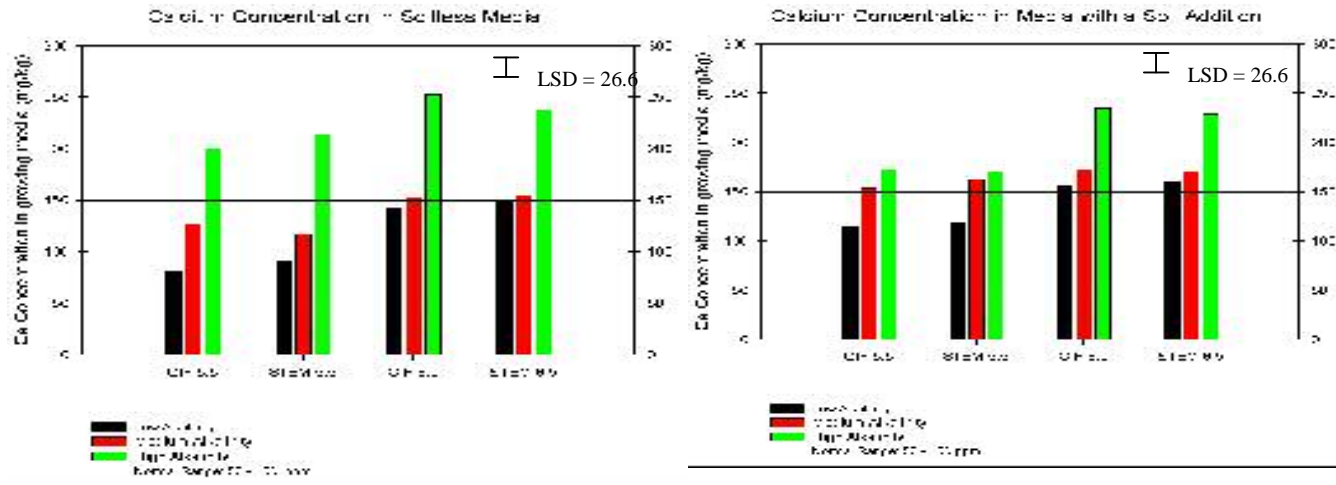
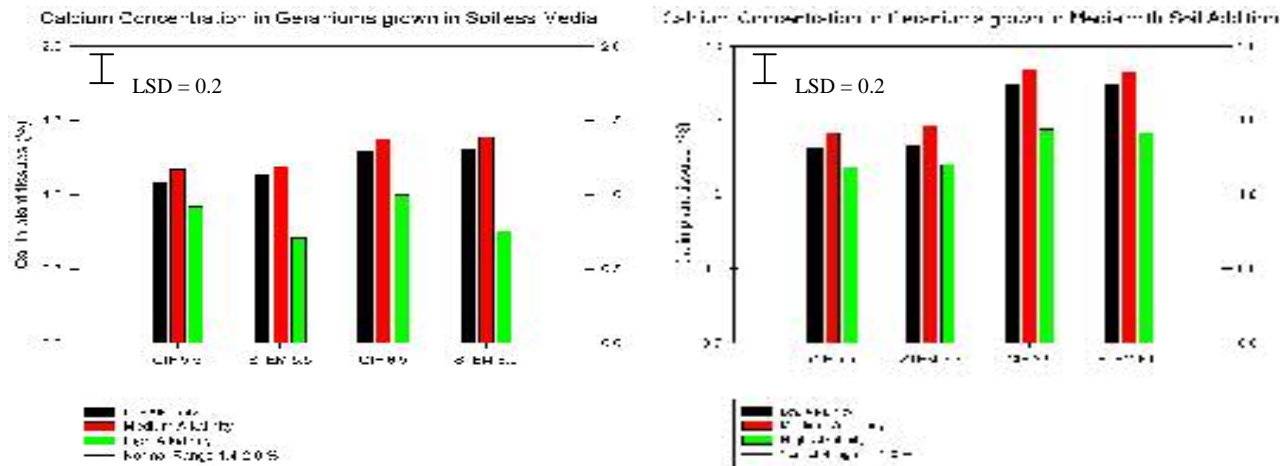


Figure 17: Mean media Ca concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source



Figures 18: Mean tissue Ca concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Table 13. Analyses of variance to determine significant effects of media, water alkalinity, fertilizer source and pH on calcium, magnesium, and iron concentrations of *Pelargonium x horticum* ‘Cardinal’ growing media.

ANOVA		----- F value -----		
Source of variation	df	Ca	Mg	Fe
Media (M)	1	369.6 ***	1.8	15.2 **
Water Alkalinity (W)	2	1293.0 ***	21.1 ***	69.8 ***
pH (PH)	1	6.1 *	636.9 ***	404.0 ***
Fertilizer Source (F)	1	3.4	6.7 *	11.0 **
M × W	2	22.3***	2.2	6.1 *
M × PH	1	3.9	64.5 ***	21.2 ***
M × F	1	2.0	1.8	0.1
W × PH	2	5.9 *	28.2 ***	11.1 **
W × F	2	0.0	1.5	0.8
PH × F	1	17.5 **	1.5	1.1
M × W × F	2	1.7	6.4 *	4.4
M × W × PH	2	32.7 ***	0.0	18.0**
M × PH × F	1	3.5	21.1 ***	1.9
W × PH × F	2	1.2	2.1	1.3
M × W × PH × F	2	1.3	18.4 ***	0.8

*, **, *** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

Magnesium

Media concentration. Magnesium concentration in the growing media of geraniums was significantly affected by pH, water alkalinity and fertilizer micronutrient source as well as interactions of M X pH, W X pH and three-way interactions between these factors and fertilizer micronutrient source (Table 13). In soilless media at pH 5.5, Mg concentration was within the recommended range for geraniums across all alkalinity levels (Figure 19). Mg concentration was above the recommended upper limit of 70 mg L⁻¹ Mg for pH 6.5 in soilless media as well as all treatments in soil-added media. No decreases in Mg concentration were observed at the lower pH for the media with a soil addition. The significant M X pH interaction indicated that pH does affect Mg availability in the media but it is dependent on the media type.

Mg concentrations in the soilless media did not differ between the low alkalinity and medium alkalinity levels in the soilless media. However, Mg concentrations in the media exhibited a 25% increase in concentration as the water alkalinity level was raised to 300 mg L⁻¹ soluble carbonates.

Tissue concentrations. Magnesium concentrations in the tissues of geraniums were significantly affected by media type, water alkalinity and pH, as well as the interactions of W X pH and the three-way interaction of M X W X pH (Table 11). In soil-added media, Mg concentration was above 0.4 % for all treatments at all alkalinity, pH and fertilizer micronutrient levels. Conversely, in soilless media, at pH 5.5, Mg tissue concentrations were deficient (below 0.2 %) at both the low and

medium alkalinity levels. Only the increase in soluble carbonates to 300 mg L^{-1} raised Mg concentration within the recommended range (0.29 %). Increasing the pH from 5.5 to 6.5 doubled the Mg concentration in the geranium leaves to levels that are considered phytotoxic to geraniums. No signs of toxicity stress were observed at harvest yet maximum leaf concentrations averaged 0.7 % Mg at pH 6.5 and 300 mg L^{-1} alkalinity (Figure 20).

Plant-media relationship. The results from this study show that in soilless media, increasing the soluble carbonates increased the Mg tissue concentration in geranium plants at both pH levels. For soil-added media, Mg tissue concentration was lowest at the high alkalinity level for both pH levels. Results for Mg concentration in geraniums grown in soilless media differ from the results of a study done by Kuehly and Morales (1998) with impatiens and pansy where the concentration of Mg in the plant tissues decreased as concentrations of NaHCO_3 increased. In soil and soilless media, it is common that Mg uptake decreases when other similar cations (Ca^{2+} , Mn^{2+}) are present or by a low pH environment (Marschner, 1996; Whipker 1998). An excess Ca concentration as seen in the media at high alkalinity levels should reduce the uptake of Mg in the plant tissues and could account for the lower Mg concentration in tissues at pH 5.5, yet does not account for the increase in tissue Mg as the alkalinity increases to 300 mg L^{-1} (Figures 31 and 32).

Significant W x pH and the three-way interaction of M x W x pH also exists that may account for variation in the soil-added media type where the highest Mg concentrations are variable among all treatments.

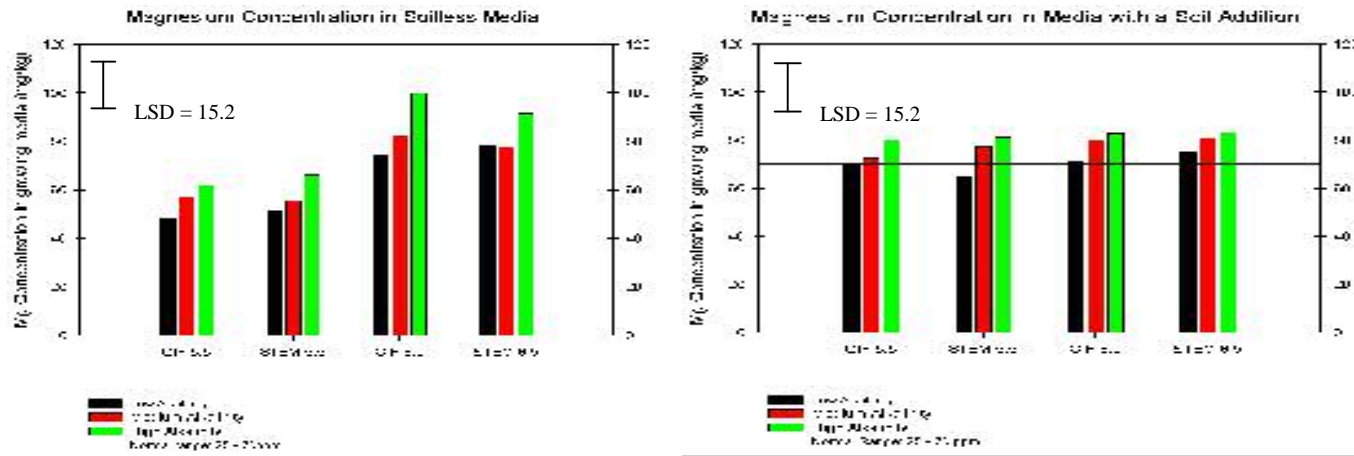


Figure 19: Mean media Mg concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

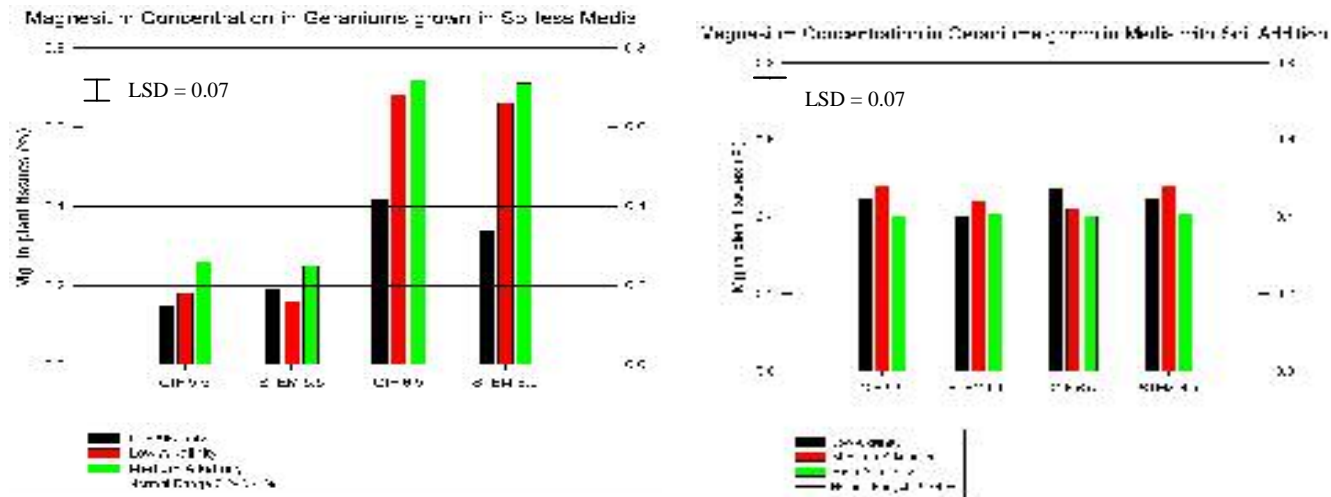


Figure 20: Mean tissue Mg concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Iron

Media concentration. Iron concentration in the growing media of geraniums was significantly affected due to the main effects of pH, water alkalinity, media type and fertilizer micronutrient source, two-way interactions of M X pH, W X pH and the three-way interaction between these factors (Table 13). pH was the factor that most affected media Fe concentration. At pH 5.5, Fe concentrations were at or above the recommended value for media Fe for zonal geraniums of 2 mg kg⁻¹ (White, 1993; Whipker, 1998). Whereas at pH 6.5, Fe concentrations were below 2 mg kg⁻¹ for both media types (Figure 21).

Water alkalinity also had a large effect on Fe concentration. As the amount of soluble carbonates increased, a reduction in iron availability in the growing media was triggered. This reduction was greater at pH 5.5 than 6.5. The effect of water alkalinity was also dependent on the media type. For soilless media, as water alkalinity was increased from 0 to 300 ppm, Fe concentration decreased by 50% compared to a 25% decrease in Fe concentration for soil-added media. Significant differences due to water alkalinity treatments were only observed at pH 5.5. At this pH, all Fe concentrations exceeded the recommended concentration of media Fe regardless of alkalinity.

Tissue concentration. Iron concentration in geranium leaf tissue was significantly affected by the main effects and three-way interaction of pH, media type and water alkalinity (Table 14). Fertilizer micronutrient source did not significantly affect Fe tissue concentrations. For both media types, when pH level

was at 5.5, Fe concentrations were within the recommended range of 110-580 mg kg⁻¹. Fe tissue concentrations at pH 5.5 ranged from 486 mg kg⁻¹ to 586 mg kg⁻¹ in soilless media, while in soil-added media the Fe concentrations were much less 355 mg kg⁻¹ to 367 mg kg⁻¹. When pH was raised to 6.5, Fe tissue concentration decreased to levels considered deficient for *Pelargonium x horticum* (Figure 22). Concentrations of Fe in the leaf tissue were observed in the soilless media with overall increases greater than 200 mg kg⁻¹ as compared to the soil-added media at pH 5.5, while differences were not significant between the media types at pH 6.5.

Increasing the water alkalinity level from 0 ppm soluble carbonates to 300 ppm soluble carbonates lowered the amount of Fe taken up into the leaves. Significant differences for water alkalinity were observed only in soilless media at a pH of 5.5; similar trends exist in the soil-added media yet significant differences were only observed between the low and high alkalinity treatments.

Plant-media relationship. The main effect for pH was the major significant factor affecting Fe concentrations in both the growing media and plant tissues. Fe concentrations were deficient in the growing media at pH 6.5 which translated into foliar deficiency in the plant tissues. Iron uptake in plant tissues is often decreased when pH is raised or by high concentrations of P, K, Ca, and Mn in the media (Mengel and Kirkby, 1979). Complexes with phosphates, carbonates and hydroxides in the soil solution are commonly the result of high pH due to over-liming growing media (Biamonte, 1993).

High pH and high levels of HCO_3^- in the media can cause Fe and Zn deficiencies in the younger plant tissues due to their effect on Fe and Zn availability in the growing media (Mengel and Kirkby, 1979; Marschner, 1996; Biamonte, 1993). The reduced availability of iron at pH 6.5 resulted in Fe tissue concentrations that were near the deficient range. The effects of water alkalinity were only apparent at the high pH. At pH 5.5, increasing water alkalinity reduced media Fe concentrations which resulted in slightly lower but not biologically important reductions in leaf tissue Fe concentrations. When there are higher levels of HCO_3^- and Ca in the media, as observed experimentally at the high alkalinity levels, Fe uptake can also be reduced accounting for the lower Fe concentrations at the higher pH. The two ions (Fe and Ca) compete for the same binding site on organic compounds (peat, chelates) and most of the time the primary cation to bind is Ca thereby reducing Fe availability (Lindsay, 1974). It would be expected to see similar trends in both media types due to the peat content, yet Fe concentration differences were more significant in the soilless media. Therefore, we can see tissue concentration differences due to media type possibly due to the natural buffering ability of the soil and peat components caused by isomorphic substitution that a soil component would add to a soilless media

Table 14. Analyses of variance to determine significant effects of media, water alkalinity, fertilizer source and pH on micronutrient concentrations of *Pelargonium x horticum* 'Cardinal' leaf tissue.

ANOVA		----- F value -----				
Source of variation	df	B	Fe	Cu	Mn	Zn
Media (M)	1	0.0	67.8***	17.0 *	44.1 ***	5.4*
Water Alkalinity (W)	2	87.6 ***	12.9 *	26.7 **	177.0 ***	27.5***
pH (PH)	1	377.0 ***	200.0***	124.0 ***	6372.0***	36.7 **
Fertilizer Source (F)	1	0.6	0.1	0.2	6.2	0.3
M × W	2	3.5	1.7	6.2*	21.0 **	2.2
M × PH	1	10.9 **	2.0	2.2	388.0 ***	0.9
M × F	1	0.0	4.1	1.5	2.9	6.4
W × PH	2	6.5 *	1.9	9.8 *	78.8 ***	13.7 **
W × F	2	1.8	0.5	1.2	3.0	5.2
PH × F	1	1.2	0.7	0.6	5.6	0.7
M × W × F	2	0.7	0.1	3.5	4.5	1.0
M × W × PH	2	2.1	22.3**	17.4 **	8.9 *	42.0 **
M × PH × F	1	3.3	2.5	0.5	3.1	1.4
W × PH × F	2	2.2	0.8	1.2	3.7	2.1
M × W × PH × F	2	1.2	3.4	8.8 **	0.0	1.9

*, **, *** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

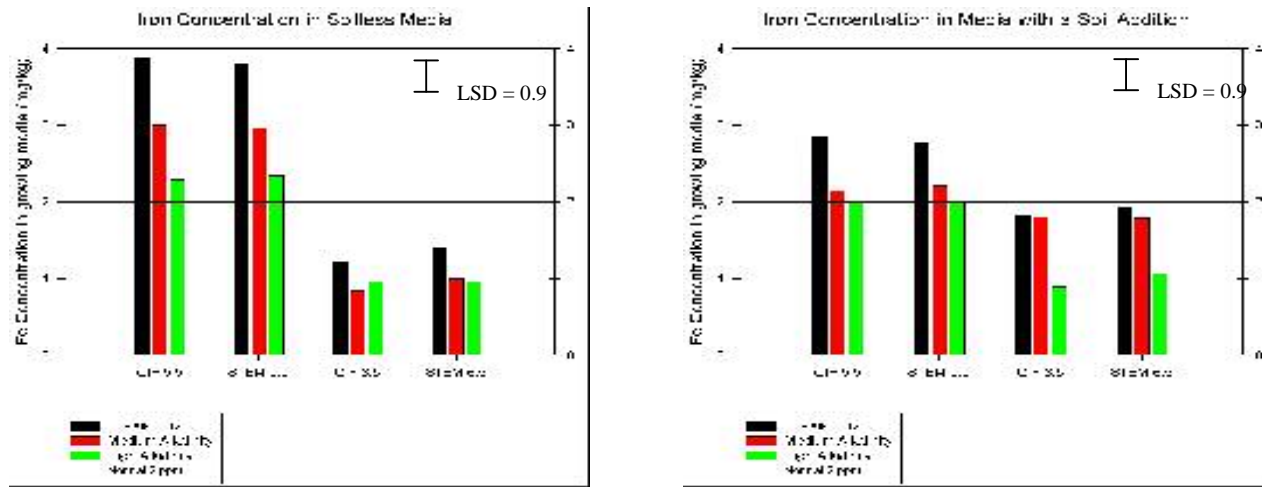


Figure 21: Mean media Fe concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

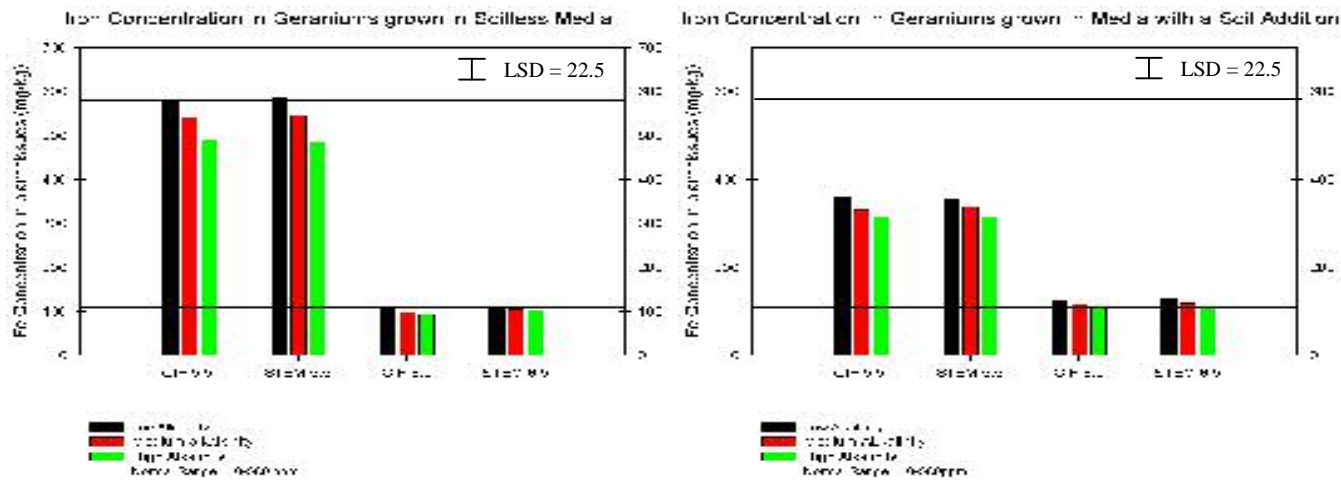


Figure 22: Mean tissue Fe concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Manganese

Media concentration. Manganese concentration in the growing media of geraniums was significantly affected by pH, media type and water alkalinity, but not fertilizer micronutrient source (Table 15). A strong M X pH interaction greatly affected Mn concentration in the media. For the soilless media, Mn concentrations were two to three times higher for the 5.5 pH substrate than the substrate at 6.5. However, for soil-added media, Mn concentrations did not differ due to pH.

In media with a soil addition, pH did not significantly effect Mn concentration, water alkalinity reduced the Mn concentrations from 1.88 mg kg⁻¹ (high alkalinity) to 1.05 mg kg⁻¹ (low alkalinity) and the mean Mn concentrations for all the treatments were within the recommended levels for zonal geraniums (Figure 23).

Tissue concentration. As in the media, Mn concentration in the geranium leaf tissue was significantly affected by pH level, water alkalinity, media type, but not fertilizer micronutrient source. Interactions of M X W, M X pH, and W X pH were also significantly higher although major differences between treatments were due to the effect of pH (Table 14). For both media types, the more acidic pH (5.5) had approximately twice the Mn concentration as compared to the tissues in the more basic pH (6.5). For the pH of 6.5, Mn concentration in the tissues were 162 mg kg⁻¹ which was below the recommended range for zonal geraniums (270–325 mg kg⁻¹) and could be classified as deficient yet no signs of stress in the tissues was observed. Plants grown in soilless media, at pH 5.5, had Mn concentrations from 1.5

to 3.5 times higher than the recommended level. The Mn concentrations were also dependent on the water alkalinity which was inversely related to Mn available in the media. As the pH was increased to 6.5, Mn concentrations decreased to recommended concentrations for zonal geraniums and increasing alkalinity only caused a small reduction in the Mn concentrations. The addition of a soil component to the soilless media greatly affected how much Mn was taken up into the leaves. A one unit decrease in pH should have increased Mn availability and translated into an increase in Mn tissue uptake. The main effect for media type as well as the M x pH interaction also had strong significant effects on Mn concentration that may account for some of these differences (Figure 24).

Water alkalinity effects on the Mn concentration were different between the media types. For soilless media, a significant decrease in Mn tissue concentration was observed at both pH levels as the water alkalinity treatment increased. At pH 5.5, all tissues, regardless of alkalinity treatment were at or above the recommended range for Mn tissue concentrations, yet no signs of Mn toxicity were observed on the plant material. In soil-added media, at pH 5.5, leaf Mn concentrations decreased as water alkalinity increased to a greater extent than in soilless media. Also, Mn concentrations in the tissues were generally less than the soilless media. Thus, 300 ppm soluble carbonates decreased the amount of Mn and caused a Mn deficiency in the leaves. For the soil-added media at pH 6.5, although all treatments resulted in tissue concentrations considered deficient, the highest mean concentration of Mn in

the tissues was at the medium alkalinity treatment containing 70 ppm soluble carbonates.

Plant- media relationship. The main effect for pH was the major significant factor affecting both Mn concentration in growing media and Mn taken up by geranium leaves. The results observed from this study agree with most current research on Mn availability in soilless media in that, as pH decreases there is an increase in availability in the media, which allows for increased uptake in the plant tissue (Marschner, 1996). Comparison of the media data with the tissue data for soil-added media showed there was an increase in Mn tissue concentration at pH 5.5 when compared to pH 6.5. In contrast to the tissue data, in the soil-added media a one unit increase in pH had no significant effect on Mn concentration. The soil-added media showed no changes in Mn concentration as pH changed, yet there was a decrease in plant tissue Mn as the pH was raised to 6.5. Possibly, the soil addition resulted in increased availability of exchangeable Mn, leading to increased concentrations in the plant tissues at pH 5.5 but not translating that increase in concentration in the actual media concentration for soil-added media. Alternately, if the geraniums were able to selectively or preferably take up Mn then Mn availability in the media is not a good indicator of Mn uptake. Although, interactions with other nutrients can be antagonistic and are most commonly associated with Fe (Biamonte et al, 1993), in this study, these antagonistic effects were not observed as shown by the nutrient uptake and media concentration data.

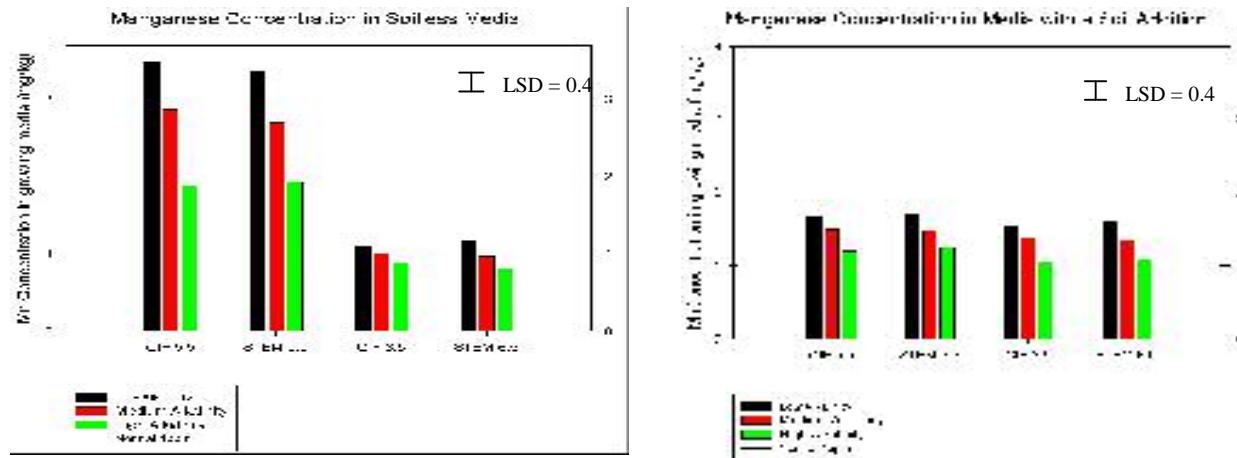


Figure 23: Mean media Mn concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

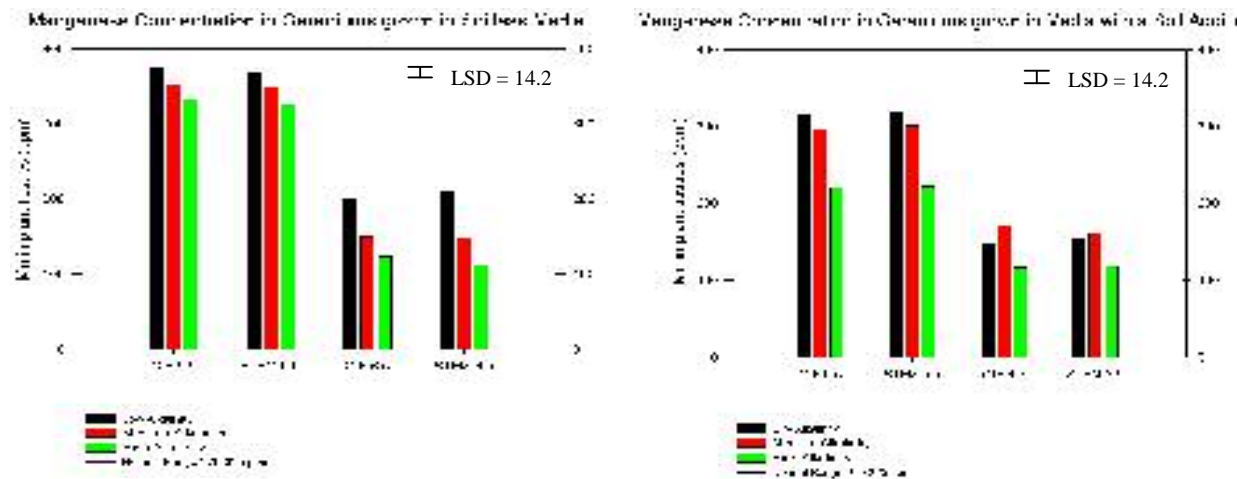


Figure 24: Mean tissue Mn concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Table 15. Analyses of variance to determine significant effects of media, water alkalinity, fertilizer source and pH on micronutrient concentrations of *Pelargonium x horticum* ‘Cardinal’ growing media.

ANOVA		----- F value -----			
Source of variation	df	B	Mn	Cu	Zn
Media (M)	1	48.2 ***	428.4 ***	82.4 ***	4.3
Water Alkalinity (W)	2	85.0 ***	33.4 ***	129.0 ***	176.0 ***
pH (PH)	1	361.6 ***	2924.0 ***	300.0 ***	563.0 ***
Fertilizer Source (F)	1	32.6 ***	4.5	1.1	2.2
M × W	2	9.0	10.8 **	4.7	0.2
M × PH	1	62.9 ***	373.7 ***	4.2	1.9
M × F	1	2.5	5.9	0.0	0.7
W × PH	2	43.7 ***	11.3 **	27.1 ***	20.5 ***
W × F	2	2.0	0.0	0.1	19.6 **
PH × F	1	0.0	1.4	0.1	5.5
M × W × F	2	1.7	3.5	1.7	1.8
M × W × PH	2	10.9 *	10.4 **	32.4 ***	0.9
M × PH × F	1	0.6	2.9	3.6	2.4
W × PH × F	2	2.3	0.0	2.2	15.1 **
M × W × PH × F	2	0.2	3.2	1.9	21.1 ***

*. **,*** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

Copper

Media concentration. Copper concentration in geranium media was significantly affected by the main effects of pH and water alkalinity and media type but not fertilizer micronutrient source (Table 14). A significant two-way interaction existed of W X pH as well as the three-way interaction of M X W X pH.

The mean Cu concentrations in the soilless media and soil-added media are shown in Figure 25. Cu concentration in the soilless media was lower than the concentration in the soil-added media. Cu concentration in the soil added media were at normal levels whereas in the soilless media when the pH was reduced the copper concentrations in the media decreased to deficient levels. In general, increasing the amount of soluble carbonates in the irrigation water decreased Cu concentration in the media. However, the three-way, M X W X pH interaction indicates that the effects of media, water alkalinity, and pH are interdependent. Thus, for the soil-added media at pH 6.5., the Cu concentrations in medium water alkalinity treatments were not significantly different from the high water alkalinity treatments. In contrast, for the soilless media at pH 6.5, Cu concentration decreased to levels well below the recommended level for geraniums when the soluble carbonates were increased to 300 ppm. At pH 5.5 more Cu was available for both media treatments.

Tissue concentration. Copper concentration in geranium leaf tissue was significantly affected by the main effects for pH, water alkalinity, media type and a three-way interaction of M X W X pH, but not fertilizer micronutrient source (Table 14). For

all treatments, the mean Cu concentrations in leaf tissues were within the normal limits for copper concentrations for zonal geraniums (5-13 mg kg⁻¹). Overall, significantly higher concentrations of copper were observed at pH 5.5 than pH 6.5. No significant differences were observed for water alkalinity treatment except in soilless media at pH 5.5 where plants that did not receive soluble carbonates had a significantly higher amount of copper in their tissues than plants receiving water with soluble carbonates added to the solution.(Figure 26).

Plant-media relationship. pH was the factor that most significantly affected Cu availability in the media and subsequent uptake in the plant tissues. Although, the main effect for water alkalinity and pH X W interaction was important in determining Cu concentrations in the plant media, these factors did not affect the overall concentration of Cu taken up into the geranium tissues to levels that would cause concern for growers. More than 98% of the Cu that is present in the soil solution is complexed with organic matter, much more so than other like micronutrients (Mn²⁺, Zn²⁺) (Mengel and Kirkby, 1979). Cu availability is highly regulated by the degree at which it is absorbed to the media and organic particles of the mix. Examination of this tissue data shows that Cu concentration was decreased in the plant media, yet the plant was able to take up adequate amounts of Cu into its tissues to be within the recommended range for zonal geraniums (5-13 mg kg⁻¹). Sufficient Cu was available so that the plant could take up necessary concentrations for plant growth while simultaneously depleting all available Cu from the growing media to below the recommended range (2 mg kg⁻¹). Lindsay and colleagues (1974)

showed that the presence of excess carbonates in a soil did not have any effect of the availability of Cu. These results suggest that Cu is complexed in the media and unavailable for plant uptake or that there was an insufficient amount of copper supplied to the media. It has been found that in a soilless environment heavily based on peat and pine bark, certain micronutrients can inhibit uptake of other similar elements (Fonteno, 1996). In this case, there is a high concentration of Zn bound to the available sites in the media especially at pH 5.5 and a water alkalinity treatment of zero soluble carbonates. Therefore, Cu was less strongly held to the media particles and more was available in the soil solution for uptake. This competition could allow for an increase in tissue Cu uptake at pH 5.5 and zero soluble carbonates.

Cu has limited mobility in soilless media, and is often restricted to the upper regions of the pot (Lindsay, 1974), which could restrict Cu uptake when drench application of STEM was used as a method to deliver the micronutrients. However, there were no significant fertilizer micronutrient source effect was observed for Cu between STEM and GIF. Possibly, sufficient water movement at the time of the drench and throughout the study allowed for an equal distribution of Cu within the pot regardless of micronutrient fertilizer type.

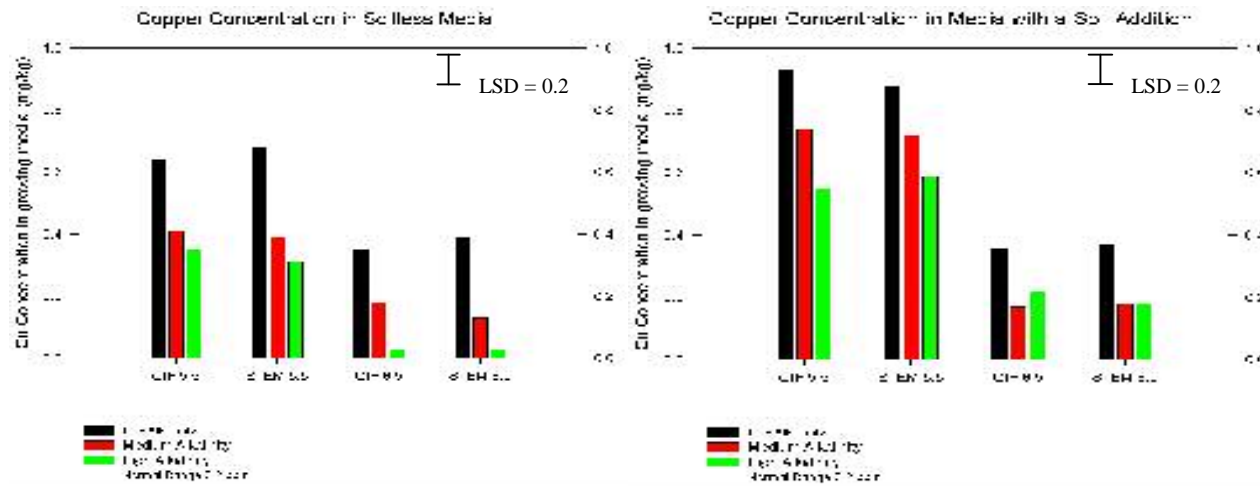


Figure 25: Mean media Cu concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

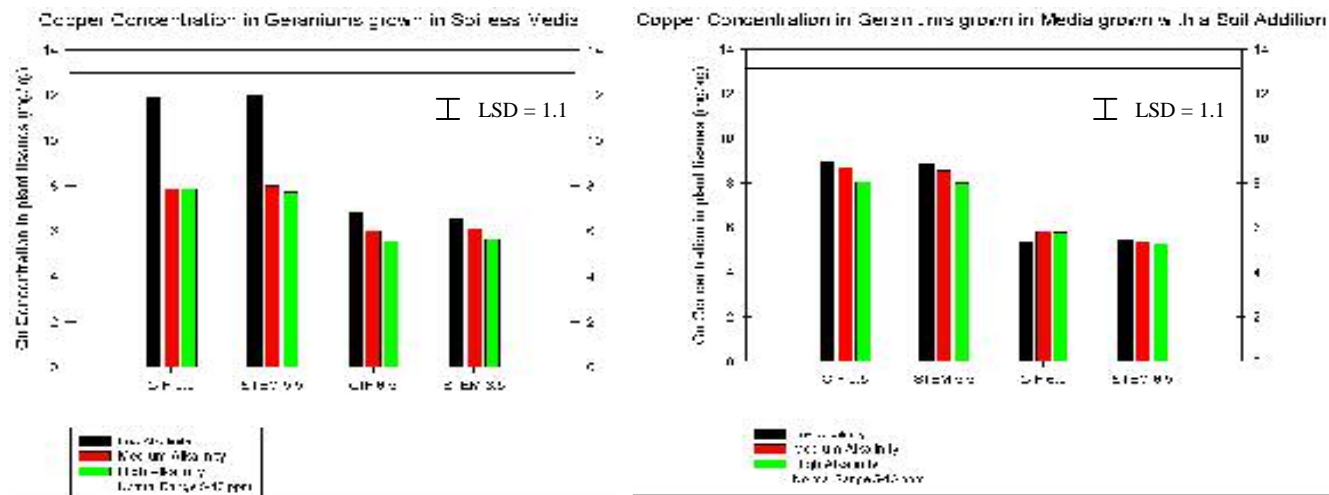


Figure 26: Mean tissue Cu concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Zinc

Media concentration. Zinc concentration in the growing media was significantly affected by the main effects for pH and water alkalinity but not media type or fertilizer micronutrient source (Table 14). There were also several two-way, three-way and four way interactions. The mean Zn concentrations in the soilless and soil-added media were graphically represented in Figure 27. Overall, higher media Zn was observed at pH 5.5, which is in agreement with most of the literature regarding Zn availability in pH dependent reactions (Marschner, 1996; Biamonte 1993, Whipker, 2001). At the higher pH (6.5), Zn concentration in the media was below the recommended range for geraniums (0.4 mg kg^{-1}), yet no signs of deficiency were observed in the plant tissues. Within each pH level, significantly higher Zn concentrations were observed at the low alkalinity level. As the soluble carbonates increased to 300 ppm there was a significant decrease in Zn media concentration, yet no significant differences were seen at the medium alkalinity treatment.

Several interactions were significant including the M X W X pH X F interaction which indicated the need to separate the individual treatment means. Thus, media with a soil addition at pH 6.5, using STEM fertilizer micronutrient source, the lowest Zn concentration was observed at 70 ppm water alkalinity, whereas for soilless media the lowest Zn concentration was observed at the highest alkalinity treatment using STEM micronutrient fertilizer source.

Tissue concentration. Zinc concentration in the tissues of geraniums was significantly affected by the main effects for pH, water alkalinity and media type

and a strong three-way interaction of these factors (Table 15). In soilless media, higher concentrations of Zn in the tissues were seen at pH of 5.5 with decreasing Zn in the tissues at pH 6.5. In addition, for both media types the highest Zn tissue concentration was observed at the low water alkalinity level with a maximum observable decrease of 10% as the water alkalinity treatment increased; there were no significant treatment differences between 100 ppm soluble carbonates and 300 ppm soluble carbonates for soilless media (Figure 28). Also, differences in Zn tissue concentration were not significant among treatments for plants grown in soil-added media. Mean Zn tissue concentrations were within the recommended range for zonal geraniums of 50-55 mg kg⁻¹.

Plant-media relationship. For most plants, a one-unit increase in media pH causes a 10-fold decrease in availability of the ion in the media causing a reduction in uptake of that ion in the plant tissues (Adams and Fonteno, 2003). In our study, the Zn concentrations in the plants grown in the soilless media followed these trends but did not result in a significant decrease in tissue Zn at pH 6.5 for the soil added media. The significant interactions indicated the effect of pH varied depending on media type and water alkalinity.

Research on zinc in geraniums is very limited partly because geraniums have an elastic tolerance to higher zinc concentrations in the plant tissues and media. However, a Zn deficiency can be caused by high phosphorus fertilizers causing a P-induced, Zn deficiency. Common signs of Zn deficiency in geraniums include leaf chlorosis, necrosis, shorter internode lengths and reduced root growth (White et al.,

1993; Marschner, 1996). A Zn deficiency easily remedied by application of Zn in the chelated or sulfate forms. Growers often supplement with more Zn than the plants require in order to prevent Zn deficiency.

In soil, Zn is less available at high pH's (above 6.0) and in the presence of calcium, potassium or sodium bicarbonate molecules. It is thought that in these environments Zn uptake is reduced due to the strong binding of Zn to soil particles or carbonate molecules instead of forming the sparingly soluble salts ($Zn(OH)_2$ or $ZnCO_3$). Therefore, it was assumed that an increase in water alkalinity would decrease the amount of available Zn in the media and the amount of Zn taken up into the leaves. At pH 5.5, in both media types, our results support this theory; yet at a pH of 6.5 for soilless media the lowest Zn in the media is observed at 70 ppm soluble carbonates rather than the high alkalinity level. The significant interactions of W X pH and M X W X pH may account for some of these differences.

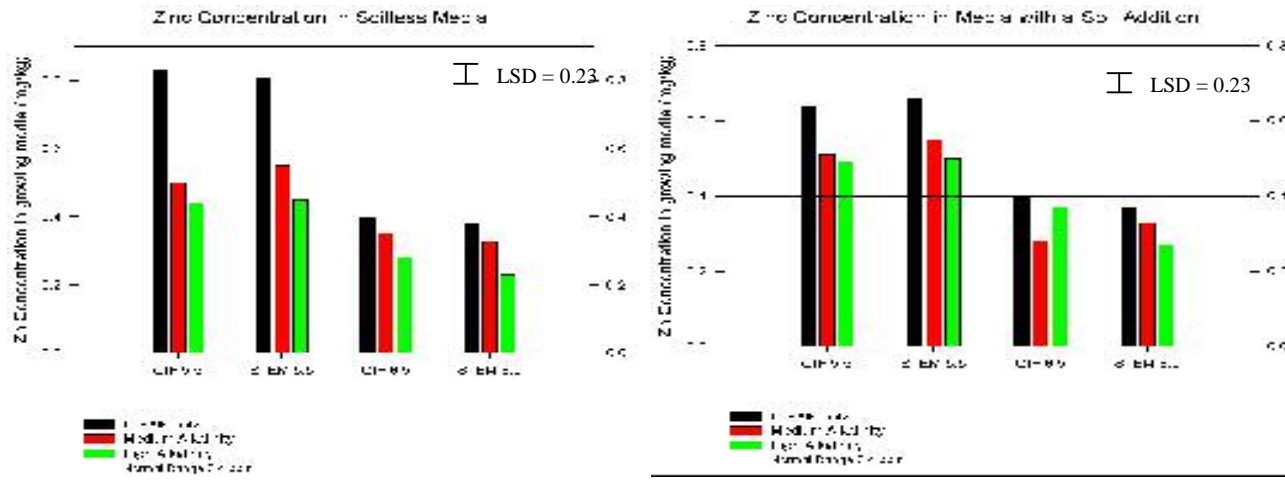


Figure 27: Mean media Zn concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soiless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

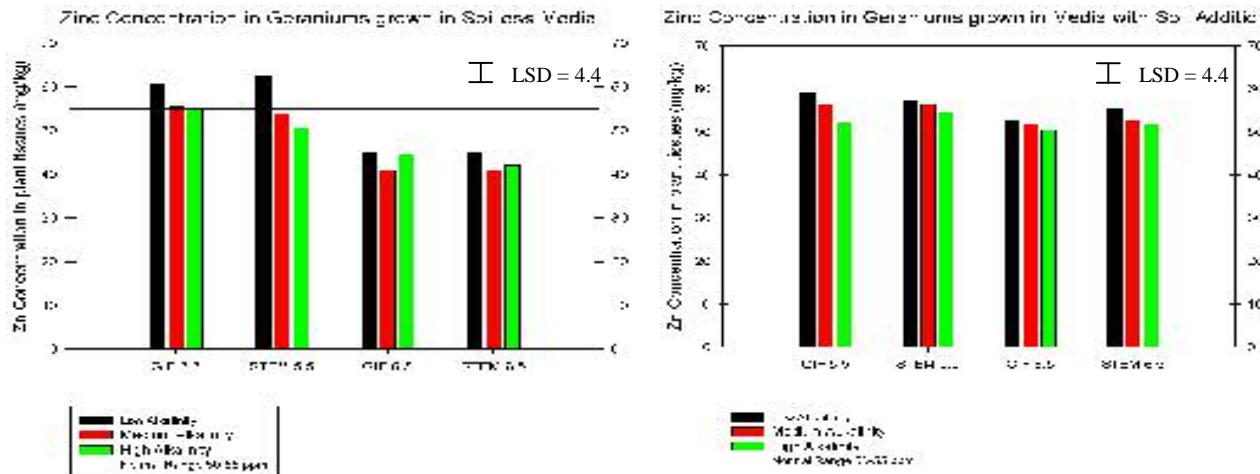


Figure 28: Mean tissue Zn concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soiless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

Boron

Media concentration. Boron concentration in the media was significantly affected by the main effects for pH level, water alkalinity, media type and fertilizer micronutrient source as well as significant 2-way interactions of M X pH, W X pH and the three-way interaction of these factors (Table 15). For both media types, as the pH was raised, B concentration decreased. A more dramatic change was shown in soilless media where B concentration decreases from a maximum of 5.87 mg kg⁻¹ at pH 5.5, 70 ppm soluble carbonates and soluble micronutrient source to a minimum of 0.89 mg kg⁻¹ at pH 6.5, 0 ppm soluble carbonates and GIF.

Differences due to water alkalinity and micronutrient source varied with media type, pH and micronutrient source. In soilless growing media, at pH 5.5, the highest concentration of B in measured at the medium alkalinity treatment, yet significant differences are only observed between the three water alkalinity treatments when the STEM fertilizer source is applied. No significant differences between water treatments occurred at pH 6.5 for the soilless media. In media with a soil addition, at both pH's, significant differences exist between the high and low water alkalinity treatments. These inconsistent results are due to strong two-way and three-way interactions of W X pH X M and are graphically represented in Figure 29.

Tissue concentration. Boron concentration in the tissues of geraniums was significantly affected by pH level and water alkalinity and the two way interactions between M X pH and W X pH. The main effects for media type or fertilizer micronutrient source do not affect B tissue uptake (Table 15). The recommended

range for B concentration in leaf tissue is 40 –50 mg kg⁻¹. At pH 5.5, tissue concentrations were much above this range, with the maximum B concentration measured at 93.4 mg kg⁻¹ for soilless media and 98.2 mg kg⁻¹ for soil-added media yet, the plants exhibited no signs of B toxicity stress.

Across all treatment combinations, higher B concentration in the leaf tissue was measured at medium water alkalinity (70 ppm). More variation in B leaf concentration is observed in the media with a soil addition, yet this main effect was not significant. No differences due to micronutrient source were observed in leaf tissue B content. Overall much lower concentrations of B were recorded in the plants treated with high alkalinity water (300 ppm) and higher pH (6.5) (Figure 30).

Plant-media relationship. The pH was the main effect that most significantly affected B availability in the growing media and uptake into plant tissues. All treatment factors seemed to play somewhat of a significant role in determining the availability of B in the media with an additional strong W x pH interaction. Even though these factors played a significant role in the plant media, it was mainly the main effect for pH, with secondary effects of water alkalinity that affected B concentrations in the plant tissues. Reduced concentrations of B in the growing media did not result in B tissue concentrations in the deficient range or B deficiency symptoms in the geranium leaves. Even at pH 6.5, the B in the leaf tissues was within the normal recommended range for zonal geraniums.

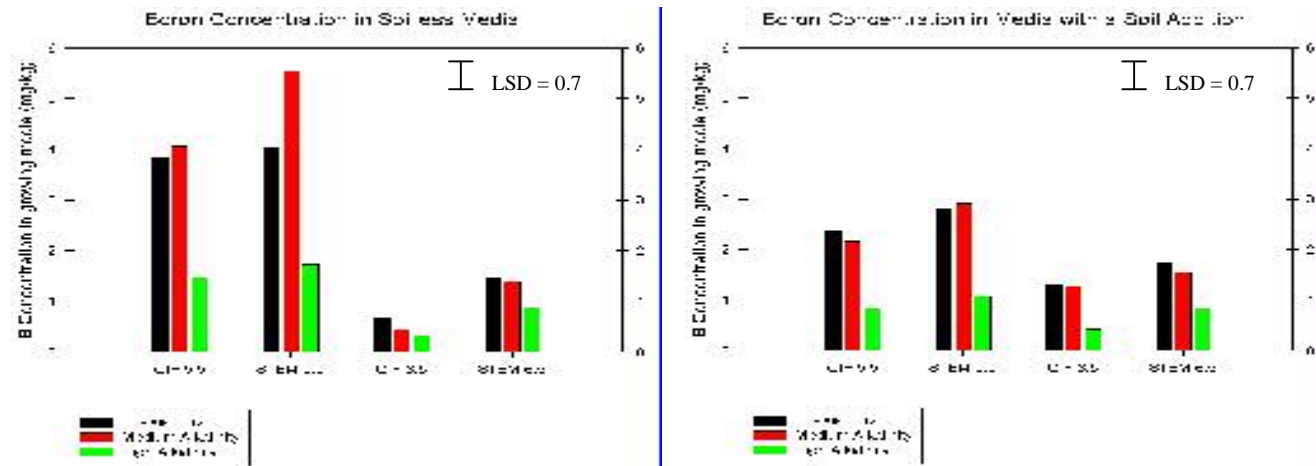


Figure 29: Mean media B concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

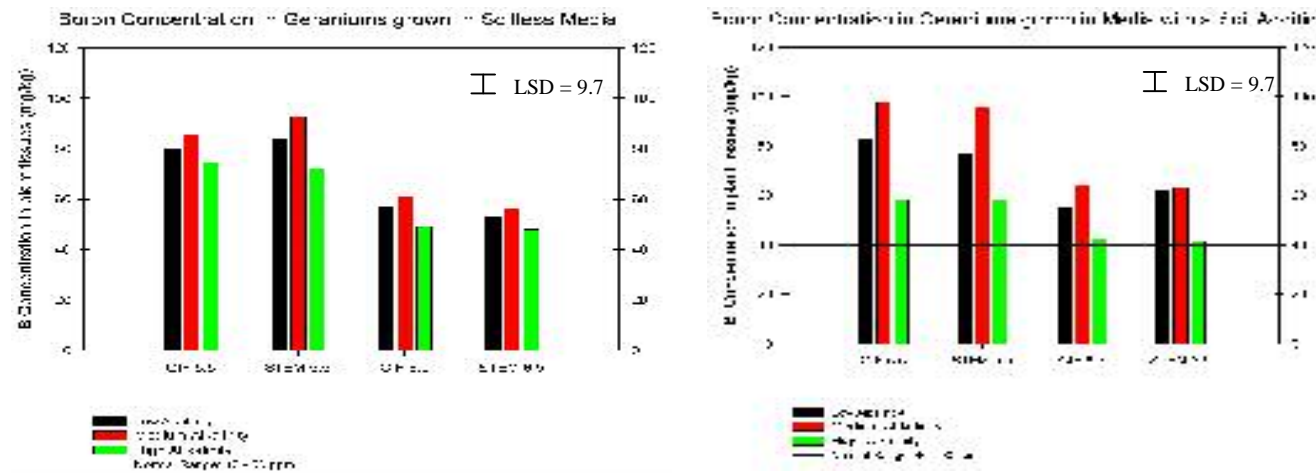


Figure 30: Mean tissue B concentration in ‘Cardinal’ geranium grown for 8 weeks in a) soilless and b) soil-added media at different levels of pH, water alkalinity and micronutrient source

pH

pH of the growing media decreased slightly during the course of the study in the pots fertigated with low alkalinity and medium alkalinity water. The mean media pH's for are shown over time in figures 31 and 32. This slight gradual decline was also recorded in the high (300 ppm) alkalinity treated media with the initial pH of 5.5 to a final pH of 4.9. Different results were seen at the 6.5 pH treatment, in that, a greater rate of decrease in pH is seen for the zero alkalinity treatments with a steep decrease around 14 days after transplant. A similar but less dramatic trend is observed at 70 ppm water alkalinity and zero ppm water alkalinity (Figure 31).

In soil-added media, at pH treatment level 5.5, pH declines over the course of the study, with the greatest decrease observed at the low alkalinity treatments. The largest decrease (1.2 pH units) was measured at pH 5.5 with low alkalinity water. When the soil-added pH was raised to 6.5, we observe similar decreases in pH over the course of the study for the low and medium alkalinity treatments. In contrast, plants treated with the high alkalinity treatment (300ppm) did not significantly lower in pH over the course of the study, rather there was a small increase from 6.5 to 6.68 at harvest (Figure 32).

The decrease in pH of the growing media over the course of the study for selected treatments is due to the reduced buffering capacity that low alkalinity irrigation water supplies and the ammonium-N content in the fertilizer itself. These two factors, especially when in combination have been shown to lower pH in both

media and soil substrates (Marschner, 1996; White, 1993; Adams and Fonteno, 2003 and Whipker et al.,2003). This trend has been shown to intensify when the leaching fraction is reduced for many horticultural crops including poinsettias and geraniums as was the case in this study (zero leaching fraction)(Ku and Hershey, 1992). The low alkalinity of the irrigation water can lead to a reduction in the buffering capacity of the growing media allowing for more rapid pH shifts. A fertilizer formula with a high ammonium-N content is thought to increase cation uptake at the ion absorption sites of the root. When this occurs excess H^+ ions can be evolved causing a reduction of the pH in the rhizosphere (Clarkson, 1996; Marschner, 1996). Adding soil to the media and increasing the overall concentration of soluble carbonates in each pot allowed for the plant to sustain pH shifts in the media at pH 6.5.

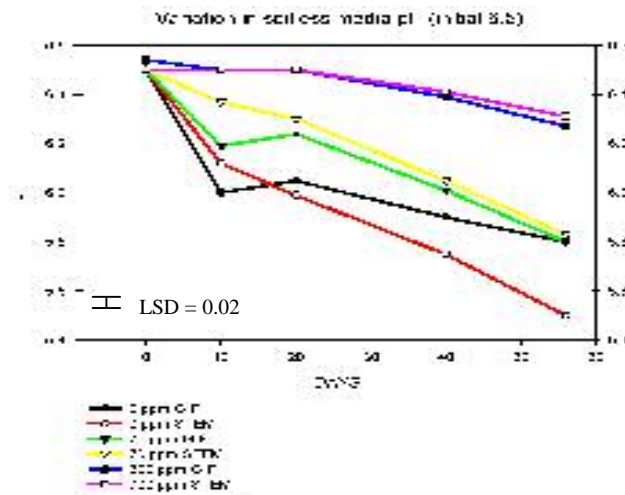
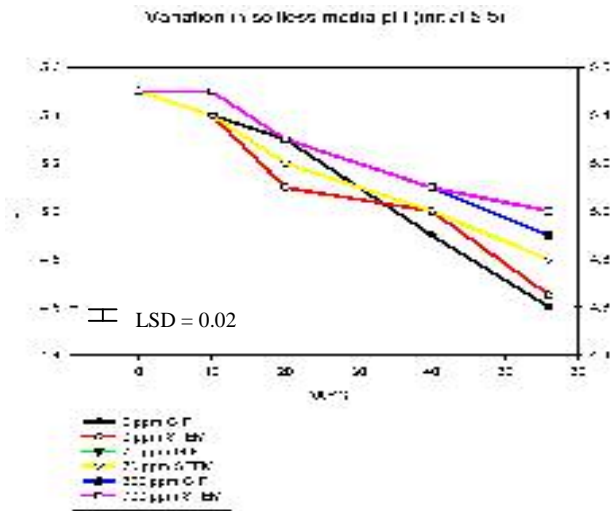


Figure 31: pH variation in soilless media for *Pelargonium x horticum* after being grown over an 8 week period in containers with varying cultural factors.

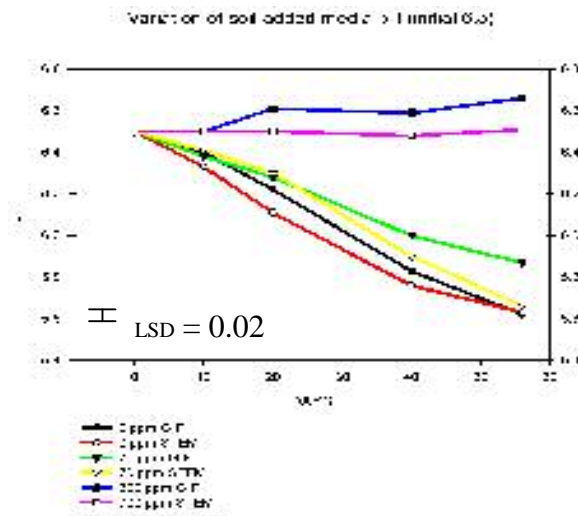
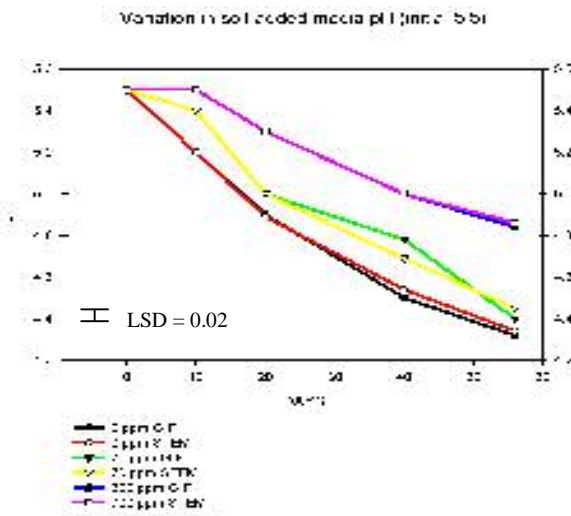


Figure 32: pH variation in soil added media for *Pelargonium x horticum* after being grown over an 8 week period in containers with varying cultural factors.

CHAPTER 2: CONCLUSION

In this study, a factorial experiment was conducted to test the significance of the main effects and interactions of pH, water alkalinity, media type and fertilizer micronutrient source on nutrient availability in the media and subsequent nutrient uptake by Cardinal geranium plants. This experiment was the first to test a sensitive zonal cultivar of *Pelargonium x horticum* and its nutrient uptake under a set combination of water alkalinity and pH conditions.

Medium water alkalinity (70 ppm) is considered optimal for zonal geranium growth. However, this research demonstrated that quality geraniums can be grown at all water alkalinity levels between 0 ppm soluble carbonates and 300 ppm soluble carbonates with proper adjustment of pH and media type. Additional supplementation of micronutrients may be required when higher alkalinity levels are combined with high pH in order to ensure sufficient micronutrient availability to the plant.

The media pH had a major effect on nutrient availability and uptake for zonal geraniums. The optimum pH for plant growth was 6.5 in that these plants had higher dry weights and showed no signs of micronutrient imbalances in the tissues. This pH level (6.5) is slightly higher than the recommended media pH currently suggested by most plant nutritionists for zonal geranium production (Fisher USA, 2003; Ball Seed Co. 2003; Oglevee, 2003). Over the last 3 years, there has been evidence in the field that zonal geraniums produce better at slightly higher pH's than the recommended 5.7 - 6.0. Our results showed that this type of zonal geranium had

higher yields and the ability to take up nutrients sufficient for adequate plant growth at higher pH level without showing signs of micronutrient deficiency.

The effects of irrigation water alkalinity, media type and pH on nutrient availability in the media and uptake by the plants were interrelated, resulting in a significant W X M X pH interaction. These significant interactions make determining the independent effects of each of these treatment factors difficult. Therefore, it is recommended that these factors be addressed simultaneously when making fertility recommendations. When high alkalinity and high pH conditions exist (above a pH of 6.5, 300ppm alkalinity), the results from this research suggest that growers should reduce these levels by scheduled injections with acid into the existing irrigation lines.

New cultivars of *Pelargonium x horticum* are being introduced each year. In order for these new cultivars to be successful they must be marketable, with compact, healthy green leaves and large flowers. This study showed that ‘Cardinal’ cultivar from Ball seed Co., when grown under optimal conditions of pH and water alkalinity, produced a plant that can sustain a nutrient media status at levels thought to cause toxicity or deficiency stress.

Media type affected plant yield and nutrient uptake. The results of this study confirmed that the common practice of adding a field soil amendment can be beneficial in maintaining proper fertility levels for *Pelargonium x horticum*. Adding soil to a standard soilless media greatly affected nutrient availability in the media and translocation to the geranium tissues. Studies have shown that the addition of

soil minerals to soilless media have increased growth and yield for many greenhouse crops including geraniums (Ehert et al, 1998). Our results indicated that a typical soilless media that is largely peat-based was more susceptible to changes in nutrient concentrations than a media with a soil addition. For most nutrients examined, the soil-addition buffered the nutrients availability as pH and water alkalinity levels were altered. The soil-added media was able to keep nutrient concentrations at a more constant level while allowing for adequate translocation of the available nutrients to the plant tissues.

The source of micronutrients, either soluble or granular, did not significantly affect the nutrient concentration in leaf tissue or the growth of *Pelargonium x horticum*. Both STEM and GIF provided available micronutrients in the media for sufficient uptake of micronutrients needed in small quantities in the geranium leaves. Some interactions did occur with the availability of the macronutrient concentrations in both media types, however this was not observed in the geranium tissues. Nutrient availability in the media and nutrient uptake in the plant tissue was mainly governed by M X W X pH interactions. Therefore, it would be beneficial to address individually each nutrient with respect to these factors regardless of fertilizer micronutrient source.

Under optimal conditions of pH and water alkalinity, growers can produce a geranium crop in 8 to 12 weeks without much nutrient manipulations. If an environment exists that has low water alkalinity, it is imperative for the grower to constantly monitor his container pH throughout the crop cycle. Further research

should be conducted to investigate the decrease in pH over time in order to identify specific timing or stage of growth associated with any variation in media pH or associated variation in nutrient uptake.

CHAPTER 3: THE EFFECTS OF pH AND WATER

ALKALINITY ON GERANIUMS

ABSTRACT

Geraniums are a commonly grown ornamental crop that can be sensitive to nutrient imbalances depending on their growing environment and cultivar. Newer cultivars appear to be more sensitive to changes in pH and water alkalinity, resulting in imbalanced nutrient uptake leading to foliar damage, lower plant quality and reduced net sales profits. The objective of this study was to determine the effects of pH and water alkalinity interactions on specific cultural factors. Geraniums were grown hydroponically at different water alkalinity, pH, and nitrogen rates in a factorial experiment in order to study the effects and interactions of these factors on the growth and nutrient uptake of two sensitive geranium cultivars. Results indicated that the pH, water alkalinity and their interaction affected plant size and micronutrient uptake in the tissues of two cultivars of zonal geraniums. In contrast, macronutrient uptake was most affected by nitrogen rate and was not significantly affected by pH and water alkalinity, while secondary nutrient uptake was affected by

the main effects for pH and alkalinity and there interactions with cultivar. The differences in uptake for most nutrients were also varied due to cultivar and stage of growth and should be considered when determining optimal fertility requirements for geranium cultivars.

INTRODUCTION

The effects of media pH, irrigation water pH, and water alkalinity on geranium growth are related with the complex interactions not fully well-defined. Basic information regarding the combined effects of growth and nutrient status of geraniums would provide information to optimize the management practices of this ornamental.

Management of pH is essential to sustain proper plant growth (Argo and Fisher; 2003a-b). Each cultivar and growing media blend has its own threshold at which pH can seriously affect nutrient uptake and plant quality. High substrate pH can reduce nutrient availability in the media causing reduced uptake in the plant tissues (Whipker et al, 1996; Biernbaum, 1992). When media pH decreases to levels below 5.0, it is common to observe foliar toxicity symptoms due to increased micronutrient uptake in the plant tissues (Biamonte, 1993, Reed, 1996).

Water alkalinity plays a significant role in determining the consistency of the pH in the media and irrigation water. It has been suggested that soluble carbonates can severely damage the ability for a plant to grow and maintain a healthy root system (Wadleigh and Brown, 1952; Whipker et al., 1996). Alternatively, it may not be the concentration of soluble carbonate ions that directly affects the root system, but rather, the interactions between available nutrient species and pH of the roots that cause the damage (Whipker et al. 1996). These relationships are difficult to distinguish in a typical experimental environment using growing media because nutrient interactions within the media cannot be separated in a container

environment. Therefore, nutrient solutions modified to mimic the growing media could isolate any nutrient interactions caused by pH and water alkalinity, independent of the media.

During the geranium production cycle, certain cultivars of zonal geraniums exhibited a leaf abnormality referred to as ‘leaf cupping’. Leaf cupping involves newly formed leaf tissue becoming puckered, rubbery and cupped upward thereby reducing the tissues ability to expand and the overall plant size. Leaf-cupping has been documented in several greenhouses across the U.S. and world-wide (personal communication. H. Lang; Fischer Inc. 2004) but has only been observed in specific “sensitive” cultivars under conditions of low alkalinity irrigation water. Previous attempts to duplicate these symptoms in a scientific, replicated experiment have been unsuccessful (Peters, 2002 (Chap 2), unpublished; Nelson and Lang. 2002 (unpublished); Bergage et al., 2001 (unpublished)). It is my hypothesis that these “sensitive” cultivars when established in conditions of low alkalinity irrigation water undergo a reduction of pH around the media at a specific stage of growth. The pH decreases to levels greater than one unit below the recommended substrate pH and thereby alter micronutrient uptake by the plant tissues. Although affected plant tissue has been tested and no micronutrient toxicity has been found (see Chapter 2), it is possible that a nutrient imbalance may exist either in the media or in the leaf tissues of the geranium that causes interactions or competition in uptake.

The main objective of this third study was to determine the effects of pH and water alkalinity interactions on specific geranium cultivar, nitrogen form and

nitrogen rate. This study followed the study described in Chapter 2, where it was found that uptake some nutrients were not significantly affected by the concentration of that nutrient in the growing media. Therefore, this experiment was designed to further study the relationships of pH and water alkalinity to nutrient uptake during the growth and development of two cultivars of geraniums. In order to eliminate any media ionic interactions occurring in the growing media that could affect plant uptake, plants were that grown in hydroponic solution. Examining the interactions and influence of water alkalinity, pH, and nitrogen rate on the nutrient status of two geranium cultivars would potentially lead to a better understanding of the causes of preferential nutrient uptake or competition by these selected cultivars of *Pelargonium x horticum*.

MATERIALS AND METHODS

A nutrient solution study was conducted to examine the effects of solution pH and water alkalinity on two cultivars of *Pelargonium x horticum* receiving two rates of nitrogen. The cultivars selected for this study, ‘Tango Dark Red’ and ‘Tango Light Pink’, are both of the zonal classification (Fischer USA, 2002). Tango Dark Red was selected because of its known sensitivity to low water alkalinity environments, while Tango Light Pink is a standard cultivar that can grow in many environments without showing plant stress.

Two hundred unrooted cuttings of each cultivar were shipped overnight in ice packed containers. Cuttings were taken the previous day from virus free stock plants at a plug production center for Fischer USA Inc. in Mexico. Seventy-two of the two hundred original cuttings of each cultivar were selected for the study, based on uniformity of height, hardiness and plant appearance at the time of rooting. Cuttings were treated with rooting powder containing 0.1% indole-3-butyric acid (Hormondin 1™; Merck Chemical, Rahway, N.J.) and placed in individual cell packs filled with sterile perlite. Cuttings were drenched with a botrytis and pythium preventative two times during the rooting stage and fertilized with a soluble 20-10-20 fertilizer with a rate set to deliver 150 mg L⁻¹ of N from Jacks Professional Peat-Lite Special™ (J.R.Peters, Inc, Fogelsville, PA). The 60% nitrate-N and 40% ammonium-N formula delivered 20 N-4.4 P-16.6 K-0.15 Mg-0.1Fe 0.56 Mn-0.2 B-0.16 Zn-0.1Cu-0.1 Mo. Cuttings were placed under mist with an 8 second on-12 minute off schedule and rooted in 14 days.

The study was conducted in an environmental growth chamber; temperature was maintained at 21 °C day and 15 °C night (± 0.2 ° C) and relative humidity was set at less than 70%. The day period was maintained for 16 hours with $>300 \mu\text{Em}^{-2} \text{sec}^{-1}$ photosynthetically active radiation at plant height with a combination of cool-white and incandescent lamps.

To initiate treatments, 8L buckets were filled with a 0.5 strength modified Hoagland solution [17.9 mM N (250 rate); 7.14 N mM (100 rate); 1.75 mM P; 5.33 mM K; 0.4 mM CaNO_3 ; 1.0 mM MgSO_4 ; 23.1 μM H_3BO_3 ; 9.8 μM Cu-EDTA; 22.4 μM Fe-EDTA; 17.1 μM MnSO_4 ; 2.6 μM NH_4Mo ; 9.6 μM Zn-EDTA] ($\mu\text{M} = \mu\text{mol L}^{-1}$) varied to supply the desired nitrogen rates of 250 ppm N or 100 ppm N and pH by modifying the $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratio of the solution.

After 14 days, Tango Dark Red and Tango Light Pink rooted cuttings were removed from the perlite and rinsed with de-ionized water to remove perlite particles that have adhered to the root system. All cuttings were then transferred to randomized 2L plastic beakers (3 plants per beaker) containing the assigned treatment nutrient solution. The plants were placed in polyurethane foam squares and inserted into customized black plastic lids that were placed over each 2L beaker. Each beaker was sprayed black to reduce light exposure to the roots and the nutrient solutions and continuously aerated by individual plastic tubing inserted into the center of each beaker lid. The solutions were changed every 7 days or less as necessary and solution levels and pH change was modified and adjusted everyday.

Treatments

Plants were grown in the 0.5 strength Hoagland solution, modified to supply adequate nutrient concentrations for zonal geraniums (see previous section). The solutions were prepared in batches containing the 2 replications from each sampling date in 8L buckets to assure nutrient homogeneity. N was supplied at two treatment strengths ($17.9 \text{ mM L}^{-1} \text{ N}$ (250 rate) and 7.14 N mM L^{-1} (100 rate) and to prevent micronutrient precipitation, the EDTA (ethylenediaminetetraacetic acid) chelator form was used for Zn, Cu, Fe, Mn.

Three pH levels were established to cover a broad range of solution pH for geraniums (5.5, 6.2, and 6.8). A pH of 5.5 was established by maintaining a 80% $\text{NH}_4\text{-N}$ and 20% $\text{NO}_3\text{-N}$ ratio in solution using NH_4NO_3 . A pH of 6.2 was set by maintaining a 50% $\text{NH}_4\text{-N}$ and 50% $\text{NO}_3\text{-N}$ ratio in solution using 21% mono ammonium phosphate (MAP) and 13.8% KNO_3 . A pH of 6.8 was set by maintaining a 20% $\text{NH}_4\text{-N}$ and 80% $\text{NO}_3\text{-N}$ ratio in solution using 94% NaNO_3 and 6% monoammonium phosphate (MAP). A preliminary experiment was conducted in order to ensure that each pH was reliably maintained in solution over a 5 day period.

Two alkalinity treatments were established to alter the solution environment to mimic a low alkalinity irrigation water system and a high alkalinity irrigation water system. Low alkalinity treatments used deionized water thereby allowing for a zero alkalinity treatment ($\pm 0.2 \text{ ppm}$) and a high alkalinity treatment of 400 ppm soluble carbonates was established by using 4.76 mM L^{-1} of NaHCO_3 .

Each batch of 6 two liter beakers were stirred, the pH was taken and poured into the individually assigned and marked 2L plastic beaker. During a solution change, plants were placed in a “control” aerated 0.5 strength Hoagland solution while this changing process took place (approximately 5-7 minutes). The pH of each of the 2L beakers was measured every 2 days for the first 2 weeks and everyday for the remainder of the experiment. Additional amounts of 0.5 M HCL and 0.5 M KOH were added as needed to maintain the pH treatment (± 0.1). As the experiment progressed, the need to measure and adjust the pH increased.

Plants were harvested at their specified harvest date pre-assigned to the treatment (2 weeks, 4 weeks, or 6 weeks); cleaved at the base of the stem just above solution contact, triple rinsed in deionized water and dried for 72 hours at 250° F in a large convection oven. Each plant was ground to a fine powder in a Wylie Mill to form a homogenous sample corresponding to a 40 intermediate mesh screen size. Two gram samples were weighed into Pyrex beakers and ashed in a muffle furnace at 450 °C for 16 hours. The ash was digested with 2 mL of concentrated HNO₃ and heated to incipient dryness, upon which 10 mL of 3N HCl was added and beakers were covered and heated at reflux for 2 hours. The solution was filtered through Whatman #40 filter paper into a 25mL Pyrex volumetric flask; to each, 1 mL of 1000 ppm Yttrium (40 ppm in 25 mL) as an internal standard and flasks were brought up to volume using 0.1 HCl. Every ten samples, there was inserted blanks as well as NTIS standard tomato leaves as a reference. Samples were analyzed for macro and micronutrients by inductively coupled plasma atomic emission

spectrometry (ICP-AES). Sample duplicates were within 10% agreement and all concentrations measured for the NTIS standard tomato were within the range specified by NTIS.

Statistical analyses of the data were conducted using the SAS. Statistical significance of factors and their interactions on plant nutrient uptake and plant growth were determined using the analysis of variance and F-tests. Means of all treatment combinations were compared using Least Significant Difference (LSD) values.

RESULTS and DISCUSSION

The results of the analyses of variances for the dry weights and tissue nutrient concentrations are presented in Tables 16 through 21. For clarity of presentation and ease of discussion, F values are used as a measure of relative importance of each source of variation.

Plant Survival

There was considerable mortality for the Tango Light Pink cultivar. At the 2 week sampling date only nine out of twenty-four plants survived. Tango Dark Red plants exhibited a lower mortality rate and twenty-two out of twenty-four plants survived. Geraniums are susceptible to pythium root rot when the root environment does not receive adequate air flow and the roots are allowed to remain wet (Ball Redbook, 2003). In a nutrient solution, the plant must adjust to a primary liquid environment and some plants may be not develop a good root system, which reduces nutrient uptake during an “adjustment” period (Jones, 1999). The Tango Light Pink plants that died exhibited symptoms that resembled pythium root rot. However, plants that survived 9 days in solution had a healthy root system (Picture 1) with no signs of root rot (Picture 2). The remainder of the plants had healthy root systems and mortality was attributed to treatment effects rather than root rot. At the 4 week sampling date, seventeen out of twenty-four Tango Light Pink and twenty-two out of twenty-four Tango Dark Red survived, while at the 6 week sampling date sixteen out of twenty-four Tango Light Pink and 16 out of 24 Tango Dark Red survived. After the two week sampling date, there was much less plant mortality as it appeared

that both cultivars adjusted to the nutrient solution environment. The mortality rates of both cultivars were similar for the remainder of the experiment and the remaining plant deaths have been attributed to the effects of the experimental treatments.



Picture 1: Healthy plants and roots at 2 weeks growth.



Picture 2: Dead plants at 2 weeks growth

Dry Weight

Dry weights of the geraniums at 2, 4, and 8 weeks of growth were significantly affected by cultivar, water alkalinity, pH and nitrogen rate (Tables 16-18). The largest differences in dry weights were between cultivars. Several highly significant two and three-way interactions indicated variable dry weight responses to the four factors (Figures 33 a-f graphically display these interactions).

For 'Tango Dark Red', an increase in the water alkalinity and the nitrogen rate increased the dry weights for all pH treatments at all sampling dates. The dry weight means, although statistically different between treatments, were small until the 6 week sampling which coincided with initial bud set. At 6 weeks, pH had a large effect on Tango Dark Red plants. The mean dry weights at 6 weeks were 4.18 g/pot, 5.92 g/pot, and 4.89 g/pot for Tango Dark Red plants grown at a pH of 5.5, 6.2, and 6.8, respectively. Thus, maintaining the pH at 6.2 would produce bigger plants upon rooting and during finishing.

Tango Light Pink had lower overall dry weights than Tango Dark Red. There was significant mortality observed for Tango Light Pink between treatment initiation and the two week sampling date and overall the plants were much smaller and unhealthy. For Tango Light Pink, no differences due to treatment effects were observed at 2 or 6 weeks growth and there was a slight increase in dry weight due to increasing water alkalinity at 4 weeks. The plants that survived past the two week sampling date exhibited increased growth and an overall increase in the health of the

plant around day 16. When this occurred, the plants began to form healthier root systems and were able to take up nutrients similar to the Tango Dark Red plants. However, at all sampling dates, Tango Light Pink were approximately half the size of Tango Dark Red at similar growth stages. Tango Light Pink plant dry weights ranged from 1.1 g/pot at 2 weeks growth to 3.8 g/pot at 6 weeks growth, whereas ‘Tango Dark Red’ dry weights ranged from 1.9 g/pot at 2 weeks growth to 5.9 g/ pot at 6 weeks growth.

The large differences in dry weight between cultivars could be due to the cultivar’s growth habit. Although both cultivars are a member of the ‘Tango’ series, the Light Pink cultivar has been bred to be more compact than the Dark Red cultivar (Fischer Inc., 2002). However, the trait of “compactability” does not necessarily equate to less dry weight. Another possible cause for the differences in dry weight could be that the Tango Dark Red cultivar is better adapted to the nutrient solution environment and was able to more fully utilize the nutrients taken up into its tissues. Tango Light Pink had poor health and a high mortality rate during the initial 2 weeks in solution. Therefore, Tango Light Pink low dry weights at 4 and 6 weeks may be due to lower nutrient uptake during the first few weeks of growth in solution.

Table 16. Analyses of variance to determine significant effects of variety, water alkalinity, pH and nitrogen rate on total dry weight and macronutrient concentrations of *Pelargonium x horticum* leaf tissue at 2 weeks.

ANOVA Source of variation	df	----- F value -----					
		Dry Weight	N	P	K	Ca	Mg
Cultivar (C)	1	1405.0 ***	476.1 **	0.1	3.9	5.9	5.5
Water Alkalinity (W)	1	41.8 ***	24.8 **	0.8	3.5	0.4	3.7
pH (PH)	2	19.4 **	1.8	2.8	2.7	0.1	34.2 ***
Nitrogen Rate (N)	1	29.8 ***	135.7 ***	60.3 ***	185.0 ***	0.1	0.1
C × W	1	42.7 ***	23.8 **	0.3	4.3	0.0	0.3
C × PH	2	6.3 *	4.2	0.6	19.3 *	4.2	5.4
C × N	1	23.2 **	43.3 ***	9.5 *	0.0	0.0	0.2
W × PH	2	3.7	4.4	0.2	5.0	0.1	2.5
W × N	1	4.7 *	1.6	0.0	6.8 *	0.2	0.0
PH × N	2	3.5	0.8	3.3	3.3	0.3	0.6
C × W × PH	1	0.4	0.2	1.8	0.1	0.0	0.1
C × PH × N	2	2.2	0.5	0.2	8.9 *	0.1	0.3
W × PH × N	1	6.4 *	0.3	0.4	17.4 *	0.7	0.1

*, **, *** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

Table 17. Analyses of variance to determine significant effects of variety, water alkalinity, pH and nitrogen rate on total dry weight and macronutrient concentrations of *Pelargonium x horticum* leaf tissue at 4 weeks.

ANOVA Source of variation	df	F value					
		Dry Weight	N	P	K	Ca	Mg
Cultivar (C)	1	214.0 ***	41.8 ***	17.5 **	3.9	122.1 ***	0.2
Water Alkalinity (W)	1	26.9 ***	89.2 ***	1.7	3.1	544.3 ***	1.9
pH (PH)	2	15.9 ***	1.5	125.2 ***	0.4	59.5 ***	4.3
Nitrogen Rate (N)	1	45.3 ***	335.7 ***	277.3 ***	135.1 ***	7.1	2.9
C × W	1	6.1 *	24.6 ***	3.6	0.0	94.3 ***	0.0
C × PH	2	4.1 *	1.3	11.2 *	11.7 *	63.4 ***	0.4
C × N	1	0.1	0.2	9.7 *	0.0	4.1	2.7
W × PH	2	11.8**	0.5	2.5	0.1	0.3	3.5
W × N	1	21.1*	0.6	3.6	0.4	0.0	2.7
PH × N	2	7.5 *	0.0	3.4	0.1	5.9	4.5
C × W × PH	2	0.1	0.7	12.6 **	0.8	41.7 ***	0.7
C × W × N	1	6.9 *	0.7	6.7	2.5	0.0	2.8
C × PH × N	2	4.6 *	0.6	45.4 **	0.6	2.2	1.9
W × PH × N	2	29.2 ***	2.4	5.9	0.2	2.9	7.3

*. **,*** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

Table 18. Analyses of variance to determine significant effects of variety, water alkalinity, pH and nitrogen rate on total dry weight and macronutrient concentrations of *Pelargonium x horticum* leaf tissue at 6 weeks.

ANOVA Source of variation	df	F value					
		Dry Weight	N	P	K	Ca	Mg
Cultivar (C)	1	738.1 ***	1.5	8.7 *	0.0	3.9	3.5
Water Alkalinity (W)	1	99.5 ***	3.2	0.4	0.2	215.0 ***	1.7
pH (PH)	2	345.1 ***	0.4	12.9 *	2.0	181.7 ***	8.3 *
Nitrogen Rate (N)	1	41.1 ***	292.1 ***	241.4 ***	58.8 ***	22.5 **	1.2
C × W	1	56.3 ***	0.8	1.2	2.4	0.3	4.4
C × PH	2	11.3*	0.0	1.2	8.5 *	3.8	6.2 *
C × N	1	13.8*	0.8	0.1	1.9	0.2	1.2
W × PH	2	6.3 *	0.6	6.9	3.3	7.7 *	2.6
W × N	1	12.8 **	0.8	5.8	2.2	4.2	0.3
PH × N	2	14.5 **	11.2 *	1.0	1.7	3.5	0.0
C × W × PH	2	1.5	0.6	1.2	3.8	1.6	1.5
C × W × N	1	2.3	0.5	2.1	13.2 *	23.7 **	0.6
C × PH × N	2	16.0 **	1.4	23.3 **	10.5 *	1.0	2.3
W × PH × N	1	6.7 *	2.7	12.5 **	17.4 **	0.2	1.4

*. **,*** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

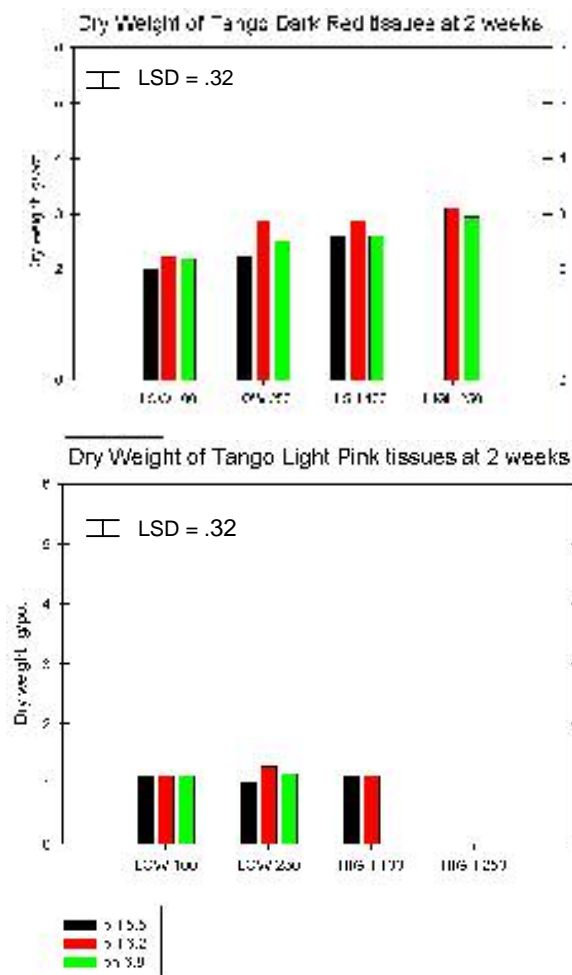


Fig. 33d

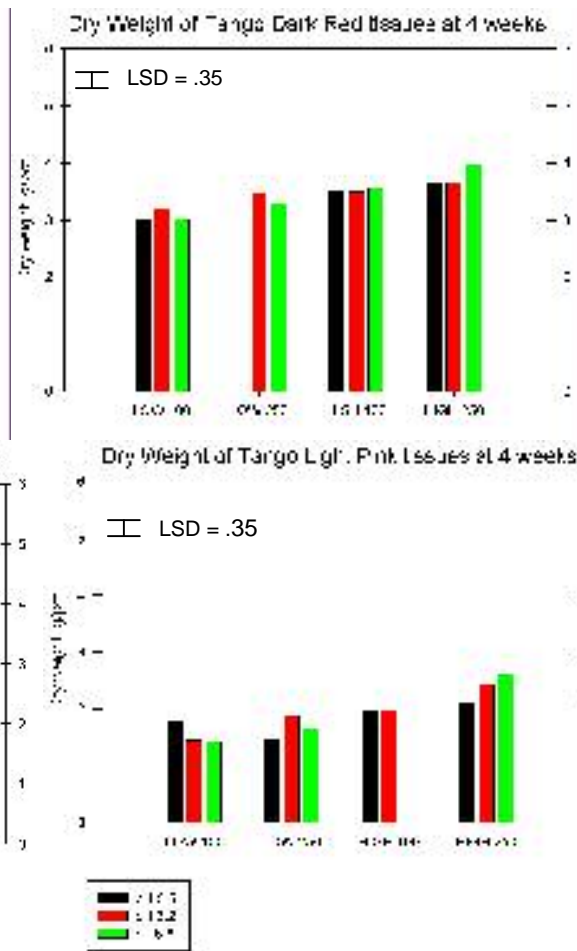


Fig. 33e

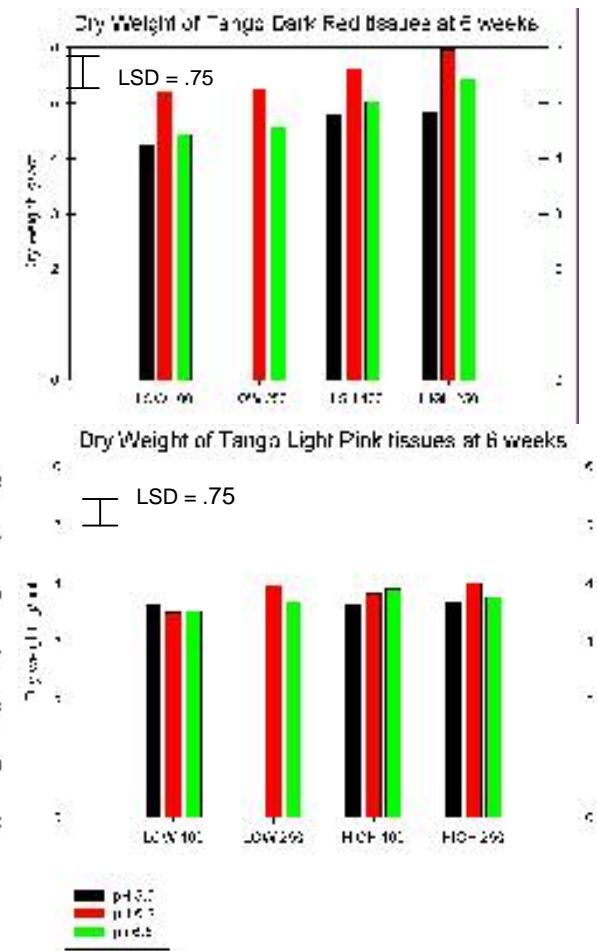


Fig. 33f

Figures 33 a-f: Dry weight of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Nitrogen

Nitrogen concentration in the geranium leaves was significantly affected by the main effects for nitrogen rate at all sampling dates. There were also significant differences in N tissue concentrations due to variety, and water alkalinity at 2 and 4 weeks but not at 6 weeks. There were no significant effects due to the main effect for pH at any of the sampling dates yet although there was a significant pH X N interaction at 6 weeks. Also, C X W and C X N were significant at some of the sampling dates (Tables 16-18).

At 2 weeks, Tango Dark Red leaves had N concentrations within the recommended range (3.8- 4.4 %) for all plants grown in the high alkalinity water. For the plants grown in low water alkalinity treatments, the N concentrations in the leaf tissue were in the recommended range at pH 5.5 but deficient (less than 2.5%) at the higher pH levels (6.2 and 6.8). The N tissue concentration could not be measured for the high water alkalinity pH 5.5 treatment because all of those plants died after 11 days growth. The surviving Tango Light Pink plants were extremely N deficient and had less than half the N concentrations in the leaves when compared to Tango Dark Red. In addition, there were no apparent effects due to increasing the N rate, pH or water alkalinity levels for these plants at this sampling date. All replications grown at 250 mg kg⁻¹ N, high water alkalinity and all pH's died after 5 days of growth.

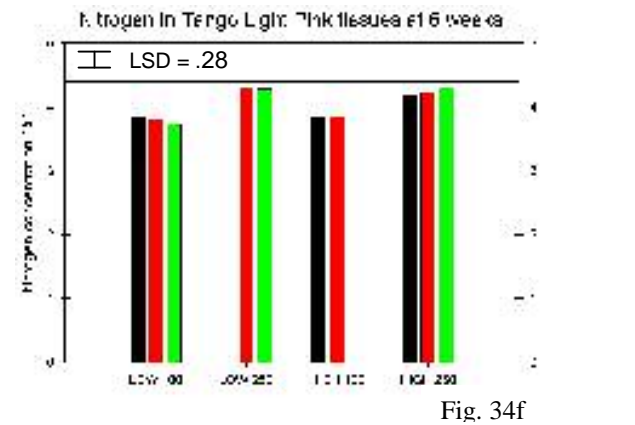
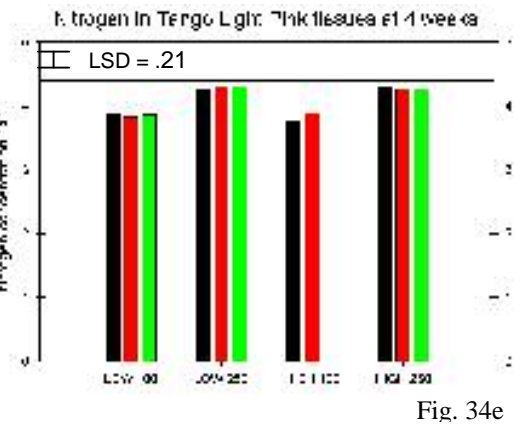
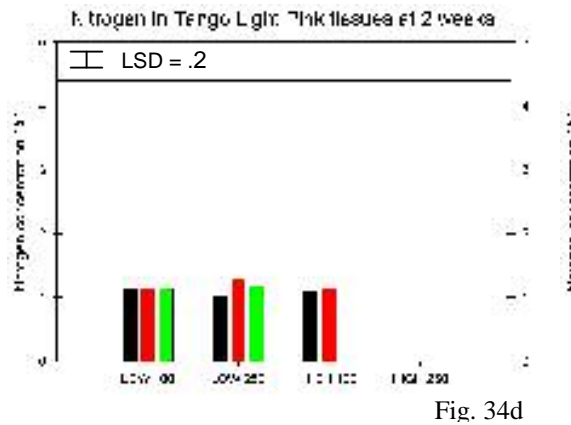
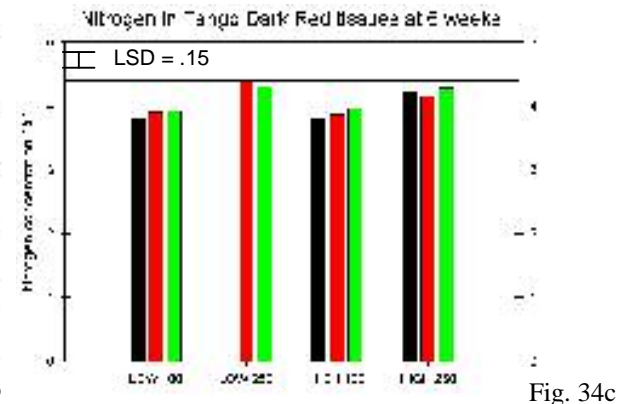
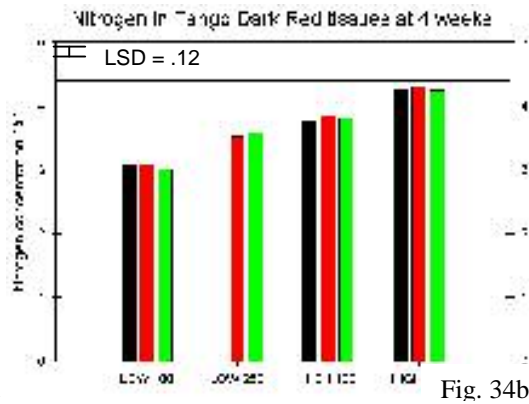
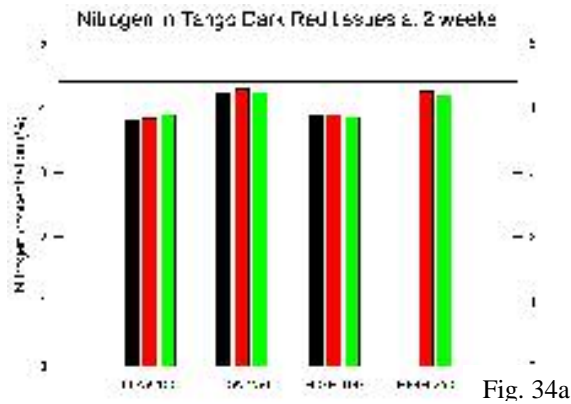
At 4 weeks, Tango Dark Red N concentrations were deficient for the low water alkalinity treatments even at the low pH treatments. When the alkalinity was

raised to 400 ppm, N concentrations were slightly below the recommended range for the low N treatments and within the recommended range for the high N treatments with an observable increase due to N rate. Similarly at 4 weeks, the mean N tissue concentration of Tango Light Pink increased by four-fold from 1% to 4% and all the means of all the treatments were within or slightly below the recommended range for N tissue concentrations. Increasing the N rate from 100 mg kg⁻¹ to 250 mg kg⁻¹, significantly increased the N in the tissue from 3.8% to 4.3%.

For the 6 week sampling date, there were no differences due to cultivar or water alkalinity treatment and a small statistically significant ($p = 0.05$) pH X N interaction. However, increasing the N treatment rate from 100 mg kg⁻¹ to 250 mg kg⁻¹ increased the tissue concentration N more than one-half percent for both cultivars (Figures 34 a-f).

Nitrogen is a macronutrient required for plant growth and development. Usually dry plant tissue contains between 2% and 4% N depending on plant type and growth habit (Mengle and Kirkby, 1979). Early research suggested that pH affected N concentration in geranium tissues since the form of N as either a cation NH_4^+ or an anion NO_3^- can directly influence the ion concentration around the media and thereby affect media pH. It has been shown that geraniums grown in the greenhouse and fertilized with a greater than 60% supply of NO_3^- -N for the sole source of N grew larger, healthier, greener plants, when compared to geraniums grown with a lesser percentage of NO_3^- -N (Biamonte, 1993). In addition, recently rooted geraniums do not grow well when fed with higher levels (above 50%) of

NH₄-N (Mengle and Kirkby, 1979; Biamonte 1993; Ball Redbook, 2003). My experimental results found no differences in N concentration in the leaves of these two cultivars of geraniums due to pH manipulation by N source. However, there were large differences in N tissue concentration between Tango Dark Red and Tango Light Pink during the first 2 weeks in nutrient solution that were not evident after 6 weeks. This indicated that the Tango Light Pink cultivar was more sensitive to the nutrient solution environment and had difficulty adjusting to this type of environment.



█ pH 5.5
█ pH 6.5
█ pH 7.5
 Home Range 26-44%

█ pH 5.5
█ pH 6.5
█ pH 7.5
 Home Range 26-44%

█ pH 5.5
█ pH 6.5
█ pH 7.5
 Home Range 26-44%

Figures 34 a-f: Mean tissue N concentration of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Phosphorus

At 2 weeks, phosphorus concentration in geranium leaves was significantly affected only by the main effect for nitrogen rate and a C X N interaction. At the 4 and 6 week sampling dates, P tissue concentrations were significantly affected by the main effects for nitrogen rate, pH, and cultivar as well as significant interactions involving these factors (Tables 16-18). Increasing the water alkalinity level had only a minor influence on P concentration in the leaves at any sampling date and was only significant in one 3-way interaction at 4 and 6 weeks.

Increasing in the N rate from 100 mg kg⁻¹ to 250 mg kg⁻¹ consistently increased the P concentration in geranium tissues at all sampling dates. Due to plants mortality at 2 weeks, there are no means for plants receiving 250 mg kg⁻¹ N and high water alkalinity treatment. At the 4 week and 6 week sampling dates, P tissue concentration generally increased as pH of the low alkalinity water treatments was increased. Conversely, the response to pH for the high alkalinity water treatments was inconsistent as indicated by significant interactions of C X pH X N. Although differences between the varieties were statistically significant at the 4 and 6 week sampling dates, these differences are biologically insignificant since all tissues were within the range of normal recommended P leaf concentrations for geraniums (0.3% -0.5%) (Figure 35 a-f).

Phosphorus is often considered a macronutrient of luxury consumption for most cultivars of geraniums (personal communication, Ron Adams Ball Seed Inc, 2004; Ball Redbook, 2003; Bethke, 1993). In general, most cultivars of geraniums

are able to take up adequate amounts of P under a variety of environmental conditions. Therefore, it can be expected that as the nitrogen rate is formulated to increase from 100 mg kg⁻¹ to 250 mg kg⁻¹ so will the P rate in a balanced fertilizer formula. This increase is translated into a greater amount of P available for the plant to take up and thereby cause a higher concentration on P in the plant tissues (Biamonte, 1993; Ball Redbook 2003). For future study, it may be beneficial to re-evaluate P concentrations in “balanced” fertilizer formulations as a means of cost effectiveness since it appears that geraniums and some other types of ornamentals (marigolds, impatiens) and woody plants (azalea, holly) do not need such elevated levels to maintain healthy growth (personal communication, J. Lea-Cox 2004).

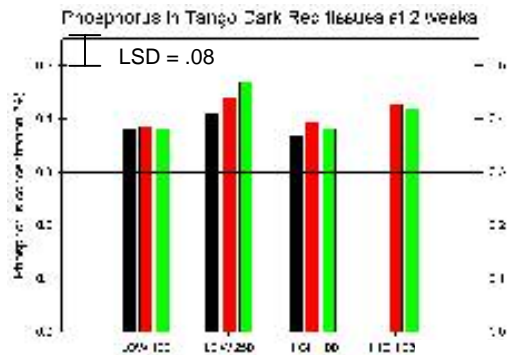


Fig. 35a

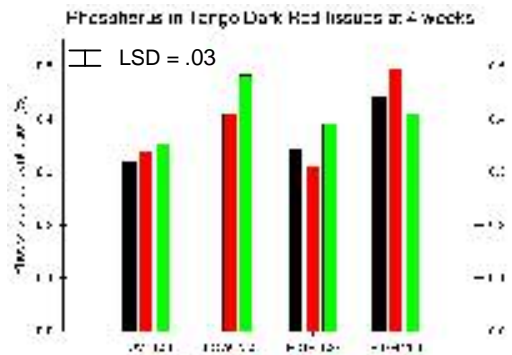


Fig. 35b

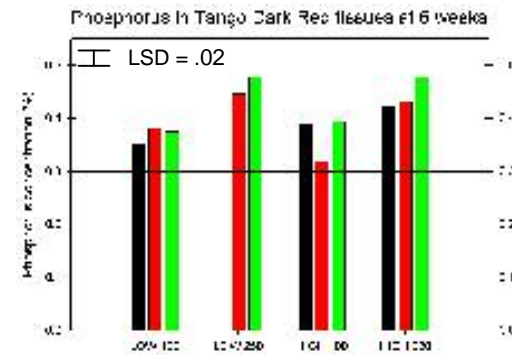


Fig. 35c

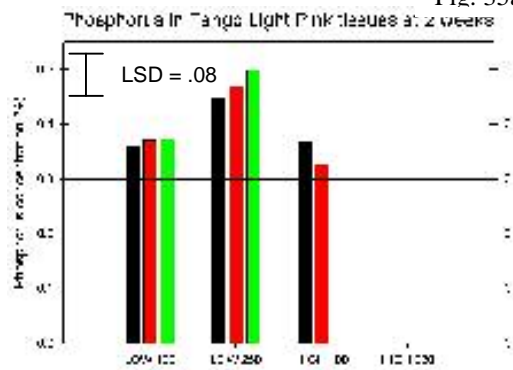


Fig. 35d

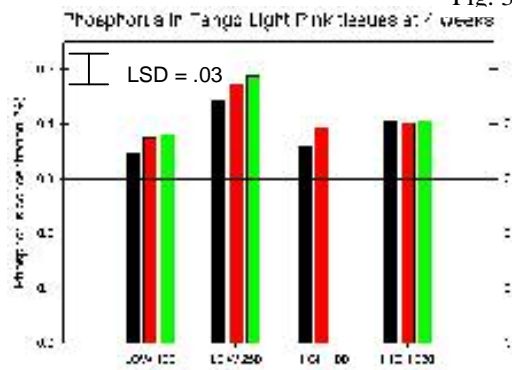


Fig. 35e

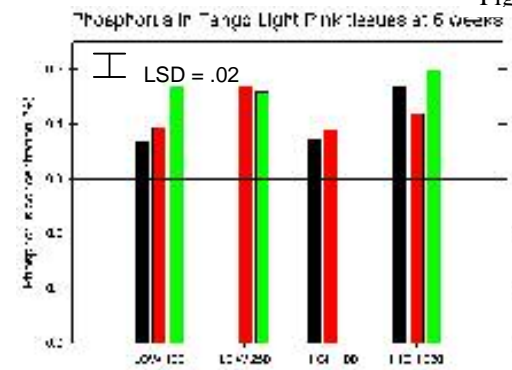


Fig. 35f

■ = 0.0
 ■ = 4.0
 ■ = 10.0
 LSD = 0.08

■ = 0.0
 ■ = 4.0
 ■ = 10.0
 LSD = 0.03

■ = 0.0
 ■ = 4.0
 ■ = 10.0
 LSD = 0.02

Figures 35 a-f: Mean tissue P concentration of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Potassium

Potassium concentration in geranium leaf tissue was significantly affected by the main effects for nitrogen rate at all sampling dates with no other main effects significantly affecting K uptake. In addition, the two-way interaction of C X pH and three-way interactions of W X pH X N as well as C X pH X N were also significant at the 2 and 6 week dates (Tables 16-18). All plants at all sampling date were within or exceeded the normal range of K concentration for zonal geraniums (0.3% - 0.5 %). The maximum K tissue concentration for Tango Dark Red and Tango Light Pink was 3.8 % and 3.7%, respectively. Both were observed at the 6 week sampling date, high water alkalinity and a N rate of 250 mg kg⁻¹, but at a pH of 6.2 for Tango Dark Red and pH 6.8 for Tango Light Pink.

As the nitrogen rate increased, K concentration in geranium tissues increased for all treatments (Figures 36 a-f). The effect of pH was variable in both cultivars across all sampling dates with no significantly different changes in K leaf concentrations. The two way interaction of C X pH and several three-way interactions were statistically significant but caused small changes in the magnitude of response, yet overall these results agree with current literature on the tissue uptake of K for *Pelargonium x horticum* (Tables 16-18). Similar to the P leaf tissue concentrations, all of the K leaf tissue concentration were within or exceeded the recommended range.

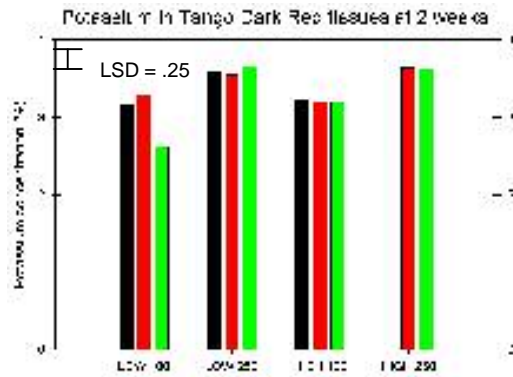


Fig. 36a

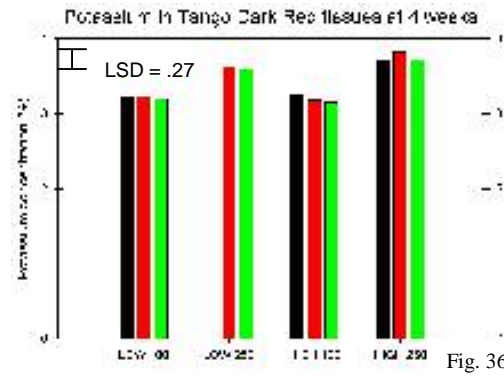


Fig. 36b

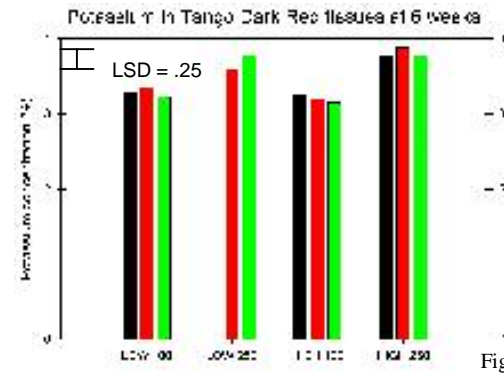


Fig. 36c

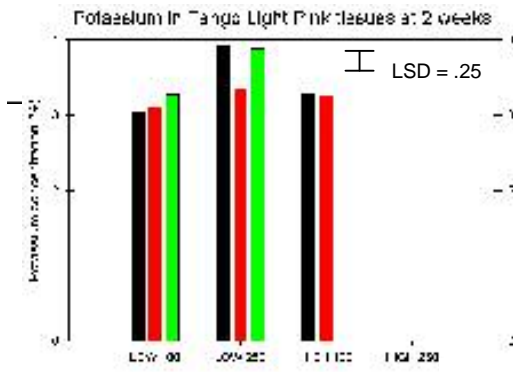


Fig. 36d

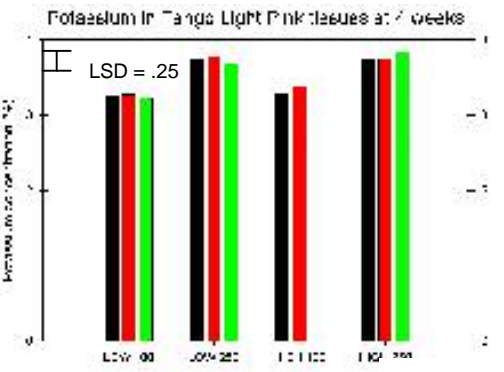


Fig. 36e

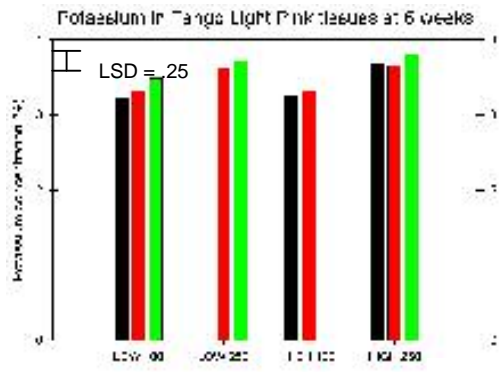
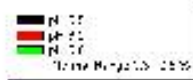
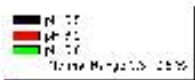


Fig. 36f



Figures 36 a-f: Mean tissue K concentration of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Calcium

There were no significant differences in Ca concentration in the tissues of geraniums at the 2 week sampling date (Table 16). At 4 weeks, there were significant main effects for water alkalinity, cultivar and pH as well as strongly significant two way interactions of C X W and C X pH and the three-way interaction between these factors (Table 17). At 6 weeks, similar main effects were significant except that there was no cultivar effect and only a slightly significant W X pH interaction (Table 18). Nitrogen rate did not significantly affect Ca concentration in geranium leaves at any of the sampling times.

In general after 2 weeks growth, there were no significant differences in calcium concentration for both cultivars across all treatment factors. However, the general trend, suggested by the significant pH main effect is that the concentration of Ca in the plant tissues increased as the pH level was raised from 5.5 to 6.8 after two weeks of growth (Figures 37 a-f). In addition, in regards to the water alkalinity level, increasing the soluble carbonates from 0 ppm to 400 ppm soluble carbonates increased the Ca concentration in the leaf tissues, especially for Tango Dark Red

At four weeks, Tango Dark Red was considered to be deficient at the low alkalinity treatments regardless of pH and nitrogen rate. Tango Dark Red consistently showed increases in Ca leaf concentrations with increasing pH level and increasing water alkalinity. Ca tissue concentrations were within the recommended levels for zonal geraniums at all treatment combinations and dates with one exception (Figures 37 a-f). The mean Ca concentrations ranged from 1.3 % at pH

5.5, low alkalinity and a nitrogen rate of 100 mg kg⁻¹ to 1.9% at pH 6.8, high water alkalinity and a nitrogen rate of 250 mg kg⁻¹. This increase of greater than 40% is extremely significant considering the normal recommended range for Ca concentration in geraniums is narrow (1.4 – 2.0 %). Tango Light Pink tissues at 4 weeks, measured slightly higher Ca concentrations when the alkalinity was raised, yet no differences were observed due to an increase in pH level.

Both cultivars showed no significant differences due to increasing the nitrogen rate from 100 mg kg⁻¹ to 250 mg kg⁻¹ at all sampling dates. However, Ca uptake was significantly lower when the water alkalinity level was decreased to 0 soluble carbonates, Ca uptake decreased significantly to borderline deficiency at the 4 and 6 week sampling dates for both cultivars. Despite the low Ca levels, no signs of Ca deficiency were seen in the plant material at time of harvest.

These results are significant and contrast the results from the previous study conducted with different media types in which it was observed that decreasing Ca tissue concentration occurred with increasing soluble carbonates in the media. In this previous study, Ca deficiency in plant tissues at pH 5.5 was observed, yet at the high water alkalinity levels (300ppm), Ca concentrations in the media were above the recommended. Thus, increased media Ca did not result in increasing the concentration of Ca taken up in the leaf tissue. Ca uptake in plant tissues for the high alkalinity treatments was highly deficient regardless of media type despite adequate available Ca in the media. In this study, Tango Dark Red and Tango Pink Light geraniums leaf Ca concentrations increased when the amount of soluble

carbonates was increased to 400 ppm , a level considered excessive for water alkalinity in nutrient solution. This suggests that interactions in the media between Ca and soluble carbonates negatively affect Ca uptake by zonal geraniums. However, by growing the plants in nutrient solutions we eliminate the possibility of media-ionic interactions and can observe the independent effects of water alkalinity on Ca uptake. Researchers have suggested that zonal geraniums have the tendency to take up specific nutrients in the media regardless of competition from other nutrients (Fonteno and Adams, 2003; Nelson and Haung, 2003). This ability of a plant to select for certain nutrients and increase uptake under various conditions has been suggested for Ca in a soilless media (Fonteno and Adams, 2003) and other nutrients in a soil environment (Marschner, 1996). Clearly the results from this experiment indicate the role that media selection plays in determining W X nutrient interactions in regards to Ca concentration for zonal geraniums and that it may not be the plants ability to 'select' for certain nutrients, rather media-ionic interactions in the media that result in variable uptake for certain nutrients.

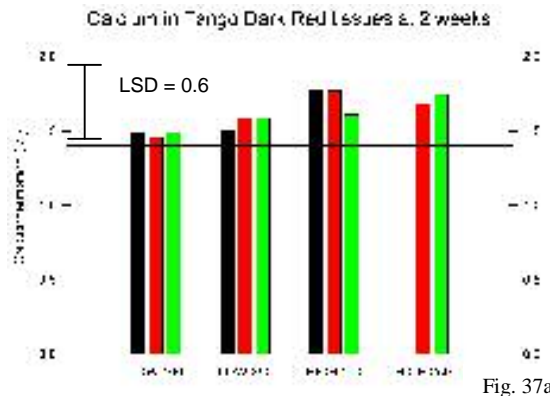


Fig. 37a

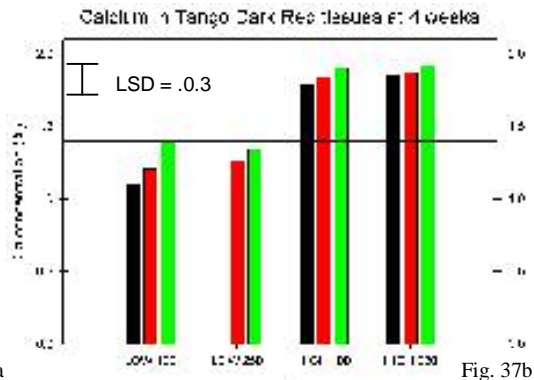


Fig. 37b

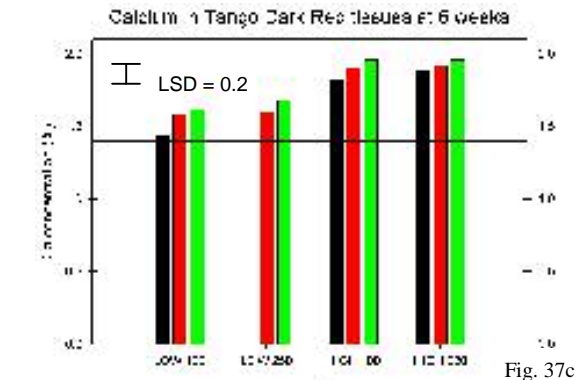


Fig. 37c

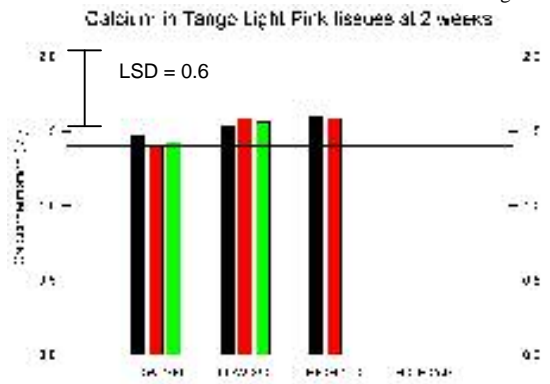


Fig. 37d

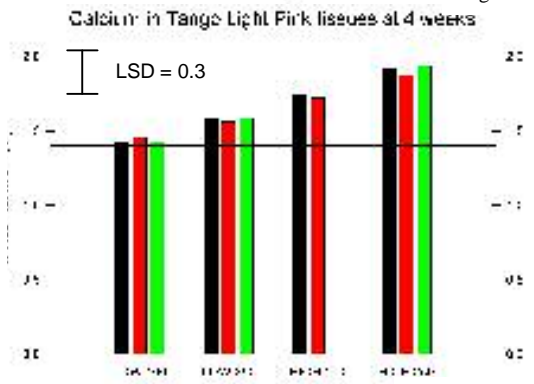


Fig. 37e

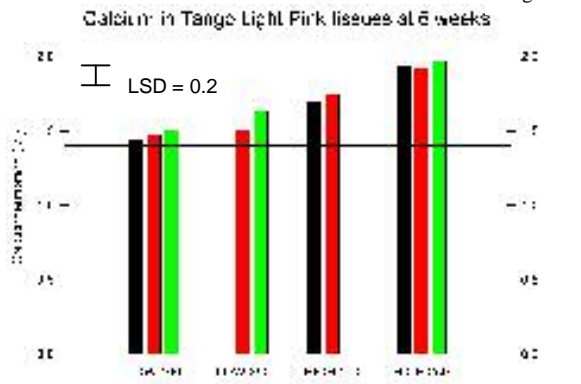


Fig. 37f

Figures 37 a-f: Mean tissue Ca concentration of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Magnesium

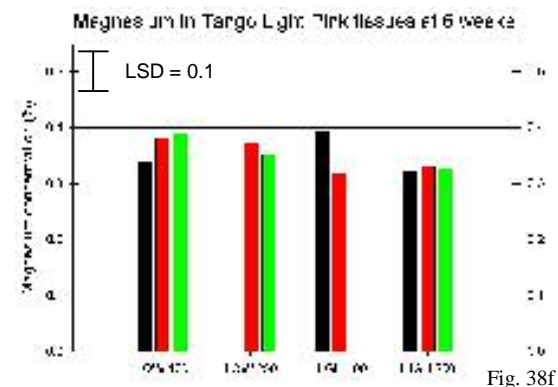
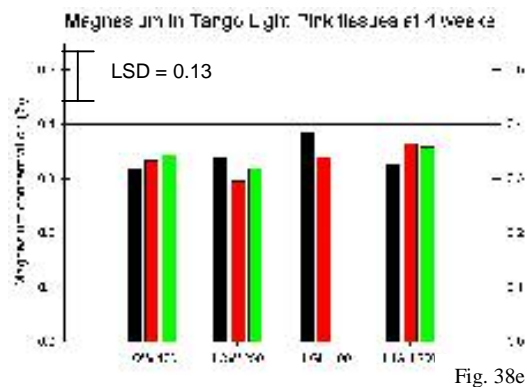
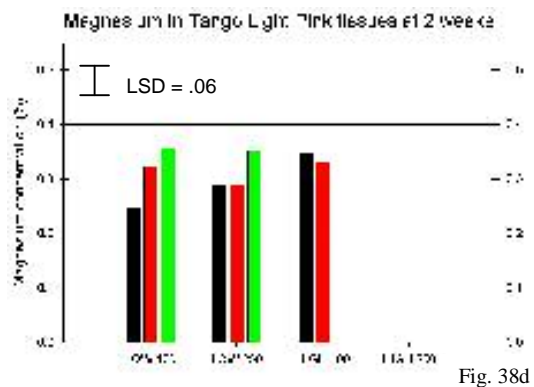
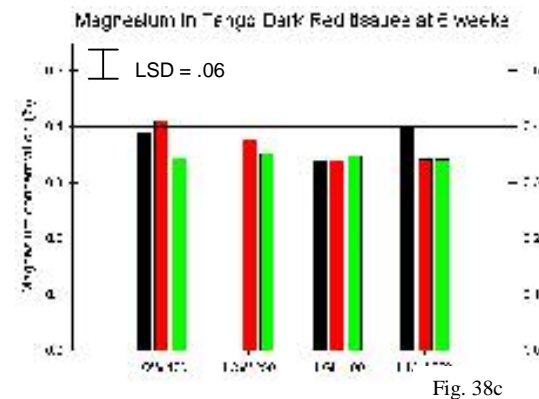
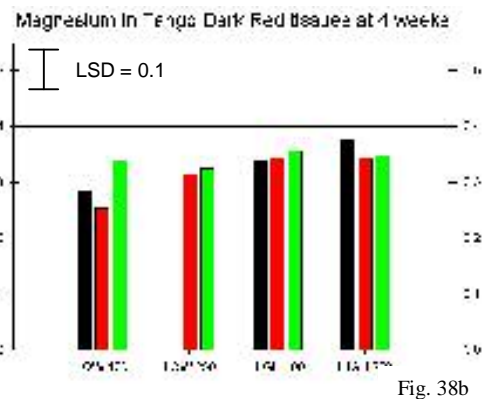
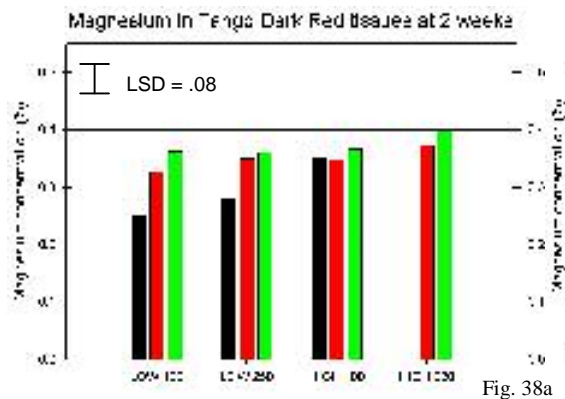
Magnesium concentration in geranium leaf tissue was significantly affected by the main effects for pH at the 2 and 6 week sampling dates with no other main effects significantly affecting Mg uptake (Tables 16-18). In addition, the two-way interaction of C X pH was slightly significant only at the 6 week sampling date (Table 18). All plants at all sampling dates were within the normal recommended range of Mg concentration in the tissues of zonal geraniums (0.3 - 0.5%).

There were few observable differences between Mg concentrations at each sampling date which is unlike most other nutrients measured in the study. Increases in Mg tissue concentration were observed as the pH increased at the 2 week sampling date for Tango Dark Red but these trends are very variable at 4 and 6 weeks growth and between cultivars. The maximum Mg tissue concentration for Tango Dark Red and Tango Light Pink was 0.41 % and 0.39%, respectively. Both were observed at the 6 week sampling date, low water alkalinity and a N rate of 100 mg kg⁻¹, but at a pH of 6.2 for Tango Dark Red and pH 6.8 for Tango Light Pink (Figures 38 a-f).

The effect due to pH was variable in both cultivars across all sampling dates with variable significantly different changes in Mg leaf concentrations. The two way interaction of C X pH was statistically significant but caused small changes in the magnitude of response, yet overall these results agree with current literature on the tissue uptake of Mg for *Pelargonium x horticum* (Tables 16-18). Similar to the

P and K leaf tissue concentrations, all of the Mg leaf tissue concentrations were within the recommended range.

During geranium production, Mg toxicity is rare. The main sources of these secondary nutrients are from dolomitic limestone supplied pre-plant as a method to maintain a stable media pH (Nelson, 1996), therefore adequate amounts of Mg are supplied to the plant over the duration of the production cycle. In addition, balanced fertilizer formulas provide small amount of Mg and Ca as secondary soluble nutrients. In a nutrient solution environment, it was imperative to replicate this constant availability of Mg and Ca to the plant to determine the effects of changes in uptake due to water alkalinity and pH interactions. The results of this study show that pH and water alkalinity did not significantly affect Mg uptake by geranium tissues when grown in a nutrient solution environment. Rather, interaction with the growing media and these factors play a more significant role in determining Ca and Mg balance and uptake into the plant tissues.



■ 0 ppm
 ■ 100 ppm
 ■ 250 ppm
 *Tango Purple 25 - 25%

■ 0 ppm
 ■ 100 ppm
 ■ 250 ppm
 *Tango Purple 25 - 25%

■ 0 ppm
 ■ 100 ppm
 ■ 250 ppm
 *Tango Purple 25 - 25%

Figures 38 a-f: Mean tissue Mg concentration of two 'Tango' zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Iron

Iron concentration in geranium leaf tissue was significantly affected by the main effects of cultivar, pH and water alkalinity at all sampling dates (Table 19-21). In addition, the two way interactions of C X W and C X pH were significant at the 4 week sampling date while only C X pH was significant at 2 and 6 weeks. Neither the main effect or interactions involving nitrogen rate significantly affected Fe tissue concentrations.

For both cultivars, across all treatments, Fe concentrations were well within the recommended range of 110-580 mg kg⁻¹. At all sampling dates, the major factor affecting Fe tissue concentrations was pH. As the pH was raised from 5.5 to 6.8, Fe concentrations in the tissues decreased. However, even though the trends were similar, no significant differences were observed for Tango Light Pink between pH of 6.2 and 6.8 at the 2 and 4 week sampling dates at the low alkalinity water treatments. The significance of the two way interactions of C X pH influenced the magnitude of response that each cultivar displayed when the pH of the solution decreased (Figures 39 a-f).

Increasing the water alkalinity level from 0 ppm soluble carbonates to 400 ppm soluble carbonates lowered the amount of Fe taken up into the leaves only in the Tango Dark Red plants. In addition, the Tango Dark Red tissues had overall higher Fe concentrations when compared to similar sampling dates and treatment combinations of Tango Light Pink. Tango Dark Red averaged between 17% and 25% greater Fe tissue concentrations than similar treatments in Tango Light Pink.

No significant differences due to an increase in water alkalinity were observed at the 2 week sampling date for Tango Light Pink and a the response to water alkalinity was less at the 4 and 6 week sampling dates when compared to Tango Dark Red.

The results of this experiment are similar to those observed in the previous pot experiment in that the main effects and interactions of pH and water alkalinity treatments affected Fe uptake. Both increasing the pH and the amount of soluble carbonates reduced Fe concentration in the leaves, however, different responses were observed according to the media type (Exp.2) and cultivar (Exp. 3).

Fe is classified as a micronutrient and is required for plant growth but in smaller amounts than the macronutrients. It is the most frequently applied micronutrient because of its complexity with the surrounding environment and the plant's need for Fe in greater quantities than other micronutrients (Reed, 1996, Biamonte, 1993). The high organic matter content of soilless media keeps Fe very soluble at pH's below 5.5. As the pH is raised or there is an increase in soluble carbonates (such as high alkalinity water), Fe can form insoluble iron oxides and hydroxides and become unavailable for plant uptake. Using the chelated form of Fe (Fe-EDTA, Fe-HEDTA, Fe-EDDHA) keeps Fe soluble over a larger range of pH and alkalinity conditions, yet most Fe-species are unavailable above a pH of 6.9 and soluble carbonate level of 250 ppm (Reed, 1996, Biamonte, 1990). Production methods of ornamental crops have become more like hydroponic systems than the previous soil environments (Reed, 1996; Lang, 2002) and require monitoring Fe in order to supply adequate amounts of Fe under the proper pH conditions. Fe

deficiency and toxicity is common in zonal geraniums at extreme pH and water alkalinity levels and should be addressed when determining the fertilization program (Sheely, 1990; Biamonte, 1990).

The results of this study support earlier research that Fe is affected by an increase in pH and water alkalinity. It was thought that certain varieties of geraniums are iron-efficient (Fisher et al., 2001) and can take up Fe under a much broader range of pH and alkalinity conditions in which other varieties would be deficient. However, for the two cultivars grown in hydroponic solutions in my study, there were no major differences between the cultivars indicating that a specific cultivar was an “iron-efficient” zonal geranium. Both cultivars were within the normal recommended range for Fe tissue concentrations in geraniums therefore we can assume that both varieties were equally efficient in taking up Fe under extreme conditions of pH and water alkalinity.

Table 19. Analyses of variance to determine significant effects of cultivar, water alkalinity, pH and nitrogen rate on micronutrient concentrations of *Pelargonium x horticum* leaf tissue at 2 weeks.

ANOVA		----- F value -----			
Source of variation	df	Fe	Mn	Cu	Zn
Cultivar (C)	1	205.8 ***	183.2 ***	256.1 ***	4.5
Water Alkalinity (W)	1	159.3 ***	4.5	14.1 *	3.9
pH (PH)	2	369.7 ***	249.9 ***	975.3 ***	3.3
Nitrogen Rate (N)	1	2.4	6.7	0.1	0.1
C × W	1	0.9	3.3	46.2 **	2.1
C × PH	2	11.2 *	258.3 ***	51.3 **	1.2
C × N	1	0.7	1.1	0.0	4.5
W × PH	2	0.1	1.7	18.4 *	0.7
W × N	1	3.4	1.5	1.0	3.1
PH × N	2	0.2	4.2	0.9	0.8
C × W × PH	1	0.5	28.1 ***	25.3 *	3.5
C × PH × N	2	0.3	5.2	0.6	1.7
W × PH × N	1	0.2	1.4	1.4	5.3

*. **,*** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

Table 20. Analyses of variance to determine significant effects of cultivar, water alkalinity, pH and nitrogen rate on micronutrient concentrations of *Pelargonium x horticum* ‘Cardinal’ leaf tissue at 4 weeks.

ANOVA		----- F value -----			
Source of variation	df	Fe	Mn	Cu	Zn
Cultivar (C)	1	450.9 ***	157.4 ***	513.1 ***	21.7 **
Water Alkalinity (W)	1	529.4 ***	205.4 ***	236.6 ***	0.0
pH (PH)	2	587.8 ***	383.8 ***	485.9 ***	212.9 ***
Nitrogen Rate (N)	1	2.3	4.0	0.2	4.1
C × W	1	64.9 ***	119.9 ***	51.1 ***	4.7
C × PH	2	19.8 **	1.3	37.9 ***	0.5
C × N	1	7.9	5.0	0.3	4.4
W × PH	2	11.8 *	123.1 ***	48.5 ***	1.2
W × N	1	4.8	1.5	0.0	0.1
PH × N	2	3.0	4.0	1.6	3.1
C × W × PH	2	4.5	164.0 ***	12.6 *	5.1
C × W × N	1	0.6	2.9	1.1	3.4
C × PH × N	2	3.0	5.4	0.1	14.9
W × PH × N	2	0.5	3.5	1.7	5.2

*, **, *** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

Table 21. Analyses of variance to determine significant effects of cultivar, water alkalinity, pH and nitrogen rate on micronutrient concentrations of *Pelargonium x horticum* leaf tissue at 6 weeks.

ANOVA		----- F value -----			
Source of variation	df	Fe	Mn	Cu	Zn
Cultivar (C)	1	237.5 ***	19.3 **	114.8 ***	0.2
Water Alkalinity (W)	1	401.4 ***	112.9 **	2.0	2.8
pH (PH)	2	522.2 ***	228.7 ***	511.1 ***	114.4 ***
Nitrogen Rate (N)	1	0.1	1.2	0.1	0.2
C × W	1	0.0	114.9 ***	25.3 **	0.2
C × PH	2	16.5 **	11.8 **	8.9 *	1.0
C × N	1	0.1	13.7 **	0.0	0.9
W × PH	2	14.6 **	12.7 **	13.5 **	1.5
W × N	1	3.2	3.6	0.0	0.5
PH × N	2	1.4	2.6	0.7	0.4
C × W × PH	2	1.1	22.3 ***	3.3	0.0
C × W × N	1	1.9	25.4 ***	0.3	0.8
C × PH × N	2	1.2	4.2	0.2	0.8
W × PH × N	1	0.9	33.9 ***	0.0	0.1

*. **,*** Indicates significance at the 0.05, 0.01, 0.001 probability levels, respectively.

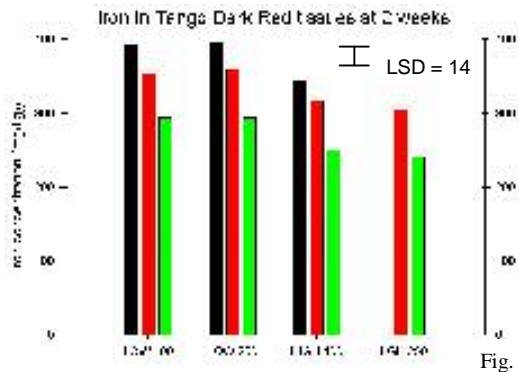


Fig. 39a

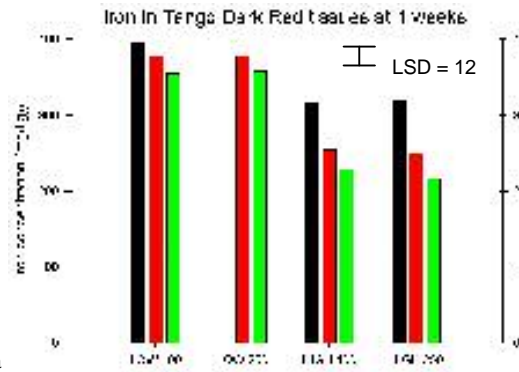


Fig. 39b

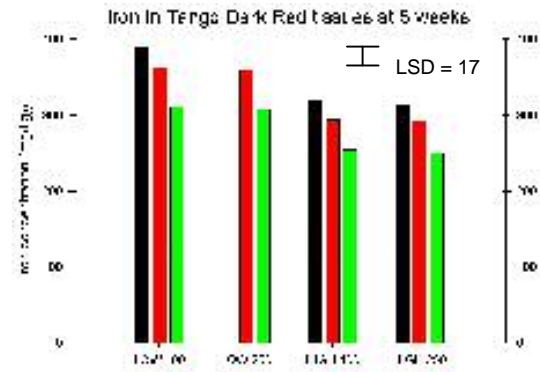


Fig. 39c

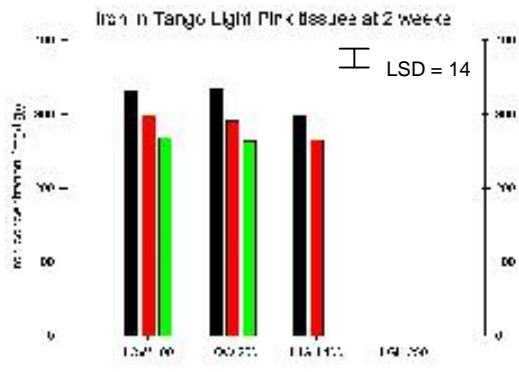


Fig. 39d

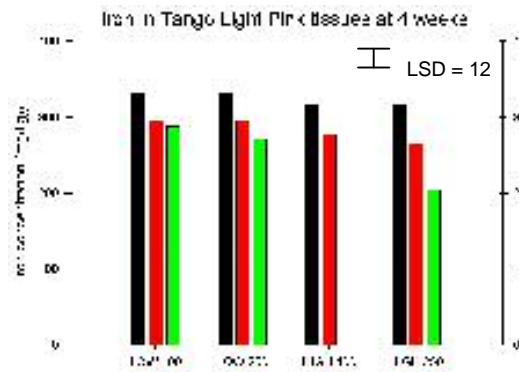


Fig. 39e

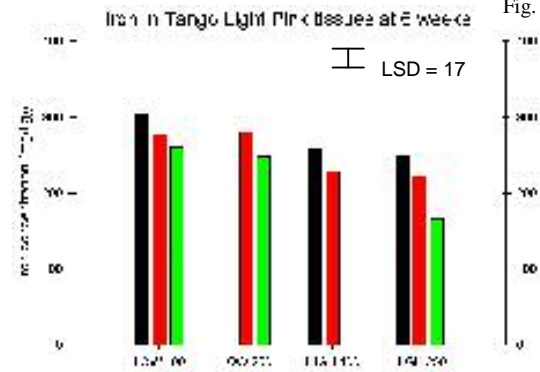
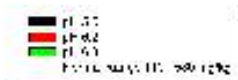


Fig. 39f



Figures 39 a-f: Mean tissue Fe concentration of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Manganese

At 2 weeks, manganese concentration in the geranium leaf tissue was significantly affected by the main effects for cultivar and pH but not water alkalinity or nitrogen rate. Interactions for C X pH and C X W X pH were also significant, although major differences between treatments were due to the main effects of cultivar and pH (Table 12).

The treatment means for Mn concentration in leaf tissue for each sampling date are graphically represented in Figures 40 a-f. Tango Dark Red showed a greater decrease in Mn leaf concentration than Tango Pink Light as the pH was raised from 5.5 to 6.8. All tissues in Tango Dark Red were within or exceeded the normal recommended range for zonal geraniums (270-325 mg kg⁻¹). Tango Dark Red plants grown at pH 5.5, low water alkalinity and receiving a nitrogen rate of 100 ppm demonstrated signs of Mn toxicity stress. These plants had small leaves which were extremely chlorotic.

At 4 and 6 weeks, the main effect for water alkalinity and several interactions became significant in addition to the significant effects found at the 2 week sampling date (Tables 20 and 21). Solution pH was the most important factor in determining Mn concentration in the leaves for both cultivars. As the pH was increased from pH of 5.5 to a pH of 6.8, the concentration of Mn in the tissues decreased. The cultivar interactions were also important. Tango Light Pink Mn mean leaf concentrations were less variable than the Tango Dark Red means. Also, all Mn concentration means for Tango Pink Light but not for Tango Dark Red were

within the recommended range for geraniums at all sampling dates. Tango Dark Red Mn concentrations decreased by as much as 75 mg kg^{-1} as the pH was raised to 6.8 while the Tango Light Pink remained within the normal recommended range. Considering the small range of the recommended concentrations of Mn for zonal geraniums ($270 - 325 \text{ mg kg}^{-1}$), the decrease observed in Tango Dark Red quite important. Water alkalinity effects on the Mn concentration differed between the varieties. For Tango Dark Red, Mn tissue concentrations significantly decreased regardless of pH as the water alkalinity increased. At pH 5.5, mean Mn concentrations of Tango Dark Red leaves were at or above the recommended range for Mn tissue concentrations regardless of alkalinity treatment, and plants displayed symptoms of Mn toxicity. In Tango Light Pink, mean Mn leaf concentrations were not significantly different between water alkalinity treatments. Mn concentrations in the tissues of Tango Pink Light were generally less than Tango Dark Red. However, 400 ppm soluble carbonates decreased the amount of Mn in plant tissue and caused a Mn deficiency in the leaves of Tango Dark Red plants but not in the leaves of Tango Light Pink plants.

Mn toxicity is rare in geranium production because only very small amounts are added to balanced fertilizer formulas to supply the plants needs. Over-supplementation with soluble micronutrients and poor pH management by the grower can cause the geraniums to take up more Mn because of increased availability in the media, not because the plant needs more of this micronutrient. Growers have found there is an increase in Mn toxicity when the pH is less than 5.8

and the predominant source of nitrogen in the fertilizer in ammoniacal-N ($\text{NH}_4\text{-N}$) (Biamonte, 1993). The plants in this study that showed Mn toxicity were subject to these conditions as well as low water alkalinity that lowered the buffering capacity around the media. The Tango Dark Red cultivar demonstrated Mn toxicity under these conditions and supports the thought Tango Dark Red plants are ‘sensitive’ to changes in pH while Tango Light Pink plants are more tolerant of harsh environmental conditions. In this study Mn foliar toxicity was observed but Fe tissue concentrations in the normal range for Tango Dark Red plants. This cultivar has been classified as an “Fe-efficient” cultivar meaning that it has the tendency to take up excess concentrations of Fe without showing signs of toxicity stress (Fisher, 2001). However, our results indicated that these plants took up only enough Fe to satisfy plant growth and be within the normal recommended range for zonal geraniums. Yet, under the same conditions the plants suffered from Mn foliar toxicity due to high concentrations of Mn uptake. These results question if Tango Dark Red is a Fe-efficient cultivar or should it just be classified as a “sensitive” cultivar to increased micronutrient uptake as in the case of Mn.

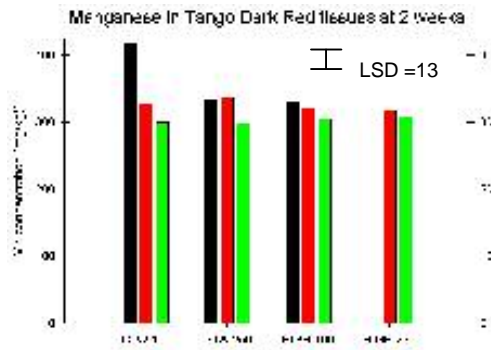


Fig. 40a

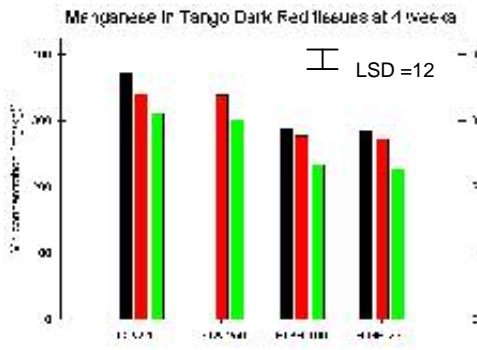


Fig. 40b

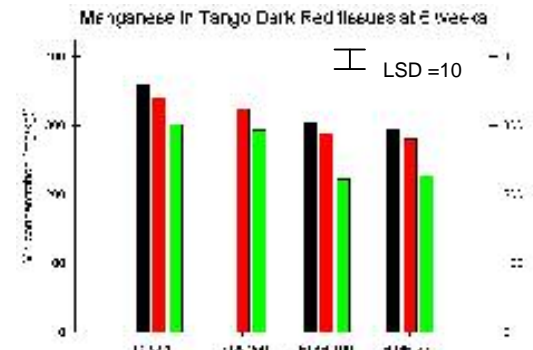


Fig. 40c

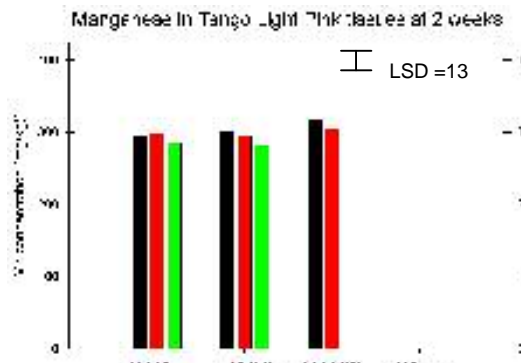


Fig. 40d

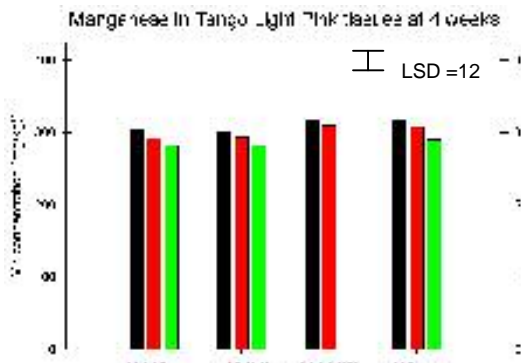


Fig. 40e

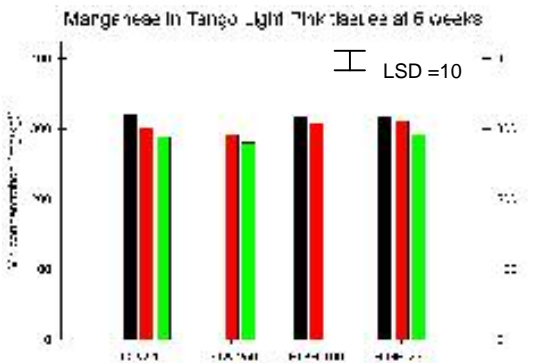


Fig. 40f



Figures 40 a-f: Mean tissue Mn concentration of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Copper

At 2 and 4 weeks, Cu concentration in geranium leaf tissue was significantly affected by the main effects for pH, water alkalinity, cultivar but not nitrogen rate. At 6 weeks, the main effect for pH and cultivar were significant, while the main effects of water alkalinity and nitrogen were not significant (Tables 19-21). The interactions of C X pH, C X W, W X pH and the three-way interaction of these factors were significant at all sampling dates.

For all sampling dates, pH was the major factor affecting Cu uptake in geranium leaves. As the pH was raised from 5.5 to pH 6.8, the mean Cu concentration in the leaves decreased for all treatments (Figures 41 a-f). Cu tissue concentrations treatment means were up to 100% higher at pH 5.5 than pH 6.8 for Tango Dark Red and up to 50% higher for Tango Light Pink. Overall, Tango Dark Red plants had significantly higher Cu concentration in their leaves and most were near the maximum or exceeded the recommended range of Cu concentrations for geraniums (5 – 13 mg kg⁻¹). Plants at pH 5.5 also took up higher amounts of Cu and Mn and were showing signs of micronutrient toxicity such as smaller leaves and interveinal chlorosis. At the 4 week sampling date, plants were not showing signs of micronutrient toxicity at pH 5.5, although tissue concentrations were above the recommended range for zonal geraniums. At pH 6.8, mean Cu concentrations in the leaves of both cultivars were borderline deficient, yet plant foliage did not demonstrate deficiency symptoms such as chlorosis, reddish tones on younger tissues and loss of green color during the experiment.

At the 2 and 4 week sampling dates, water alkalinity treatments increased Cu levels for the Tango Dark Red but not Tango Pink Light. Tango Dark Red plants that did not receive soluble carbonates had much greater concentrations of Cu in the leaves than plants that received 400 ppm soluble carbonates. At the 6 week sampling date, there were minor differences in Cu concentration between water alkalinity treatments for both cultivars. For Tango Light Pink plants grown at a 6.5 pH, increased water alkalinity significantly increased Cu tissue concentrations, which was the opposite of the expected response.

Copper deficiency in geraniums is rare because the Cu requirement is small but it can occur as a result of high pH and high alkalinity in the irrigation water (Biamonte, 1993, Reed, 1996). Because the treatments in my experiment included pH and water alkalinity levels that are considered at the extremes of the recommended ranges, large increases and decreases in copper concentration for both varieties were expected. Tango Light Pink leaf copper concentration plants were sensitive to solution pH, but not water alkalinity levels. Tango Dark Red plants had much higher concentrations of Cu in the plant tissues at the lower pH levels and when the soluble carbonates in the water source were reduced. As the pH and water alkalinity treatments increased plants exhibited symptoms of foliar deficiency. Therefore, it may be argued that Tango Dark Red is sensitive to micronutrient levels under changing conditions of pH and water alkalinity.

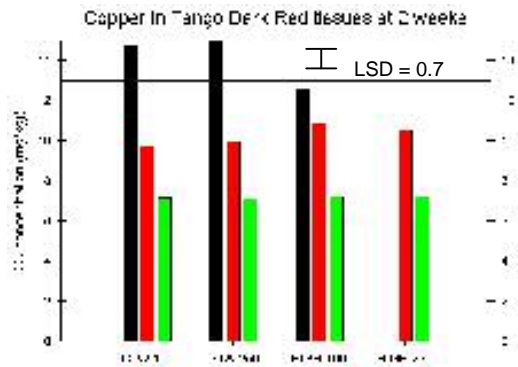


Fig. 41a

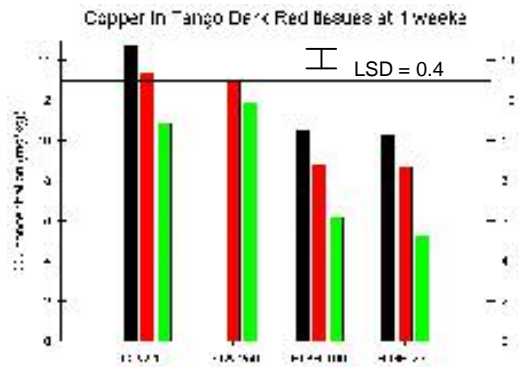


Fig. 41b

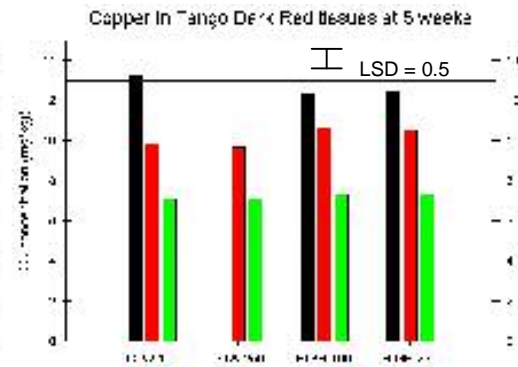


Fig. 41c

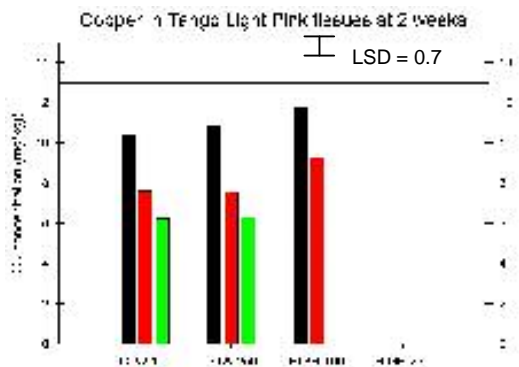


Fig. 41d

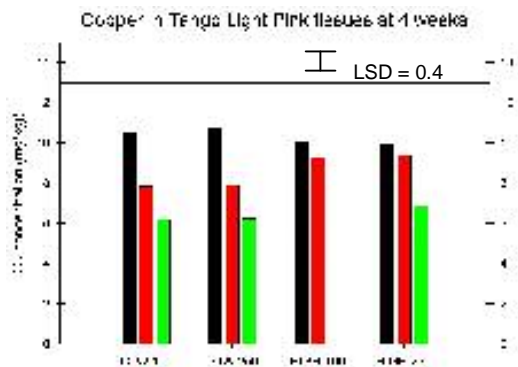


Fig. 41e

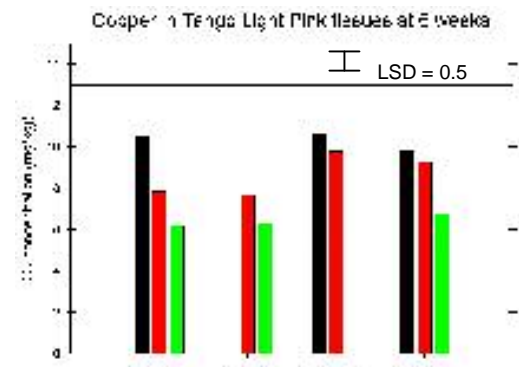
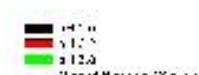
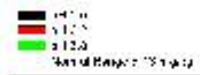


Fig. 41f



Figures 41 a-f: Mean tissue Cu concentration of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

Zinc

At the 2 week sampling date, there were no significant differences in Zn concentration due to any of the treatment factors. At the 4 week sampling date, Zn concentration in geranium leaf tissue was significantly affected by the main effects of pH and cultivar. At the 6 week sampling date, only the main effect of pH was significant. Water alkalinity and nitrogen rate and interactions were not significant at any sampling date (Tables 19-21).

After 2 weeks, pH was the major factor in determining Zn uptake in geranium leaves. As the pH was raised from pH 5.5 to pH 6.8, the Zn concentration in the leaves decreased at all treatment levels (Figures 42 a-f). Both varieties had similar Zn concentration in their leaves at all treatments and sampling dates. The recommended range for Zn concentration in zonal geraniums is 50-55 mg kg⁻¹ and the mean Zn tissue concentrations for most treatments were within this range or borderline deficient. After 4 weeks, plants at pH 5.5 also took up higher amounts of Zn, Cu and Mn and were showing signs of micronutrient toxicity such as smaller leaves and interveinal chlorosis. Most tissues of both cultivars had Zn concentrations in the leaves that were borderline deficient at pH 6.8, yet plant foliage did not exhibit deficiency symptoms at plant harvest.

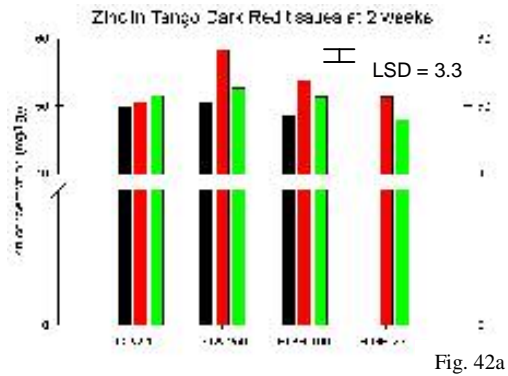


Fig. 42a

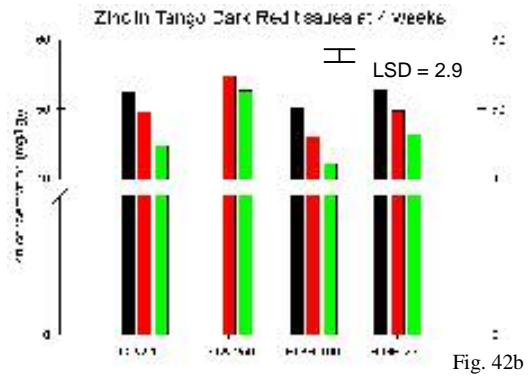


Fig. 42b

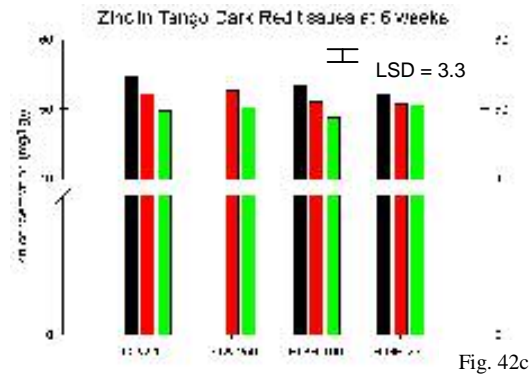


Fig. 42c

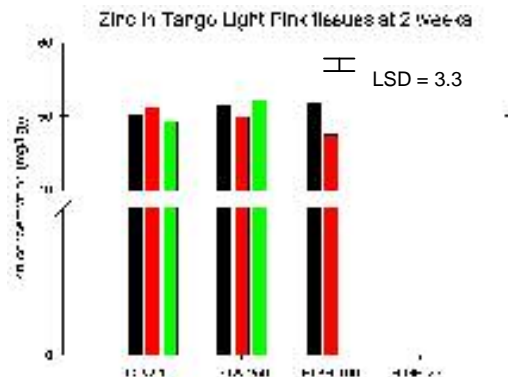


Fig. 42d

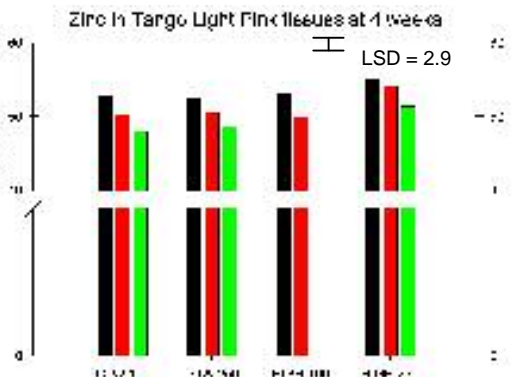


Fig. 42e

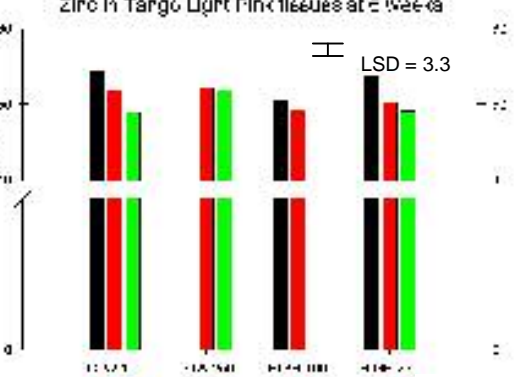
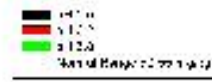
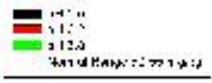


Fig. 42f



Figures 42 a-f: Mean tissue Zn concentration of two ‘Tango’ zonal geraniums grown in solution for 2, 4 and 6 weeks. Bar graph categories are grouped according to pH level, a low (0ppm) and high (400 ppm) water alkalinity and a low (100 ppm) and high (250 ppm) nitrogen rate.

CHAPTER 3: CONCLUSIONS

Water alkalinity, pH and their interactions affected plant growth and nutrient uptake for two cultivars of zonal geraniums with significant differences specific to cultivar and stage of growth. Elemental concentrations in the leaves of the geraniums varied according to the nutrient tested in that macronutrient uptake was most affected by the treatment of N rate, while the secondary and micronutrients were most affected by treatment due to pH. In general, the largest variation in nutrient uptake was observed due to the cultivar grown, where Tango Dark Red plants were larger and exhibited much different uptake patterns when compared to Tango Light Pink plants.

The effects of water alkalinity on nutrient uptake of geraniums varied according to stage of growth and can be addressed by strategic monitoring during the course of the production cycle. Based on significant interactions, generalized statements regarding the affects of water alkalinity and pH on nutrient uptake are not valid and may lead to incorrect nutritional recommendations. Also, supplementation with a pre-formulated total micronutrient package such as STEM™ may fulfill the plant's need of one micronutrient while causing an unwanted extreme concentration for another micronutrient. For extreme water alkalinity levels, it is recommended that each micronutrient be assessed individually and be added on a per need basis taking into consideration cultivar sensitivities and stage of plant growth

This experiment utilized hydroponic nutrient solutions to effectively eliminate any media ionic interactions that could have existed in a container

environment. The nutrient solution supplied a non-limiting nutrient environment and allowed for isolation of the pH and water alkalinity main effects and their interactions with N rate and cultivar. Plants grown in solutions produced significant differences for some nutrients that contradicted the results observed in the previous greenhouse experiment of zonal geraniums grown in two different media types (Chapter 2). The most interesting were the differences were observed in Ca concentrations in the media or solution environment and plant tissue. Plants that were grown in soilless and soil-added media exhibited opposite responses in compared to plants grown in hydroponic solutions as treatment levels of alkalinity increased. Experiments conducted in the greenhouse under standard geranium production conditions would be the most relevant to growers, however basic research of plants grown in solutions can provide the information needed to address the significant three way interaction of M X W X pH and make appropriate fertility recommendations.

Future experiments should be conducted to include cultivars of the zonal, ivy and regal commercial geranium classes to determine if these results can be used more broadly. In addition, it is imperative to disseminate this information to the grower so that she can easily and effectively use the information on nutrient uptake to manage the fertility of the specific cultivar grown.

OVERALL CONCLUSIONS

Three experiments were designed to test the effects of media pH and alkalinity on geranium growth and nutrient uptake of geraniums. It was found that zonal and ivy geraniums undergo a reduction of media pH at a specific time in the plant's growth cycle. The pH response is specific to class and cultivar and recommendations for an optimum pH range should be re-evaluated to incorporate stage of growth and cultivar.

Medium water alkalinity level (70 ppm) is the optimum level of soluble carbonates for geranium growth. However, plants can be grown over a large range of alkalinity with proper container monitoring and management.

Media type affects plant yield and nutrient uptake in that adding a soil component to a standard soilless media buffers nutrient availability and could prevent micronutrient imbalances that lead to foliar damage and plant loss.

W x M x pH interactions were significant. The effects of pH and water alkalinity on nutrient uptake in geraniums is specific to cultivar, stage of growth and nutrient tested and fertility recommendations must account for media composition.

Based on these findings it is recommended that the geranium be considered as a major factor in determining appropriate status of nutrients in the media and plant tissue. Optimal pH, water alkalinity and nutrient ranges should be cultivar specific in order to customize fertilizer levels based on nutrient needs at specific stages of geranium growth. Current nutrient management issues call for the

implementation of fertility guidelines that address pH, water alkalinity and nutrient use to promote efficient growth and reduce over fertilization and nutrient loss therefore this data would be useful to address those concerns for geranium greenhouse production.

Through the course of these three experiments, I was unable to replicate the symptoms of the “leaf cupping” effect as described in previous sections. It was thought that by reproducing conditions that naturally existed in greenhouses with plants that were cupped I would be able to design an experiment with specific factors that could cause the symptoms. This was in an attempt to isolate the specific causal factors of the symptoms and suggest an explanation of why and how this occurs in geraniums. Even though I was not successful producing leaf cupping, the data resulting from these experiments brought about useful information on pH and water alkalinity interactions in a media and nutrient solution environment for geraniums. In addition, these experiments identified flaws in the recommended ranges for nutrient concentrations in the media and plant tissue. It would be beneficial to reevaluate optimum nutrient concentrations for all cultivars of geraniums in experiments designed to test deficiency and toxicity limits according to the geranium class.

REFERENCES

Albano, J. P. and W. B. Miller (1996). "Iron Toxicity Stress Causes Bronze Speckle, a specific Physiological Disorder of Marigold (*Tagetes erecta* L.)." *Journal of American Society of Horticultural Science* 121(3): 430-437.

Albano, J. P. and W. B. Miller (1998). "Marigold Cultivars vary in Susceptibility to Iron Toxicity." *Hort Science* 33(7): 1180-1182.

Argo, W. R. and J. Biernbaum (1996). "The Effect of Lime, Irrigation-water Source, and Water Soluble Fertilizer on Root-zone pH, Electrical Conductivity, and Macronutrient Management of Container Root media with *Impatiens*." *Journal of American Society of Horticultural Science* 121(3): 442-452.

Argo, W. R. and J. Biernbaum (1997). "Lime, Water Source and Fertilizer Nitrogen form Affect Medium pH and Nitrogen Accumulation and Uptake." *Hort Science* 32(1): 71-74.

Argo, W. R. and J. Biernbaum (1997). "The Effect of Root Media on Root Zone pH, Calcium and Magnesium Management in Containers with *Impatiens*." *Journal of American Society of Horticultural Science* 122(2): 275-284.

Argo, W. R. and P. R. Fisher (2003a). *Understanding Water Quality: Part 1- Water pH, Alkalinity and Control of Media pH*. Columbus, OH, OFA Ohio Florist Association: May/June: 11-14.

Argo, W. R. and P. R. Fisher (2003b). *Understanding Water Quality: Part 2*. Columbus, OH, Ohio Florist Association Bulletin: July/ August: 3-7.

Baas, R., A. Brandts, et al. (1995). "Growth regulation of bedding plants and poinsettia using low phosphorus fertilization and ebb-and- flow irrigation." *Acta Horticulturae* 378: 129-137.

Bachman, G. R. and W. B. Miller (1995). "Iron Chelate Inducible Iron/Manganese Toxicity in Zonal Geranium." *Journal of Plant Nutrition* 18(9): 1917-1929.

Beche, B., R. Nelson, et al. (1999). "Consumer preferences for Geranium Flower color, Leaf variegation and Price." *Hort Science* 34(4): 740-742.

Bethke, C. L. (1993). *Growing Media. Geraniums IV*. J. W. White. Batavia, IL, Ball Publishing: 3-24.

- Biamonte, R. (1990). The effect of fertilizer on iron toxicity symptoms in 'Red Elite' geraniums. Folgersville, PA, W.R. Grace Co.: 1-18.
- Biamonte, R. (1993). Fertilizer. Geraniums 4th Ed. E. J. Holcomb and J. W. White. Geneva, IL, Ball Publishing: 39-54.
- Biernbaum, J. (1992). "Root-zone Management of Greenhouse Container-grown Crops to Control Water and Fertilizer Use." Hort Technology Jan./Mar.(2(1)): 127-131.
- Biernbaum, J. and W. Fonteno (1989). Minimize groundwater contamination. Greenhouse Grower. 7: 90-92, 94-95.
- Bloom, P. R. (2000). Soil pH and pH buffering. Handbook of Soil Science. M. E. Sumner. New York, NY, CRC Press: B333-B351.
- Clarkson, D. T. (1996). Root Structure and the Sites of Ion Uptake. Plant Roots: The Hidden Half. Y. Waisel, A. Eshel and U. Kafkafi. New York, Marcek Dekker, Inc.: 483-506.
- Cunningham, W. A., M. H. Jensen, et al. (1986). The effects of wavelength selective film on greenhouse energy and plant growth. 19th national agricultural plastics congress, Peoria, Illinois.
- Decoteau, D. R. and D. D. Daniels (1986). Colored plastic mulches and tomato morphogenesis. 19th National Agricultural Plastic Congress, Peoria, Illinois.
- Durand, R. and N. Bellon (1994). "The influence of the growth media and mineral nutrition on corn root hydrogen / bicarbonate releases and rhizosphere pH." Plant Nutrition 17(5): 817-838.
- Ehret, D., B. Zebarth, et al. (1998). "Clay additions to soilless media promotes growth and yield of greenhouse crops." Hort Science 33(1): 67-70.
- Evans, M. and R. Harkess (1997). "Growth of *Pelargonium hortorum* and *Euphorbia pulcherrima* in rubber containing substrates." Hort Science 32(5): 874-877.
- Fischer_Inc. (2003). Propagation and nutritional recommendations for new cultivars of zonal geraniums. Boulder, CO.: 1-13.
- Fisher, P. R. and W. R. Argo (2001). "Iron-Out": A Nutritional Program for Geraniums and Other Crops Prone to Iron and Manganese Toxicity at Low Media pH. Columbus, OH, FIRST: Floriculture Industry Research and Scholarship Trust: 1-24.

- Fisher, P. R., W. R. Argo, et al. (2001). Understanding Media-pH Management. *Greenhouse Grower*. April: 50-56.
- Fonteno, W. (1992). Geraniums. *Introduction to Floriculture*. R. Larson. Philadelphia, Academic Press, Inc.: 452-455.
- Fonteno, W. and R. Adams (2003). Media. *Ball Redbook- Crop Production*. D. Hamrick. Batavia, IL, Ball Publishing. 2: 19-27.
- Godo, G. H. and H. M. Reisenauer (1980). "Plant effects on Soil Manganese Availability." *Soil Science Society of America Journal* 44: 993-995.
- Greig, D. (1991). *Scented Geraniums and Pelargoniums*. Batvia, IL, Kangaroo Press.
- Hageman, R. H. and E. L. Hartman (1941). "Injuries produced by saline and alkaline water on greenhouse plants and the alleviation of alkaline injury by neutralization." *American Society of Horticultural Sciences* 39: 375-380.
- Handreck, K. (1994). "Pour-through extracts of potting media: Anomalous results for pH." *Communication in Soil Science and Plant Analysis* 25(11,12): 2081-2088.
- Heally, W. (2001). *Cultural recommendations for new Zonals of 2001*. Chicago, IL, Ball Seed Company: 1-22.
- Helling, C. S., G. Chesters, et al. (1964). "Contribution of organic matter and clay to soil CEC as affected by the pH of the saturating solution." *Soil Science Society of America Journal* 28: 517-520.
- Holcomb, E. J. and J. Mastalerz, Eds. (1982). *Geraniums: a manual on the culture of geraniums as a greenhouse crop*, Pennsylvania Flower Growers.
- Hummel, R. L., S. Kuo, et al. (2000). "Fishwaste compost medium improves growth and quality of container-grown marigolds and geraniums without leaching." *Journal of Environmental Hort.* 18(2): 93-98.
- Jones, J. B. (1999). Advantages gained by controlling root growth in a new hydroponic growing system. *International Symposium of Growing Media and Hydroponics*, Windsor, Ontario, Canada, Acta Horticulture ISHS.
- Kramer, L. L. and J. C. Peterson (1990). "Influences of Water pH, Alkalinity and acid additions on growth and nutrient relationships in *Crysanthemum Moriforolium* 'Bright Golden Anne'." *Plant Nutrition* 13(2): 169-186.

- Ku, C. S. M. and D. R. Hershey (1992). "Leachate Electrical Conductivity and Growth of Potted Geranium with Leaching Fractions of 0 to 0.4." *Journal of American Society of Horticultural Science* 117(6): 893-897.
- Kuehny, J. S. and B. Morales (1998). "Effects of Salinity and Alkalinity on Pansy and Impatiens in three different growing media." *Journal of Plant Nutrition* 21(5): 1011-1023.
- Laboratory, U. S. S. (1954). pH reading of saturated paste extracts. Washington, DC, U. S. Government Printing Office.
- Lang, H. (2002). Nutritional imbalances under low alkalinity water conditions for certain cultivars of geraniums. (personal communication). C. Peters. Ohio Short Course; Columbus, Ohio.
- Lindsay, W. L. (1974). Role of chelation in micronutrient availability. *The Plant Root and its Environment*. E. W. Carson. Charlottesville, VA, Univ Press of VA.
- Lucas, R. E., P. E. Rieke, et al. (1982). Lime and Fertilizer Requirements for Peats. *Peat in Horticulture*. D. W. R. a. J. G. D. Lamb. London, Academic Publications.
- Marschner, H. (1996). Mineral nutrition of higher plants. Univ of Hohenheim; Germany, Academic Press.
- Mengel, K. and E. A. Kirkby (1979). Principles of Plant Nutrition. Worblaufen-Bern, Switzerland, International Potash Institute.
- Mikesell, J. E. (1992). "Influence of Calcium on Vegetative and Reproductive Development of Pelargonium." *Journal of Plant Nutrition* 15 (8): 1323-1341.
- Nassour, M., G. Chasseriaux, et al. (2003). "Optimization of protoplast-to-plant system for Pelargonium x hutorum 'Alain' and genetic stability of the regenerated plants." *Plant Science* 00: 1-8.
- Nelson, P. V. (1991). *Greenhouse Operation and Management*. Englewood Cliffs, NJ.
- Nelson, P. V. (1996). Macronutrient Fertilizer programs. *Water, Media and Nutrition*. D. W. Reed. Batavia, IL, Ball Publishing: 141-170.
- Nelson, P. V. and J.-S. Huang (2003). Plant influences on root substrate pH. *Ohio Florists Association Bulletin*. March/ April 2003: 10-13.

- Newman, S. and M. Follett (1989). "Comparison of the effects of Super-start to a standard soluble fertilizer on geraniums." Mississippi Agricultural and forestry experiment station 14(2).
- Nye, P. H. (1979). "Changes of pH across the rhizosphere induced by the roots." Journal of Soil Science 30: 43-51.
- Peters, R. B. and J. R. Peters (1990). Soluble Trace Element Mix. U.S. Patent. United States: 1-15.
- Rao, T. P., K. Yano, et al. (2000). "A Simple Method for Quantitative Estimation of Rhizosphere pH along Root Axes through Visualization." Plant Production Science 3(2): 94-100.
- Reed, D. W. (1996). Micronutrient Nutrition. Water, Media and Nutrition for Greenhouse Crops. D. W. Reed. Batavia, IL, Ball Publishing: 171-195.
- Rhoades, J. D. (1982). Soluble salts. Methods of soil analysis: Part 2: Chemical and microbiological properties. A. L. Page. Madison, WI, ASA Monograph number 9: 167-179.
- Ribeiro, H. M., E. Vasconcelos, et al. (2000). "Fertilization of potted geranium with a municipal solid waste compost." Bioresource Technology 73: 247-249.
- Ruiz, L. and J. C. Arvieu (1990). Measurement of pH Gradients in the Rhizosphere. Symbiosis. INRA. Philadelphia, Balaban Publishers. 9: 71-75.
- Sheely, J. (1990). Iron Toxicity in Zonal Geraniums. Greenhouse Grower. January: 20-22.
- Sheldrake, R. (1980). Lime source and quantity study on peat and vermiculite. Benchmarks. 1(7): 6-7.
- Sonneveld, C., W. Voogt, et al. (1999). A Universal Algorithm for Calculation of Nutrient Solutions. Int. Symposium on Growing Media and Hydroponics, Windsor, Ontario, Canada, Acta Horticulturae.
- Tayama, H. K. and T. J. Roll, Eds. (1989). Growing Bedding Plants, Ohio Cooperative Extension Service; Ohio State University.
- Taylor, J. (1989). Geraniums and Pelargoniums: The Complete Guide to Cultivation, Propagation and Exhibition. Philadelphia, PA, Crowood Press.

- USDA and NASS (2001). Floriculture Crop Annual Summary, National Agricultural Statistic Service, Agricultural Statistic Board.
- Van Iersel, M. (1999). "Fertilizer concentration affects growth and nutrient composition of subirrigated pansies." *Hort Science* 34(4): 660-663.
- Vetanovetz, R. P. (1996). Tissue Analysis and Interpretation. Water, Media and Nutrition for Greenhouse Crops. D. W. Reed. Batavia, IL, Ball Publishing: 197-219.
- Wadleigh, C. H. and J. W. Brown (1952). "The chemical status of bean plants afflicted with bicarbonate induced chlorosis." *Botanical Gazette* 113: 373-392.
- Whipker, B. E. (1998). Fertility Management for Geraniums. Leaflet 504, NC State University Dept of Horticultural Sciences.
- Whipker, B. E., D. A. Bailey, et al. (1996). "A novel approach to calculate acid additions for alkalinity control in greenhouse irrigation water." *Communication in Soil Science and Plant Analysis* 27((5-8)): 959-976.
- Whipker, B. E., T. J. Cavins, et al. (2003). Plant Nutrition. Ball Redbook- Crop production. D. Hamrick. Batavia, IL, Ball Publishing. 2: 29-38.
- Whipker, B. E. and P. A. Hammer (1994). "Determination of Injurious Phosphorus Levels in Poinsettias." *Hort Science* 29((2)): 85-87.
- Whipker, B. E. and P. A. Hammer (1997). "Nutrient Uptake in Poinsettia during difference stages of physiological development." *Journal of American Society of Horticultural Science* 122(4): 565-573.
- White, J. W., Ed. (1993). Geraniums iV. Batavia, Illinois, Ball Publishing.
- Wright, R. (1986). "The Pour-through Nutrient Extraction Procedure." *Hort Science* 21(2): 227-229.
- Xu, J. M., R. W. Wang, et al. (2001). "Soil Boron Fractions and Their relationship to Soil Properties." *Soil Science Society of America Journal* 65:: 133-138.