THESIS

THE EFFECTS OF ROOT-ZONE TEMPERATURE AND LIMESTONE ON ROOT-ZONE MEDIUM PH AND ELECTRICAL CONDUCTIVITY ON NEW GUINEA IMPATIENS 'CELEBRATION ORANGE'

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ABSTRACT

THE EFFECTS OF ROOT-ZONE TEMPERATURE AND LIMESTONE ON ROOT-ZONE MEDIUM PH AND ELECTRICAL CONDUCTIVITY ON NEW GUINEA IMPATIENS 'CELEBRATION ORANGE'

The purpose of this experiment was to examine the effects of various media temperatures and pH on nutrient availability for New Guinea impatiens (*Impatiens x hawkeri* Bull.). It is important for greenhouse growers to be cognizant of the root-zone medium pH, as New Guinea impatiens are sensitive to nutrient toxicities at low pH. It is thought that limestone at low root-zone medium temperatures is not quickly activated leading to these toxicities. The objectives of this project were to determine: The effect of root-zone medium pH on foliar symptoms of iron and manganese toxicity; and the effect rates and grind size of limestone have on root-zone medium pH. Various rates of limestone and different grind sizes were incorporated into a sphagnum peat moss-based medium at set temperatures. This experiment used a two-way thermogradient plate to maintain nine varying, but stable root-zone medium temperatures. Plant growth as well as root-zone medium pH was monitored. Changes in root-zone medium pH were monitored over time. The goal of this research was to provide New Guinea impatiens growers with information on root-zone media interactions so as to produce a more saleable product with lower energy input.

A few of the 'Celebration Orange' New Guinea impatiens grown for the studies expressed foliar symptoms of marginal chlorosis, but not at the level that was expected. Without any limestone added to the root-zone medium the pH was too low. At the 3 kg/m^3 rate of limestone incorporation the pH ranged from 6.2 to 7.15 over all the root-zone medium

temperatures. The 6 kg/m^3 incorporation rate was too high; the lowest pH was 6.73, which is above the desired pH range.

The smallest calcitic limestone grind sizes of 45 and 75-150 μm grind size did raise the pH faster than the 250-1,200 μm grind size. Both the 45 μm and the 75-150 μm grind sizes of limestone incorporated preplant at the rate of 3 kg/m^3 did have some root-zone medium pH readings that fell within the target pH range.

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Chapter 1: Introduction

Floriculture crops are commonly grown in soilless medium because it is uniform, easy to reproduce, has a high level of total pore space and a low bulk density, which reduces shipping and handling costs of the medium and the finished product (Dole and Wilkins, 1999). Most root-zone media are sphagnum peat moss based and acidic; therefore, limestone is added to raise the pH (Argo and Fisher, 2002; Fisher and Argo, 2001b). Monitoring the pH of crops grown in a soilless root-zone medium is important because a soilless medium does not have the buffering capacity of soil-based root-zone medium (Argo and Fisher, 2002; Fisher and Argo, 2001b). Without this buffering capacity, rapid changes, up to 1 pH unit per week, may occur in a sphagnum peat based root-zone medium (Argo and Fisher, 2002; Fisher and Argo, 2001b).

Root-zone medium temperature affects the uptake of nutrients and water by plant roots and as a result, plant quality and yield (McMichael and Burke, 2002). Medium temperature is an important factor in nutrient movement and absorption by plant roots, root development, medium water holding capacity and the speed at which chemical reactions occur in the medium (Pregitzer and King, 2005). The number of roots and the period of root growth as well as the structure and arrangement of the roots can all be influenced by medium temperature (Pregitzer and King, 2005).

Medium pH is another important factor affecting micronutrient solubility and availability for plant uptake (Biernbaum and Argo, 1995). The most important nutrients affected by medium pH are phosphorus, iron, manganese, copper, zinc and boron (Argo and Fisher, 2002; Fisher and Argo, 2001b). Iron and manganese are very soluble at low medium pH increasing root uptake and excessive levels can accumulate in plant tissue and cause damage (Argo and Fisher, 2002; Bishko, Fisher and Argo, 2002; Fisher and Argo, 2001a, 2001b).

The production and sales of New Guinea impatiens (*Impatiens x hawkeri* Bull.) by the U.S. floriculture industry has continued to rise as the plant increases in popularity (Bailey, 1999). New Guinea impatiens are used not only as bedding plants, but grown as hanging baskets and potted plant crops as well (Bailey, 1999). According to the United States Department of Agriculture Floriculture Summary, published May 31, 2012, a total of 16.1 million units of New Guinea Impatiens baskets, pots and flats were sold. Current sales comprise 3.58% of the total 1.33 billion dollars in bedding plant sales (USDA, 2012). New Guinea impatiens have quickly become an economically important floriculture crop across the globe (Dole and Wilkins, 1999).

It is important to evaluate problems that arise due to low medium pH, especially nutrient toxicities that are irreversible and can render a crop unmarketable. Working to prevent nutrient toxicity problems that affect the quality of New Guinea impatiens will help growers produce a better product and therefore receive a premium price.

Objectives and Hypotheses:

The objectives of this study were to determine:

1) The effect of root-zone medium pH on foliar symptoms of iron and manganese toxicity; and
2) The effect different rates and grind sizes of calcitic limestone have on root-zone medium pH.

The hypotheses included:

1) A smaller limestone grind size will raise the pH faster;
2) Higher root-zone medium temperatures at a medium rate of limestone application will provide the best plant growth; and

3) Warmer root-zone medium temperatures will allow for faster activation of limestone, keeping pH constant and preventing iron toxicity.

Chapter 2: Literature Review

New Guinea impatiens were introduced into the United States in 1972 and have experienced a uniform growth in popularity ever since (Bailey, 1999). Hybridization of the species has resulted in a wide range of flower color and variegated foliage options in present day cultivars (Bailey, 1999). New Guinea impatiens have become a mixed-use crop and are produced as bedding plants, potted plants and hanging baskets (Bailey, 1999).

The best plant growth results when New Guinea impatiens are grown at a constant 25° to 27°C (Erwin, 1995). Excessively high day or night temperatures, above 27°C, reduce growth rate and plant quality (Erwin, 1995) and create a higher demand for water (USDA, 1992). The growth rate of New Guinea impatiens at temperatures below 17°C is severely decreased, especially in young plants and flowering is delayed 10 to 14 days (Erwin, 1995). The internode length of New Guinea impatiens is affected by the average daily temperature and the difference between the day and night temperatures (Erwin, 1995). As the difference between the day and night temperatures increases so does the internode length (Erwin, 1995; USDA, 1992). Keeping the day and night temperatures close together or maintaining a cooler day temperature than night temperature will greatly reduce stem elongation and produce a more compact plant (Erwin, 1995; USDA, 1992).

To produce high quality New Guinea impatiens, grow them under bright light levels, 32.3-48.4 klux in the greenhouse (Erwin, 1995; USDA, 1992). Light levels below 32.3 klux usually produce plants with long internodes and poor flowering (Erwin, 1995 and USDA, 1992). Shade needs to be provided if the light levels exceed 53.8 klux or reduced growth and flower expansion may occur (Erwin, 1995). Photoperiod does not trigger flowering of New Guinea impatiens, however, bright light and long days encourage more flowering because flowering increases as the overall amount of light the plant is subjected to in a 24-hour period increases

(Erwin, 1995). Higher light levels lead to a greater amount of total daily carbohydrates produced during photosynthesis which increases flowering (Erwin, 1995).

It is best to irrigate New Guinea impatiens with clear water the first two weeks after planting (Bailey, 1999). Allowing the root-zone medium to dry down between irrigation intervals encourages root development; however, a grower should not allow plants to become severely wilted and avoid overwatering (Bailey, 1999). The water requirements of the plant will increase as it becomes more established (USDA, 1992). For the success of the crop it is important to find the correct balance of providing just enough moisture to new transplants and meeting the water needs of the mature plants (Hartley, 1995).

The ideal root-zone medium for growing New Guinea impatiens provides both good aeration and water-holding capacity (USDA, 1992). Root-zone medium containing about 50% sphagnum peat moss will fulfill the above requirements (USDA, 1992). To increase the root-zone medium pH of a sphagnum peat moss based growing medium to a level more acceptable for growth limestone is added (Argo and Biernbaum, 1996a, 1996b) during mixing to achieve a target pH range of 5.5-6.5 range after wetting (Elliott, 1994). Due to New Guinea impatiens sensitivity to salt injury, the rooted cuttings should be planted in a root-zone medium that does not contain a large nutrient charge and has a pH range of 5.8-6.2 for best nutrient uptake (Bailey, 1999). Hartley (1995) advises a pH range of 5.8 to 6.5 for growing New Guinea impatiens in soilless medium.

Water sources and fertilizer rates vary greatly between production locations and influence the pH attained; therefore, the grower must check the root-zone medium pH regularly and make the necessary adjustments (Elliott, 1994). Healy (1995) echoes the statement made by Elliott that

the type, grind size and amount of limestone added to the root-zone medium are dependent upon a production facility's water quality and the amount and formulation of fertilizer used.

The three main factors that influence how much limestone should be added to the root-zone medium to achieve the desired pH range are: limestone type, particle size and hardness of the limestone (Argo and Fisher, 2002). The pH at equilibrium is influenced by both particle size and incorporation rate of the limestone (Argo and Biernbaum, 1996a, 1996b, 1996c).

The most common types of limestone used in greenhouse production are calcitic (calcium carbonate) and dolomitic (calcium and magnesium carbonate) (Argo and Fisher, 2002). Dividing an identical batch of root-zone medium in half and adding the same rate of calcitic and dolomitic limestone to each half usually results in a higher pH of the half that the calcitic limestone was added due to the higher reactivity of calcitic limestone (Argo and Fisher, 2002). When choosing which type of limestone to add to the root-zone medium it is important to consider the affect pH has on nutrient solubility and availability as it may take up to two weeks for the root-zone medium, which has just had limestone added, to reach a stable pH (Argo and Biernbaum, 1996a).

The size of a limestone particle affects its reactivity; a limestone comprised of fine particles will react chemically faster than a limestone made of mostly coarse particles (Argo and Fisher, 2002). The smaller a limestone particle is, the greater its initial buffering capacity (Healy, 1995). A bag of limestone is labeled with the percentage of particle sizes that pass through different sized mesh screens (Argo and Fisher, 2002). The larger the screen size number, the smaller the particle, for example when 95% of the particles pass through the 45 μm mesh screen the limestone is considered to be microfine versus the superfine limestone where 60% of the particles pass through a 75 μm mesh screen (Argo and Fisher, 2002).

The hardness of the limestone is a crucial factor when deciding how much limestone to add to a root-zone medium (Argo and Fisher, 2002). Every limestone source is different, a fine limestone particle may be very hard and react very slowly, while a large coarse particle may be soft and react very quickly (Argo and Fisher, 2002).

Five to ten days after planting a grower can expect that the pH has stabilized, but only a portion of the limestone has reacted in the medium (Argo and Fisher, 2002). The reactive fraction as its name suggests reacts first and the remaining portion is the residual limestone (Argo and Fisher, 2002). The long-term buffering capacity of a root-zone medium is influenced by the amount of residual limestone it contains (Argo and Fisher, 2002).

When growing New Guinea impatiens, it is time to begin a fertilizer program when new roots reach the side of the pot (Bailey, 1999). Maintaining low fertility levels with young plants will provide the best results (USDA, 1992). High nutrient levels or high soluble salts in the growing medium will harm New Guinea impatiens (Hartley, 1995). Young plants may become stunted, weak and will not develop healthy roots (Hartley, 1995). Expanding leaves of a mature plant may develop a ripple like surface (USDA, 1992) and cupped leaf margins if the plant is fertilized excessively (Hartley, 1995). Under fertilizing New Guinea impatiens will result in small, chlorotic leaves, small flowers and an overall small plant (Hartley, 1995; USDA, 1992). A constant liquid feed program of 150 ppm nitrogen (USDA, 1992) or 100-200 ppm nitrogen with a complete NPK fertilizer when plants are young is recommended (Hartley, 1995). As plants mature, constant liquid feed rates can be raised to 200 or 250 ppm nitrogen (Hartley, 1995; USDA, 1992).

Root-zone temperature greatly affects all root functions (Miller, 1986). Temperature controls seed germination, seedling emergence and root temperature. Plant growth is affected

indirectly because root-zone medium temperature regulates which nutrients are most available (Miller, 1986). Temperate plant species vary greatly in their response to root-zone temperature; however, as an overall model as the root-zone temperature increases from 5°C to 25°C so does root growth, but once root-zone temperatures go above 25°C root growth quickly decreases (Miller, 1986.)

The temperature of the root-zone medium affects a plant's ability to grow and develop roots and to take up nutrients and move them from one part of the plant to another (Cooper, 1973). Results from a study conducted on the tomato hybrid, (*Lycopersicon esculentum* 'Big Boy') showed that temperature did not significantly affect the uptake of iron by the tomato (Tindall et al., 1990). Maintaining a root-zone temperature around 25°C was determined to be the most favorable for uptake of the majority of macro and micronutrients and ideal for root and shoot growth of the Big Boy tomato (Tindall et al., 1990). It was postulated that temperatures below 20°C and above 30°C were too cold or hot, respectively and would impair root growth, which in turn would negatively impact the plant's ability to take up nutrients and water (Tindall et al., 1990).

In contrast, Hood and Mills (1994) found that as the root-zone temperature increased, the amount of boron, iron, manganese and zinc taken up by the roots of the cut flower snapdragon cultivar, (*Antirrhinum majus* L. 'Peoria') increased significantly and in quadratic form. They concluded that 23.9°C provided the optimum root-zone temperature for the uptake of iron by the snapdragon (Hood and Mills, 1994). Their experiment demonstrated that root-zone temperature can have quadratic effect on the leaf, stem and root dry weights and shoot length of snapdragons, the peak dry weights and tallest stems occurred at a root-zone temperature average of 22°C

(Hood and Mills, 1994). Usually the root-zone temperature has a greater effect on the nutrient uptake of a plant species rather than on overall plant growth (Cooper, 1973).

In container grown crops the root-zone medium pH largely influences micronutrient solubility and plant uptake availability (Biernbaum and Argo, 1995; Wik et al., 2006). The root-zone medium pH of approximately 12,000 floriculture medium samples was analyzed and more than 95% of the medium-pH measurements fell in the pH range of 4.5 to 8.5 (Argo and Fisher, 2002). Producing plants in soilless medium generates a smaller pH range than is found in a chemical solution with the ideal growing medium pH range of 5.8 to 6.2 (Argo and Fisher, 2002). This pH range for soilless growing medium allows for micronutrient solubility to meet the plants' nutritional needs without releasing excess nutrient amounts that could result in micronutrient levels toxic to the plants (Argo and Fisher, 2002; Fisher and Argo, 2001b).

The significance of the root-zone medium pH, or concentration of hydrogen ions, is due to its effect on the growth of plant roots and soil microorganisms (Taiz and Zeiger, 2006). The pH scale is used to measure how acidic or basic a solution is and is calculated by taking the negative logarithm of the hydrogen ion concentration, in moles (Argo and Fisher, 2002). The log based scale, ranges from 0 to 14, with 7 as the neutral pH and a pH less than 7, acidic and higher than 7 basic. At a neutral pH of 7 the concentration of hydrogen ions is 10^{-7} molar. Decrease the pH to 6 and the concentration of hydrogen ions is 10^{-6} molar which is ten times the amount of hydrogen ions that were in solution at a pH of 7 (Argo and Fisher, 2002). The higher the concentration of acidic hydrogen cations (H^+); the lower the pH and the more acidic the solution, as the pH increases the more basic the solution is and the higher the concentration of basic hydroxide anions (OH^-) (Argo and Fisher, 2002). Both the hydrogen cations and hydroxide

anions are always present in a solution so pH measures the balance between them (Argo and Fisher, 2002).

Cation Exchange Capacity (CEC) measures the cations (positively charged ions) in the growing root-zone medium and is reliant upon the ingredients used to make the medium (Healy, 1995). Peat moss, vermiculite and bark are negatively charged, which draws the positively charged ions to them (Dole and Wilkins, 1999), while perlite and sand have a low CEC (Healy, 1995). The higher the CEC, the greater the number of nutrient ions the root-zone medium retains (Dole and Wilkins, 1999). The overall CEC of a growing medium is altered when the ratio between high and low CEC ingredients in the root-zone medium changes (Healy, 1995). It is important that a growing medium contain the right balance of nutrients as well as a have a CEC favorable for plant growth or the grower may face problems with the plants showing nutrient toxicity or deficiency symptoms (Healy, 1995).

Root-zone medium pH affects the CEC of the root-zone medium (Healy, 1995). If the pH drops the amount of hydrogen ions in the soil solution increases which in turn causes more hydrogen ions attach to the exchange sites, decreasing the number of other essential nutrients available in the soil solution (Healy, 1995). This switch of available nutrients occurs in the growing root-zone medium even if the CEC remains the same (Healy, 1995).

Electrical conductivity (EC) measures the level of soluble salts or ions dissolved in the water held by the root-zone medium (Whipker and Cavins, 2000). It is important that growers apply the right amount of fertilizer to a crop to meet its nutritional needs, if the EC increases over the course of growing then the plants are not taking up the available salts, but if the EC is declining, then the plants are taking up more nutrients than are being applied (Healy, 1995).

Nutrients must be dissolved in the root-zone solution to be available for absorption by plant roots (Argo and Fisher, 2002; Fisher and Argo, 2001b). The solubility of the nutrients is affected by root-zone medium pH; the most important being phosphorus and several micronutrients (Argo and Fisher, 2002; Fisher and Argo, 2001b). At a high root-zone medium pH iron and phosphorus will undergo independent reactions into solid forms (Argo and Fisher, 2002). Plant growth is affected by nutrient deficiencies that occur when the growing medium pH is too high, the solubility of the following micronutrients: boron, copper, iron, manganese and zinc decreases at high pH resulting in insufficient micronutrients being available to the plant (Wik et al., 2006). On the other hand, toxicity can occur if the pH of the growing medium is too low and solubility of the micronutrients increases (Argo and Fisher, 2002; Wik et al., 2006). Damage to the crop can occur when the micronutrients accumulate in plant tissue at levels beyond the norm, (Bishko and Fisher, 2002) on average dry plant tissue should contain 50-250 ppm of iron (Jones and Jacobsen, 2005).

Plants require iron to produce chlorophyll and for proper enzyme function (Fisher and Argo, 2001b; Hochmuth, 2011; Jones and Jacobsen, 2005; Marschner, 1995); however when the root-zone medium pH is less than 5.8, New Guinea impatiens are capable of absorbing abnormally high levels of micronutrients, specifically iron and manganese (Hartley, 1995).

The following components affect how iron is taken up and moved throughout the plant: root-zone medium pH, nutrient interactions, temperature and light, iron-efficiency reactions (Albano and Miller, 1998) and fertilizer application (Argo and Fisher, 2002). High root-zone medium pH limits the availability of iron in the soil solution, a plant can be categorized as iron-efficient or iron-inefficient dependent on its ability to take up iron even when availability is low (Wik et al., 2006).

The “Geranium Group” contains plants that are prone to iron and manganese toxicity at low medium pH (Argo and Fisher, 2002; Fisher and Argo, 2001b). The following plants: seed and zonal geraniums, marigolds, lisianthus and New Guinea impatiens, are very efficient at taking up iron and therefore more susceptible to iron and manganese toxicity at low growing root-zone medium pH (Fisher and Argo, 2001b). Problems with iron and manganese toxicity arise when species from the Geranium Group are grown at low medium pH (Argo and Fisher, 2002). There is an inverse relationship between the growing root-zone medium pH and the amount of available iron and manganese, as the pH decreases the solubility of iron and manganese increases so there are higher levels of the micronutrients in the medium solution (Argo and Fisher, 2002). Low root-zone medium pH combined with iron-efficient plant species and increased levels of available iron and manganese causes an oversupply of these metals in the plant leaves (Albano, Miller and Halbrooks, 1996; Argo and Fisher, 2002).

Raising the pH of the root-zone medium may prevent harm to the plant tissue if the low pH problem is caught early enough (Argo and Fisher, 2002). When tissue damage occurs and the leaves have necrotic spots and marginal burn, the grower must increase the pH and grow symptom free new leaves to cover the damage (Argo and Fisher, 2002; Fisher and Argo, 2001a). Yellowing and death of the leaf margins and leaf spots (Argo and Fisher, 2002; Fisher and Argo, 2001a, 2001b) along with dieback of the growing tips and even plant death (Bailey, 1999) occur when New Guinea impatiens take up too many micronutrients. Chlorotic and necrotic spotting of the tissue may lead to death of the entire leaf due to the presence of free radicals that cause oxidative damage to cell membranes (Wik et al., 2006). Other symptoms include distortion, stunting and cupping of upper leaves (Dole and Wilkins, 1999; Hartley, 1995); however, usually the older leaves show signs first and suffer the most harm because they have built up the highest

levels of micronutrients (Fisher and Argo, 2001a, 2001b.) The surplus of iron builds up in the bottom leaves of the plant (Wik et al., 2006). If the pH of the root-zone medium is allowed to drop below 6.0 toxicity symptoms can show up as quickly as 1 to 2 weeks (Argo and Fisher, 2002).

Applying a fertilizer containing iron is necessary for healthy plant growth due to its immobility within the plant (Wik et al., 2006) and the essential role iron plays in respiration, photosynthesis, nitrogen fixation and cell division (Lobréaux, Massenet and Briat, 1992). Different forms of iron vary in their level of solubility in response to pH so the iron compound applied to the crop may be more or less available depending on the root-zone medium pH (Wik et al., 2006). Knowing whether a crop is iron-efficient or iron-inefficient, allows the grower to control the medium pH, raising or lowering the pH, to provide the ideal rate of available iron depending on plant needs (Wik et al., 2006).

The essentiality of iron was discovered by J. Sachs in 1860 and Arnon and Stout coined the phrase essential mineral nutrient in 1939 (Marschner, 1995). For an element to be essential it must meet the following standards (Marschner, 1995):

1. The plant would be unable to complete its lifecycle without the element.
2. Another element cannot substitute for the function of the designated element.
3. The element is a necessary part of plant metabolism, contributing to the plant's growth and reproduction.

The shoot dry matter of a plant must contain an average of 100 ppm of iron for the plant to have acceptable levels of the nutrient for growth (Marschner, 1995).

The form of iron is less important when growing iron efficient plants at a low pH than at a high pH, because as the pH decreases both inorganic and chelated forms of iron are more

soluble (Wik et al., 2006). Overall, the level of solubility of the chelated forms of iron is higher than the inorganic forms of iron because the chelates are not as sensitive to changes in pH, keeping the micronutrient more readily available (Reed, 1996). The two most frequently used chemical forms of iron in commercial water-soluble fertilizers are iron sulfate ($FeSO_4$) and ferric ethylenediamine tetraacetic acid (Fe-EDTA) (Wik et al., 2006). The total amount of iron supplied by the fertilizer and other possible sources influence the probability of iron toxicity occurring at a low pH (Wik et al., 2006). Keeping the root-zone medium pH above 6.0 prevents the available iron from reaching toxic concentrations (Wik et al., 2006).

When looking at pH it is important to understand why fertilizers are classified as "acidic" or "basic" (Argo and Fisher, 2002). In 1933, these designations were used to classify whether the fertilizer applied to a "standard" field soil without plants, would raise or lower the pH over a period of time; it did not pertain to the pH of the fertilizer solution (Argo and Fisher, 2002).

The type of nitrogen used in a fertilizer, (nitrate, ammonium, or urea) and its interaction with the root-zone medium, irrigation water and the plant affects how much the medium pH is altered during the course of plant growth (Argo and Fisher, 2002). Of all the mineral elements plants use nitrogen the most (Taiz and Zeiger, 2006), which is why the form of nitrogen impacts the medium pH so greatly (Argo and Fisher, 2002). A fertilizer formulation comprised primarily of ammoniacal-nitrogen (NH_4^+) increases the number of H^+ ions in the root-zone medium (Argo and Fisher, 2002). The addition of acidic H^+ ions into the root-zone medium will displace another cation, most likely calcium, into the medium (Argo and Fisher, 2002). When added to the root-zone medium urea, ($CO(NH_2)$) undergoes a reaction and releases amides (NH_2^+) which are then transformed into ammoniacal-nitrogen, so it is treated as another supply of ammoniacal-nitrogen (Argo and Fisher, 2002; Dole and Wilkins, 1999). Whereas the ammoniacal-nitrogen

and urea add acid to the root-zone medium, a nitrate-nitrogen (NO_3^-) based fertilizer will add a base, (OH^- or $HCO3^-$), to the root-zone medium, freeing a H^+ ion (Argo and Fisher, 2002). The freed H^+ ion will undergo a chemical reaction with the OH^- or $HCO3^-$ ion and create water (H_2O) or carbon dioxide (CO_2) (Argo and Fisher, 2002). Notwithstanding the form of nitrogen used in a fertilizer formulation and its affect on pH, plant roots can only absorb nutrients dispersed in the soil solution (Argo and Fisher, 2002).

Nitrification, carried out by two species of specialized bacteria, changes ammoniacal nitrogen to nitrite and then nitrate nitrogen (Argo and Fisher, 2002; Cornell University, 2010). This is an important part of the nitrogen cycle because nitrate is the form of nitrogen most plants prefer for uptake from soil or water (Cornell University, 2010). This process lowers the root-zone medium pH because of the acidic, H^+ ions released during oxidation (Argo and Fisher, 2002; Cornell University, 2010; Taiz and Zeiger, 2006). Root-zone temperatures of 19.4 to 30.0°C are ideal for nitrification to take place as well as moist, well aerated root-zone medium (Cornell University, 2010). Cool root-zone medium temperatures, low medium pH and wet root-zone medium, which causes decreased oxygen levels, are all factors that prevent nitrification from occurring (Argo and Fisher, 2002).

Raising the nitrogen content in a fertilizer formula uniformly increases the concentration of iron and the other nutrients (Albano and Miller, 1998). Past research has shown that the type of iron applied, chelated or salt, impacts the amount of soluble iron in the root-zone medium because chelated forms of iron have higher levels of solubility (Albano and Miller, 1998). Leaf tissue samples have been measured with very high iron and manganese concentrations, 400-2,500 ppm, (Albano et al., 1996) compared to 100 ppm, the average amount of iron the shoot dry matter should contain for a plant to have acceptable levels of iron for growth (Marschner, 1995).

In the 1996 study conducted by Lee, Choi and Pak, several micronutrients were applied in solution to seed geraniums (*Pelargonium x hortorum* 'Ringo Scarlet') growing in a peat based medium with the goal of evaluating the effects of micronutrient toxicity. Iron was one of the micronutrients tested, as the applied solution concentration increased from 0.01-6.0 mM so did the iron tissue content going from 82 to 951 $mg \cdot kg^{-1}$ (Lee, Choi and Pak, 1996). When iron was added at lower concentrations, 0.01-0.5 mM, the green pigmentation of the leaves and the dry matter yield were greater (Lee et al., 1996). All of the plants receiving additional iron, up to 6 mM, had higher levels of chlorophyll-a and chlorophyll-b than the control group (Lee et al., 1996). However, when the concentration of iron reached 3 mM and higher the fresh and dry weights were negatively impacted and as the iron concentration continued to increase the growing medium pH decreased (Lee et al., 1996). Data were analyzed using linear regression and the following equation for predicting the iron concentration in plant tissue, based on dry weight, was derived, $y=0.70+0.10x$ ($r^2=0.97$) where, y= tissue iron content in $g \cdot kg^{-1}$ dry weight and x =mM (Lee et al., 1996).

A study showed African marigold (*Tagetes erecta* L.) cultivars differ in sensitivity to iron toxicity and their ability to take up and translocate iron throughout the plant (Albano and Miller, 1998). The pivotal point when iron levels cause toxicity is not the same from plant to plant, it depends on environmental factors, the age of the leaves and the amount of iron available (Albano et al., 1996). In research conducted on *Pentas lanceolata* Benth. (Harbaugh, 1995) and *Schlumbergera* sp. (Ramirez and Lang, 1997) variance between cultivars in the uptake and translocation of iron was also noted (Albano and Miller, 1998). This particular study did not establish a relationship between iron levels and the degree of toxicity symptoms expressed by the plant (Albano and Miller, 1998). Albano and Miller found that in general, their research

corroborates a 1978 study by Foy, Chaney and White, the main physiological characteristic of iron toxicity is simply more iron being taken up by the plant and transferred to the shoots (Albano and Miller, 1998).

Usually liquid fertilizers containing chelated micronutrients are applied to a marigold crop because the micronutrients remain available in the root-zone medium even with a wide range of root-zone medium pH (Albano et al., 1996). The level of iron-chelate in a liquid fertilizer changes based on the amount of nitrogen in the liquid fertilizer so if the fertilizer injector isn't calibrated properly or if the grower makes a change in the fertilizer regime, he may not know how much iron-chelate was actually put on the plants (Albano et al., 1996). The amount of iron in the leachate rose as the study went on demonstrating that the continued applications of iron not only contributed to the bronze speckle disorder, it also had a summative effect (Albano et al., 1996). As the rate of ferric-diethylenetriaminepentaacetic acid (Fe-DTPA) increased so did the amount of iron in the leaves and the expression of the symptoms, even the low rate of 0.018mM (1 ppm), which is common in production, caused toxicity symptoms (Albano et al., 1996). After analyzing the data the authors feel that in commercial production the disorder and the level it reaches is influenced by amount of iron-chelate in the liquid fertilizer program (Albano et al., 1996).

Bronze speckle, a physiological disorder, may occur when African marigolds take up too much iron due to low growing medium pH (Albano et al., 1996). Bronze speckle symptoms include: chlorosis or bronze spotting of the leaves, downward leaflet curling, stunting and delay of flowering (Albano et al., 1996). Initially the disorder may be mistaken for spider mite damage (Albano et al., 1996). The symptoms first appear on older, mature leaves, before moving to the

younger growth (Albano et al., 1996). Very simply iron toxicity occurs when plants take up and distribute too much iron throughout the plant (Albano et al., 1996).

By adapting extraction methods that were developed for use with mineral soils the metal content of peat moss can be estimated and there is great variation in the metal content of different sources of peat moss, especially iron (Albano et al., 1996). Metal chelates are commonly used in floriculture production; therefore chelates may be a contributing factor of bronze speckle because chelates are able to extract iron from peat (Albano et al., 1996). The iron source experiment conducted by Albano, Miller and Halbrooks in 1996 showed that whether or not chelated iron was applied, marigolds began to express symptoms of iron toxicity at rates as low as 1 ppm iron, which is a rate commonly used in greenhouse production.

To induce iron toxicity symptoms four different rates of ferric-diethylenetriaminepentaacetic acid (Fe-DTPA) treatments were applied (1, 5, 15 or 20 ppm) to two African marigold cultivars, 'First Lady' and 'Voyager' (Albano et al., 1996). The plants treated with 15 and 20 ppm Fe-DTPA expressed typical iron toxicity symptoms, interveinal chlorosis, followed by necrotic speckling of the leaf tips and as the severity increased the leaflets curled downward and more of the leaf showed the bronze speckling (Albano et al., 1996). Interestingly, this experiment demonstrated a difference between cultivars and how they react to iron toxicity (Albano et al., 1996). The older leaves of the 'First Lady' marigolds showed more severe iron toxicity symptoms than the younger leaves, but with 'Voyager' the reverse was true with the younger leaves showing greater damage (Albano et al., 1996).

General recommendations for controlling iron toxicity include, managing media pH and water and fertilizer solution pH above critical values, 6.0-6.2, which reduces the availability of iron and manganese in soilless media (Albano et al., 1996). This experiment demonstrated that

controlling the disorder by altering nutrient solution or medium pH is not a plausible solution; Fe-DTPA is stable in the 4-7 pH range and water-soluble in a root-zone medium with a high pH (Albano et al., 1996).

The study conducted by Albano and Miller in 1998 analyzed the response of different marigold cultivars to iron toxicity and showed that there is a big difference between cultivars and their response to iron toxicity. Seven different cultivars were treated with 2 different rates of iron, 1 or 20 ppm, applied with a base nutrient solution (Albano and Miller, 1998). Only the plants treated with the solution containing 20 ppm of iron showed iron toxicity symptoms (Albano and Miller, 1998). The average amount of iron found in the asymptomatic and symptomatic leaves at the higher application rate of 20 ppm, ranged from 492 to 685 $\mu g \cdot g^{-1}$ of iron respectively (Albano and Miller, 1998). These numbers fit with what other studies have shown, that the critical concentration for iron toxicity ranges from 400 to 800 $\mu g \cdot g^{-1}$ (Albano and Miller, 1998).

This study demonstrated that African marigold cultivars vary in the amount of iron taken up by the plant and how vulnerable the plant is to developing iron toxicity (Albano and Miller, 1998). The mean leaf iron content of the asymptomatic and the symptomatic leaf tissue of the cultivar 'Yellow Galore' differed by only 7 $\mu g \cdot g^{-1}$, whereas the largest difference between mean levels of iron in the asymptomatic and the symptomatic leaf tissue was 323 $\mu g \cdot g^{-1}$ in the cultivar 'First Lady' (Albano and Miller, 1998). It is possible that 'Yellow Galore' differs from other marigold varieties in the production of ferritin, a protein that stores iron in the plant (Albano and Miller, 1998).

Ferritin releases the iron it stores in a controlled manner, thereby; acting as a buffer on the cellular level (Albano et al., 1996) because of this buffering capability it has been suggested

that ferritin may provide plants with the capacity to tolerate potentially toxic levels of iron (Albano et al., 1996; Albano and Miller, 1998). Ferritin is located in the plastids and root meristems (Albano and Miller, 1998; Briat et al., 1999; Lobréaux et al., 1992). Ferritin is important because it helps maintain the equilibrium of a plant cell's iron content because of its ability to accumulate and store up to 4,500 iron atoms in its internal cavity (Briat et al., 1999; Lobréaux et al., 1992). Not only is it able to store surplus iron, ferritin has the capability to hold on to the iron and keep it in a soluble yet non-toxic form (Briat et al., 1999; Lobréaux et al., 1992).

Chapter 3: Materials and Methods

Research was conducted in a greenhouse located on the Colorado State University Campus, Fort Collins, Colo. during the following time periods: September 21-October 26, 2004, December 17, 2004-January 31, 2005, July 5-August 9, 2005 and August 15-September 26, 2005. The greenhouse had a triple layer polycarbonate walls and a single layer polycarbonate roof with a 50% aluminum mesh shade screen. The greenhouse environment was maintained with Wadsworth Controls, Inc. EnviroSTEP (Arvada, Colo.) system and fan and pad cooled with in-floor heating.

Experiments consisted of a base root-zone medium amended with different grind sizes of calcitic limestone, provided by Colorado Lien Co., Fort Collins, CO, applied at a constant rate or limestone of the same grind size incorporated into the root-zone medium at different rates. Two studies were conducted:

Limestone, at a mesh size of 45 μm[1] (#325 sieve), was incorporated into a sphagnum peat moss root-zone medium at three different rates, 0, 3 and 6 kg/m^3 pre-plant and maintained at 9 different root-zone medium temperatures (13.1, 16.0, 19.0, 22.7, 26.0, 29.0, 33.4, 37.2 and 41.8°C). These nine root-zone medium temperatures were the averages of the temperatures for the two repetitions of Study One and they were averaged together for statistical analysis.

At a rate of 3 kg/m^3, limestone was incorporated, pre-plant into the root-zone medium at three different mesh sizes, 45 μm[1](#325 sieve), 75-150 μm[2] (#100-200 sieve) and 250-1,200 μm[2] (#16x60 sieve) and held at nine root-zone medium temperatures (12.4, 14.9, 18.0, 22.3, 25.8,

[1] Average chemical characteristics for 45 μm limestone: Calcium Carbonate, 96.30%; Calcium Oxide, 53.90%; Magnesium Carbonate, 0.58%; Acid Insoluble, 2.40%

[2] Average chemical characteristics for 75-150 μm and 250-1,200 μm limestone: Calcium Carbonate, 96.30%; Calcium Oxide, 54.00%; Magnesium Carbonate, 0.72%; Acid Insoluble, 2.30%; Acid Solubility, 26.6%

29.6, 34.1, 37.5, 42.3°C). These nine root-zone medium temperatures were the averages of the temperatures for two repetitions of Study Two and they were averaged together for statistical analysis. Both studies were conducted using a two-way thermogradient plate (Figures 1 and 2) as described by Larsen (1971).

The two-way thermogradient plate (Larsen, 1971) is a square aluminum plate with channels mounted on the top and bottom sides along each of the four edges. Warm water circulates through the channels along two adjacent edges and cool water through the channels on the opposite edges. The temperatures of the water in the channels establish the limits of the gradient and the units on either side of the plate control the water temperatures. It was first used in seed germination research because it supplies any number of constant or alternating root-zone temperatures in a predetermined range (Larsen, 1971). This facilitates determining the ideal root-zone temperatures for germinating various seeds. For the purposes of these experiments water channels on only two opposite sides were connected to provide a gradient of hot to cold root-zone medium temperatures running perpendicular across the plate.

On September 21, 2004, Study One: Trial One began. Four and one half 1801 trays, each cell 400 mL in volume, were filled with the prepared growing root-zone medium, a 2:1 ¼" peat: perlite mix, that provided three different rates of calcitic limestone: medium #1: the control, no lime, medium #2: calcitic limestone, grind size 45 μm (#325 sieve), incorporated at a rate of 3 kg/m^3 and medium #3, calcitic limestone, grind size 45 μm (#325 sieve), added at a rate of 6 kg/m^3 (sphagnum peat moss from Premier Tech Horticulture, Québec, Canada) . Each 1801 tray had 18 individual cells, each cell 400 mL in volume, in a 6 cell long x 3 cell wide layout. The four and one half 1801 trays were placed onto the two-way thermogradient plate to form a 9

rows x 9 rows square grid for a total of 81 cells. Each cell was labeled with an identification number from 1-81.

All root-zone medium used in the experiments was mixed at an offsite location, in a commercial Patterson-Kelley V-Shell Blender, East Stroudsburg, Penn, 0.14 m^3 capacity. Peat and perlite were added to the blender at a rate of 2:1 by volume and mixed for 30 minutes. After 30 minutes the root-zone medium was emptied out into containers with a 22.7 L capacity. The first 22.7 L container was emptied back into the mixer and the 325 limestone was added at a rate of 3 kg/m^3 and blended for 10 minutes. The limestone was weighed separately before being added to the root-zone medium. This process was repeated with the next 22.7 L container of root-zone medium and the limestone added at a rate of 6 kg/m^3. The procedure was replicated until the treatment root-zone media were all uniformly blended.

All treatments were randomly assigned to each row on the grid. Each individual cell was filled accordingly with the respective root-zone medium. After the preliminary filling the trays were tapped on the bench three times to settle the root-zone medium before each cell was topped off with the root-zone medium. After the trays were filled deionized water, mixed with the wetting agent, AquaGro 2000 L (Aquatrols, Cherry Hill, N.J.) at a rate of 185.4 g/m^3 was used to water the trays to the point of leaching and then the trays drained for 24 hours before the rooted cuttings were planted.

Twenty-four hours later, each of the 81 cells was planted with a single rooted cutting of New Guinea impatiens ‘Celebration Orange’ an in-kind contribution from Ball FloraPlant (West Chicago, Ill.). Each cell was labeled 1, 2 or 3 to differentiate the treatment for that cell (Figure 3).

After planting, the trays were watered in with clear tap water to the point of leaching and allowed to drain on the greenhouse bench for one hour. After one hour, the trays were placed onto the two-way thermogradient plate to provide the gradient of hot to cold root-zone temperatures, with nine rows across and nine rows down the plate. Each of the nine rows across was a different root-zone temperature, 12.9, 15.2, 17.9, 21.6, 24.7, 28.2, 32.3, 36.0, 41.0 °C. There were nine temperature ranges across the gradient plate and three replications of each treatment in each row. A split plot design was used where temperature was the whole plot and the rate of limestone incorporation as the subplot.

The two-way thermogradient plate was located at the northwest corner of the greenhouse. The trays were placed on the two-way thermogradient plate in the following manner for each experiment, three Styrofoam pieces, running north to south, were slid into place between every three rows to help prevent heat loss and keep the temperatures constant. Two large Styrofoam borders were placed around the gradient plate underneath the lips of the trays also to help maintain constant temperatures (Figure 4).

The plants were watered as needed to the point of minimal leaching. To water the plants all trays were removed from the two-way thermogradient plate and placed on the greenhouse bench. The trays were then watered with clear tap water or with fertilizer, depending on the treatment schedule, until minimal leaching. The trays drained for one hour and then were placed back onto the two-way thermogradient plate into their respective places. Watering the plants on the gradient plate would have caused a change in the gradient plate surface temperature because the water would not have been able to drain off the plate and any leachate would have had to evaporate off of the two-way thermogradient plate.

The plants were fertilized weekly with 200 ppm N from Peter's 20-10-20 (N-P_2O_5-K_2O), where 40% of the nitrogen was in the ammoniacal form. This fertilizer was chosen to drive the pH down and encourage expression of nutrient toxicity problem for study purposes.

Leachate pH and electrical conductivity (EC) data was collected weekly. Root-zone medium solution leachate was extracted via the PourThru method (Whipker et al., 2001) and the pH and EC measured. The North Carolina State University Floriculture Research Program designed the Pour Thru program for use in monitoring and managing greenhouse crops (Whipker et al., 2001).

All of the 1801 trays were removed from the two-way thermogradient plate, irrigated to the point of leaching and allowed to drain for one hour. After one hour the first 18 test tubes numbered with 1-81 ID numbers were placed into the holes of a PourThru "sample collection machine" and 18 funnels were placed into the tops of the 18, 50 ml screw cap centrifuge tubes (Figure 5). A 50 ml test tube was used to pour enough deionized water onto each cell until 50 ml of leachate was collected in each of the test tubes below. The tray of plants was removed, placed back on the greenhouse bench and funnels were removed from the test tubes placed on the greenhouse bench and rinsed with deionized water. After the first 18 samples were collected the test tubes were capped and set aside for testing. Then the next 18 plants were tested in the same manner until all 81 samples were collected. After the sample collection was complete, all were tested for pH and EC. The pH and EC were measured. The PourThru analyses were conducted as a repeated measures design (Kempthorne, 1979).

On October 26, 2004 after five weeks the experiment was terminated and the plants harvested. Plant growth was measured via observations of plant quality, final dry weight and final plant height and root length. Plant quality was evaluated based on the guidelines outlined by

Pi Alpha Xi National (1998), the National Honor Society for Floriculture, Landscape Horticulture and Ornamental Horticulture. Comments were also recorded about the overall plant quality and a number assigned to rate the severity of marginal chlorosis observed on the plant. Each plant was harvested at soil level and the leaves and flowers were separated from the stem. A fresh weight for stems, leaves, buds and flowers was recorded. Each individual plant was placed in a paper bag labeled with its identification number and placed in a drying oven at 70°C for 48 hours. After 48 hours the bags were removed, weighed and dry weights recorded.

On December 17, 2004 Study Two: Trial One was implemented. Four and one half 1801 trays were filled with the prepared growing root-zone medium, a 2:1 peat: perlite mix, that provided 3 different grind sizes of calcitic limestone: medium #1: 45 μm (#325 sieve), incorporated at a rate of 3 kg/m^3, medium #2: calcitic limestone, sieve size 75-150 μm (#100-200 sieve), incorporated at a rate of 3 kg/m^3 and medium #3, calcitic limestone, 250-1,200 μm (#16x60 sieve), added at a rate of 3 kg/m^3.

Each 1801 tray had 18 individual, each cell 400 mL volume cells in a 6 cell long x 3 cell wide layout. The four and one half 1801 trays were placed onto the two-way thermogradient plate to form a 9 rows x 9 rows square grid for a total of 81 cells as previously described.

To achieve the 75-150 μm limestone grind size, 5 cups of the 250-1,200 μm limestone were added to a 20 lb capacity, Lortone Rock Tumbler, LORTONE, Mukilteo, WA, with 20 small rocks, to act as grinders and run for 24 hours. After 24 hours the rocks were removed and the limestone was filtered through a stack of sieves and only limestone collected from the 75-150 μm sieves was used in the experiments. The 45μm and 250-1,200 μm limestone grind sizes were pre-ground. The limestone was an in-kind contribution from the Colorado Lien Company, Fort Collins, Colo.

Each of the nine rows across was a different root-zone temperature, 11.7, 14.1, 17.4, 21.9, 25.6, 29.6, 35.0, 38.7 and 43.8 °C. The protocols for this experiment were the same as those in Study 1: Trial 1. This experiment was harvested on January 31, 2005 six weeks later as previously described.

On July 5, 2005, Study One: Trial Two began. Four and one half 1801 trays were filled with the prepared growing root-zone medium, a 2:1 peat: perlite mix, that provided 3 different rates of calcitic limestone: medium #1: the control, no lime, medium #2: calcitic limestone, grind size 45 μm (#325 sieve), incorporated at a rate of 3 kg/m^3 and medium #3, calcitic limestone, grind size 45 μm (#325 sieve), added at a rate of 6 kg/m^3. Each 1801 tray had 18 individual, equal volume 400 mL cells in a six cell long by three cell wide layout. The four and one half 1801 trays were placed onto the two-way thermogradient plate to form a 9 x 9 grid for a total of 81 cells. Each cell was labeled with an identification number from 1-81. Each of the nine rows across was a different root-zone temperature, 13.3, 16.8, 20.0, 23.8, 27.3, 29.8, 34.5, 38.4 and 42.6 °C. The protocols for this experiment were the same as those in Study 1: Trial 1. On August 09, 2005 after 5 weeks the experiment was terminated and the plants harvested.

On August 15, 2005 Study Two: Trial Two was implemented. Four and one half 1801 trays were filled with the prepared growing root-zone medium, a 2:1 peat: perlite mix, that provided 3 different grind sizes of calcitic limestone: medium #1: grind size 45 μm (#325 sieve), incorporated at a rate of 3 kg/m^3, medium #2: grind size 75-150 μm (#100-200 sieve), incorporated at a rate of 3 kg/m^3 and medium #3: 250-1,200 μm (#16x60 sieve), incorporated at a rate of 3 kg/m^3. Each 1801 tray had 18 individual, equal volume 400 mL cells in a 6 cell long x 3 cell wide layout. The four and one half 1801 trays were placed onto the two-way thermogradient plate to form a 9 x 9 grid for a total of 81 cells. Each cell was labeled with an

identification number from 1-81. Each of the nine rows across was a different root-zone temperature, 13.1, 15.8, 18.5, 22.7, 26.1, 29.6, 33.2, 36.4 and 40.7 °C. The protocols for this experiment were the same as those in Study 1: Trial 1. On September 26, 2005 after 6 weeks the experiment was terminated and the plants harvested.

Data were analyzed separately for Study One and Study Two using analysis of variance (ANOVA) and regression using general linear models and Type III Sums of Squares (SAS Institute, 1999). The ANOVA tables can be found in the Appendix.

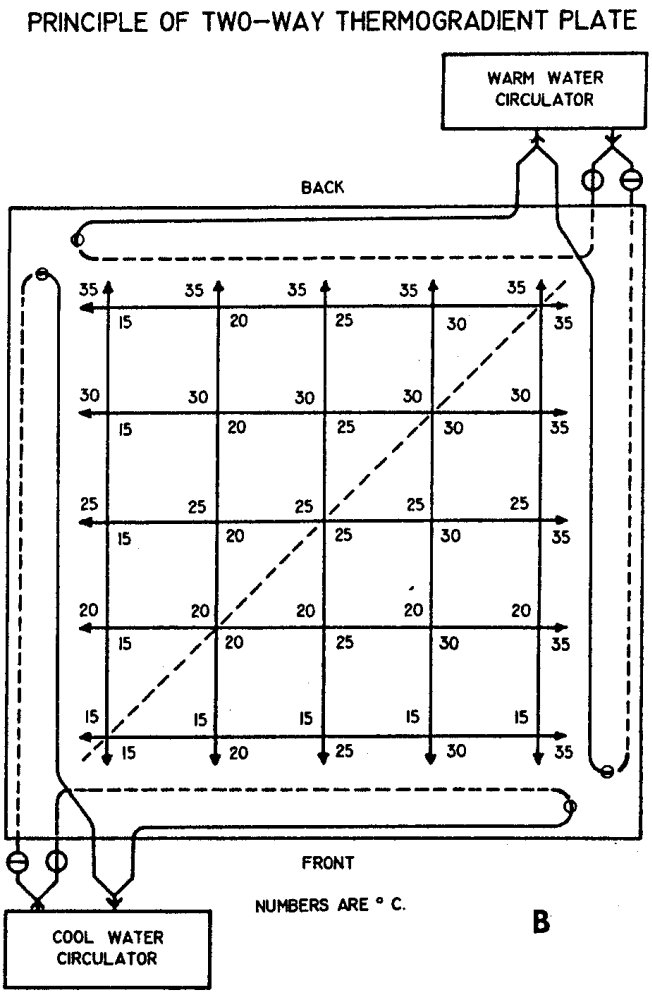

Figure 1. Diagram of the two-way thermogradient plate. (Larsen, 1971).

Figure 2. Picture of the two-way thermogradient plate in the CSU greenhouse.

Figure 3. New Guinea impatiens ‘Celebration Orange’ labeled with respective treatments.

Figure 4. Newly planted New Guinea impatiens 'Celebration Orange' placed on the two-way thermogradient plate with Styrofoam to help insulate the plants and keep temperatures constant.

Figure 5. Using a PourThru "sample collection machine" to collect 50 mL of leachate from each of the 81 cells to test pH and EC.

Chapter 4: Results and Discussion

Study One: Effects of Limestone Rate and Root-zone Temperature

The data evaluation for the effects of limestone rate and root-zone temperature on the root-zone medium pH can be found in Table 1. Within each of the different limestone incorporation rate treatments the pH remained fairly consistent over the course of 5 weeks. Without any limestone incorporated into the root-zone medium preplant, the average pH at the cooler temperatures tended to be slightly lower than the average pH at the higher temperatures. At the coolest temperature, 13.1°C the pH decreased from 4.15 at the beginning to 3.97 at the end of the five weeks. In the highest temperature group 41.8°C, the pH started at 4.22 and decreased ever so slightly over the five weeks to 4.20. The temperatures on the cooler end of the gradient plate, from 22.7°C down to 13.1°C started week 1 with a pH range of 4.18 to 4.15, respectively which decreased over the course of the 5 weeks to a range of 4.00 to 3.95. At the warmer end of the gradient plate, with temperatures ranging from 29.0°C up to 41.8°C, the beginning pH values ranged from 4.22 to 4.25 and ended between 4.15 to 4.20. Right in the middle at 26.0°C, the pH started at 4.25 and ended at 3.93. Overall, the pH of all 9 soil temperatures started out very close together, ranging from 4.15 to 4.25 the first week, only a 0.10 difference between them. By week 5 the difference in the pH range increased to 0.27 between the different root-zone temperatures, with the final pH test results ranging from 4.20 to 3.93. From week 1 to week 5 the pH within the individual temperatures decreased, overall for the 0 kg/m^3 limestone treatment the pH readings remained close together but showed a slight downward trend.

Week 1, at the limestone incorporation rate of 3 kg/m^3 the pH ranged from 6.43-6.72, a difference of 0.29 at the cooler temperatures, 22.7°C down to 13.1°C, at the end of the 5 weeks the pH values ranged from 6.50-6.80, a difference of 0.30. While the pH of the root-zone

medium at the lower temperature treatments increased slightly over time the pH values for the warmer temperatures, 29.0°C up to 41.8°C, ranged from 6.45-6.57, a difference of 0.12 at the beginning of the experiment to 6.37-6.47, a difference of 0.10 at the end of the 5 weeks. The pH of the middle temperature group, 26.0°C, started at 6.55 and ended at 6.40, a change of 0.15. The range between the pH readings remained consistent over the course of the experiment. Most of the 9 temperatures treatments had a slight increase in pH from the starting pH but from week 4 to week 5 the pH decreased for 8 of the root-zone medium temperatures, except at 29°C, which remained stable with a pH of 6.47. Overall, the root-zone medium temperatures ranging from 29.0 to 41.8°C provided a pH range closest to Hartley's (1995) recommended pH range of 5.8 to 6.5.

When 6 kg/m^3 of limestone was incorporated into the root-zone medium the starting pH for the coolest temperatures, 13.1°C to 22.7°C ranged from 6.82 to 7.07, which is higher than the desired pH range of 5.8 to 6.5 (Hartley, 1995). At the end of 5 weeks the pH for the coolest temperatures ranged from 6.87 to 7.05, still too high for growing a quality crop of New Guinea impatiens. The warmer temperatures, 29.0°C to 41.8°C, had a starting pH range of 6.85 to 7.15, as previously mentioned this is not a desirable pH range for the production of New Guinea impatiens. At the end of 5 weeks the pH values ranged from 6.73 to 6.98. Right in the middle at 26.0°C, the pH started at 6.98 and ended at 6.78. None of the pH values recorded for the addition of the 6 kg/m^3 of limestone, across all 9 temperatures were in the target pH range for growing New Guinea impatiens.

The data evaluation for the effects of limestone rate and root-zone temperature on the root-zone medium electrical conductivity (EC) can be found in Table 2. As a general trend the EC increased from week 1 to week 5 for all 3 rates of limestone incorporated into the root-zone

medium. When the EC increases over the course of crop production then the plants are not taking up all of the available salts (Healy, 1995). The EC week 1 for the 0 kg/m^3 group ranged from 0.28 to 0.37 over all 9 temperatures, a difference of only 0.09. For the 3 kg/m^3 group the starting EC ranged from 0.29 to 0.40, a difference of 0.11. In the 6 kg/m^3 treatment group the starting EC ranged from 0.35 to 0.51, which is a difference of 0.16. At the end of the 5 weeks the EC for the 0 kg/m^3 group ranged from 0.45 to 0.91, a difference of 0.46. The 3 kg/m^3 group's final EC ranged from 0.53 to 0.79, a difference of 0.26. In the 6 kg/m^3 treatment group the final EC ranged from 0.53 to 0.74, which is a difference of 0.21.

Interestingly at the three different incorporation rates the EC for most of the warmer temperatures was higher than at the cooler temperatures. It was anticipated that at the warmer temperatures the New Guinea impatiens would have a lower EC because the warmer temperatures would encourage faster growth; therefore the plants would be using a higher rate of fertilizer than at the cooler temperatures. Some of the root-zone temperatures were too hot for the roots to take up nutrients.

The data evaluation for the effects of limestone rate and root-zone temperature on the height of New Guinea impatiens can be found in Table 3. The average height of the New Guinea impatiens plants ranged from 6.27 to 11.23 cm, a difference of 4.96 cm. The plants grown at 13.1°C, the coldest temperature, across all 3 limestone rates averaged 8.27 to 8.88 cm in height. At the hottest temperature, 41.8°C, the growth of the New Guinea Impatiens in all 3 treatments was severely limited; the plants never reached a height taller than 6.87 cm. The average was 6.27, 6.87 and 6.55 cm for the respective 0, 3 and 6 kg/m^3 treatments at 41.8°C. With 0 kg/m^3 incorporated preplant the plants ranged in height from 6.27 to 11.48 cm, at the 3 kg/m^3 incorporation rate the heights ranged from 6.87 to 11.22 and with 6 kg/m^3 incorporated into the

medium, the heights ranged from 6.55 to 11.23 cm. Within each treatment group the smallest difference amongst the plant height was with the 3 kg/m^3 incorporation rate, with a 4.35 cm height difference between all the plants. The largest difference occurred at the 0 kg/m^3 incorporation rate, with a difference of 5.21 cm in height between the plants.

The data evaluation for the effects of limestone rate and root-zone temperature on the plant dry weight of New Guinea impatiens can be found in Table 4. The average dry weight of the New Guinea impatiens plants ranged from 4.77 to 5.34 g. The average dry weights were the lowest for the plants grown at 41.8°C, ranging from 4.77 to 4.8 g. This is to be expected as the average plant height was the shortest for the plants grown at the 41.8°C root-zone medium temperature. The average dry weights for all of the other temperatures ranged from 5.02-5.34 g, a difference of 0.32g. Within the limestone rate treatment groups the average dry weight ranged from 4.77 to 5.19 g, at the 0 kg/m^3 incorporation rate, a difference of 0.42 g. At the 3 kg/m^3 incorporation rate, the average dry weights were 4.77 to 5.34g, a difference of 0.57 g. When 6 kg/m^3 of limestone was added to the growing medium the dry weight averaged 4.80 to 5.28 g, a difference of 0.48 g.

Study Two: Effects of Limestone Grind Size and Root-zone Temperature

The data evaluation for the effects of limestone grind size and root-zone temperature on the root-zone medium pH can be found in Table 5. At a rate of 3 kg/m^3 limestone and grind size, 45 μm, the pH over the course of 6 weeks was fairly consistent, ranging from 6.08 to 6.97, a difference of 0.89. When the 75-150 μm grind size limestone was incorporated into the growing medium at a rate of 3 kg/m^3, the pH from week 1 to week 6 showed an upward trend. The pH ranged from 6.05 to 6.87, a difference of 0.82. The greatest change in pH was at the 42.3°C,

week 1 the pH was 6.42 and at week 6 it was 6.80, a difference of 0.38. At the warmest root-zone medium temperature the limestone reacted quickly and raised the pH faster than at other root-zone temperatures. Not only did the pH at 42.3°C fall outside the ideal range for growing New Guinea impatiens the root growth was severely restricted by the hot root-zone temperatures.

When the coarsest limestone, the 250-1,200 µm grind size was incorporated at 3 kg/m^3 the pH ranged from 4.32 to 5.97, a difference of 1.65. This was the largest difference between pH readings in the 3 treatments. Only the pH week 6 at 25.8°C and 42.3°C reached a pH level recommended for growing, the readings were 5.82 and 5.97 respectively. This coarser grind size of limestone would not be recommended for incorporation into the growing medium as it took too long to achieve the desired pH range and as previously mentioned 42.3°C, was too hot to support root growth. From 22.3 to 37.5°C with the 75-150 µm size limestone, the pH readings from week 1 to 6 were the closest to the desired pH range of 5.8 to 6.5 mentioned by Hartley (1995).

The data evaluation for the effects of limestone rate and root-zone temperature on the root-zone medium electrical conductivity (EC) can be found in Table 6. The EC did increase from week 1 to week 6 for all 3 grind sizes of limestone incorporated into the root-zone medium at 3 kg/m^3. Week 1 the EC at the 45 µm grind size ranged from 0.24 to 0.32 over all 9 temperatures, a difference of only 0.08. When the 75-150 µm grind size limestone was incorporated the EC week 1 ranged from 0.24 to 0.31, a difference of 0.07. In the 250-1,200 µm grind size treatment group the beginning EC ranged from 0.16 to 0.23, a difference of 0.07. At the end of 6 weeks the EC for the 45 µm grind size ranged from 0.34 to 0.48, a difference of 0.14. The 75-150 µm grind size final EC ranged from 0.39 to 0.50, a difference of 0.11. The 250-1,200 µm grind size treatment group's final EC ranged from 0.24 to 0. 40, a difference of 0.19.

The increase in EC from week 1 to week 6 was very small, so the plants were taking up the fertilizer that was applied.

The data evaluation for the effects of limestone rate and root-zone temperature on the height of New Guinea impatiens can be found in Table 7. The final plant height was the shortest for the New Guinea impatiens grown at the hottest temperature, 42.3°C with an average height of 8.71 cm. It was too hot for the plants to grow roots past a few centimeters and to put on the corresponding top growth. The next shortest group was the coldest temperature, 12.4°C with an average height of 10.24 cm. The plants in all of the other temperature groups ranged in height from 11.55 to 12.92 cm. The tallest group with the average height of 12.92 cm was the middle temperature of 25.8°C. Amongst the different temperatures the plants in the 250-1,200 μm group had the largest variation in height.

When comparing plant height between the different grind sizes the treatment with the tallest plants was the 75-150 μm grind size group with an average height of 11.85 and this group also contained the two tallest plants at 13.30 and 13.07 cm tall. The shortest plants were in the 250-1,200 μm grind size group, with an average of 11.31 cm and the 45 μm grind size group was in the middle averaging 11.59 cm in height.

The data evaluation for the effects of limestone rate and root-zone temperature on the height of New Guinea impatiens can be found in Table 8. The average dry weights for the 45 μm and 250-1,200 μm grind size groups, were the same at 5.25 g. The 75-150 μm grind size treatment wasn't far behind with an average dry weight of 5.33 g. Across the different temperatures the highest temperature of 42.3°C produced the lowest average dry weight of 5.09 g. The temperature of 34.1°C produced the New Guinea impatiens with the largest dry weight of 5.6 g.

Observations

A few of the 'Celebration Orange' New Guinea impatiens grown for the studies expressed foliar symptoms of marginal chlorosis, but not at the level that was expected. This may have been due to the iron and manganese content not reaching toxic levels required for visual expression in this experiment. None of the leaf margins or growing tips died nor were any necrotic leaf spots observed. Upper leaves of the plants remained normal and did not exhibit distortion, stunting or cupping.

As expected, the smaller calcitic limestone grind size of 45μm did raise the pH faster than the 250-1,200 μm grind size but the results were very similar for the 75-150 μm grind size. As previously mentioned, the ideal pH range for growing New Guinea impatiens is 5.8-6.5 (Hartley, 1995). Both the 45 μm and the 75-150 μm grind sizes of limestone incorporated preplant at the rate of 3 kg/m^3 did have some root-zone medium pH readings that hit the target range, however, over the course of the 6 weeks there were also readings in these 2 treatments that were higher than desired.

Over all nine of the different temperatures the pH ranged from 6.18 to 6.97 at the 45 μm grind size. With the 75-150 μm grind size the pH ranged from 6.12 to 6.93 over all nine different temperatures. At grind size 250-1,200 μm the pH never went above a 5.97 and that wasn't until week 6 at the warmest temperature of 42.3°C, which produced a very poor quality plant because the root-zone medium temperature was so hot root growth was inhibited.

Without any limestone added to the root-zone medium the lowest pH was 3.93 and the highest was 4.50, none of which are adequate for growing a quality crop of New Guinea impatiens. At the 3 kg/m^3 rate of limestone incorporation the pH ranged from 6.2 to 7.15 over all of the temperatures. When the temperature was 29.0°C and 3 kg/m^3 of calcitic limestone was

added to the root-zone medium the pH ranged from 6.42 to 6.58 over the course of 5 weeks, meeting the upper end of the ideal pH range for growing New Guinea impatiens.

The warmer root-zone temperatures did seem to allow for faster reactivity of the limestone, however, as previously mentioned, the temperatures were sometimes too high causing poor root growth and as a result poor plant quality.

Table 1. The effects of limestone rate and root zone medium temperatures on leachate pH collected weekly for five weeks after transplanting for New Guinea impatiens 'Celebration Orange' (± values represent the standard error of the mean).

Limestone Rate (kg/m^3)	Root zone Temperature (°C)	Weeks After Transplant									
		1		2		3		4		5	
		Leachate pH									
0	13.1	4.15	±0.04	4.05	±0.08	4.07	±0.11	4.00	±0.04	3.97	±0.04
	16.0	4.15	±0.04	4.05	±0.10	4.12	±0.10	4.00	±0.04	3.95	±0.04
	19.0	4.15	±0.02	4.10	±0.11	4.25	±0.15	4.08	±0.04	4.00	±0.04
	22.7	4.18	±0.06	4.08	±0.10	4.50	±0.24	3.98	±0.04	3.98	±0.04
	26.0	4.25	±0.05	4.05	±0.11	4.38	±0.24	3.98	±0.04	3.93	±0.02
	29.0	4.25	±0.07	4.10	±0.11	4.33	±0.20	4.10	±0.05	4.15	±0.03
	33.4	4.25	±0.06	4.08	±0.10	4.23	±0.13	4.18	±0.06	4.15	±0.03
	37.2	4.23	±0.06	4.03	±0.14	4.17	±0.12	4.15	±0.04	4.15	±0.06
	41.8	4.22	±0.05	4.12	±0.12	4.23	±0.08	4.22	±0.06	4.20	±0.11
	Linear	0.0602 [z]		0.8016		0.6861		0.0001		0.0001	
	Quadratic	0.0839		0.9690		0.1972		0.0001		0.0001	
3	13.1	6.43	±0.08	6.67	±0.09	7.15	±0.25	6.93	±0.07	6.80	±0.06
	16.0	6.58	±0.07	7.05	±0.18	7.05	±0.16	6.82	±0.14	6.73	±0.19
	19.0	6.55	±0.07	6.92	±0.18	6.80	±0.13	6.75	±0.20	6.58	±0.14
	22.7	6.72	±0.15	6.53	±0.09	6.88	±0.25	6.67	±0.19	6.50	±0.15
	26.0	6.55	±0.04	6.55	±0.11	6.83	±0.36	6.65	±0.25	6.40	±0.20
	29.0	6.52	±0.06	6.58	±0.14	6.42	±0.15	6.47	±0.17	6.47	±0.13
	33.4	6.45	±0.03	6.67	±0.20	6.65	±0.40	6.50	±0.23	6.37	±0.22
	37.2	6.57	±0.15	6.68	±0.22	6.48	±0.13	6.60	±0.17	6.47	±0.13
	41.8	6.57	±0.12	6.43	±0.22	6.50	±0.17	6.52	±0.12	6.42	±0.15
	Linear	0.9276		0.557		0.0080		0.0303		0.0247	
	Quadratic	0.8336		0.1601		0.0236		0.0555		0.0298	

Table 1 continued

6	13.1	6.82	±0.17	7.03	±0.08	7.25	±0.04	7.23	±0.06	7.00	±0.06
	16.0	6.92	±0.09	7.13	±0.08	7.40	±0.14	7.22	±0.09	7.05	±0.06
	19.0	6.85	±0.11	7.12	±0.07	7.47	±0.24	7.12	±0.17	6.97	±0.08
	22.7	7.07	±0.14	6.93	±0.03	7.17	±0.25	7.05	±0.16	6.87	±0.06
	26.0	6.98	±0.13	6.90	±0.03	7.17	±0.28	7.10	±0.16	6.78	±0.05
	29.0	7.15	±0.09	6.98	±0.06	6.93	±0.22	6.88	±0.08	6.73	±0.04
	33.4	6.85	±0.12	7.07	±0.12	6.78	±0.23	6.87	±0.11	6.73	±0.10
	37.2	7.03	±0.11	7.07	±0.08	7.35	±0.28	7.07	±0.13	6.98	±0.03
	41.8	7.15	±0.12	6.95	±0.07	7.12	±0.16	7.12	±0.13	6.92	±0.05
	Linear	0.0688		0.3280		0.1966		0.1295		0.0699	
	Quadratic	0.1804		0.4723		0.2766		0.0483		0.0005	

[z] *Pr>F*

Table 2. The effects of limestone rate and root zone medium temperatures on leachate electrical conductivity collected weekly for five weeks after transplanting for New Guinea impatiens 'Celebration Orange' (± values represent the standard error of the mean).

Limestone Rate (kg/m^3)	Root zone Temperature (°C)	Weeks After Transplant									
		1		2		3		4		5	
		Leachate Electrical Conductivity (dS/m)									
0	13.1	0.30	±0.05	0.47	±0.13	0.39	±0.11	0.44	±0.04	0.58	±0.07
	16.0	0.28	±0.06	0.54	±0.17	0.32	±0.09	0.44	±0.04	0.55	±0.06
	19.0	0.31	±0.07	0.55	±0.17	0.35	±0.10	0.42	±0.06	0.45	±0.08
	22.7	0.37	±0.11	0.56	±0.18	0.42	±0.12	0.47	±0.06	0.59	±0.07
	26.0	0.30	±0.09	0.60	±0.19	0.44	±0.13	0.42	±0.07	0.60	±0.03
	29.0	0.35	±0.10	0.59	±0.19	0.48	±0.16	0.44	±0.06	0.48	±0.05
	33.4	0.27	±0.06	0.70	±0.22	0.54	±0.17	0.53	±0.09	0.72	±0.04
	37.2	0.30	±0.08	0.78	±0.26	0.63	±0.21	0.50	±0.09	0.79	±0.08
	41.8	0.32	±0.09	0.75	±0.28	0.54	±0.15	0.51	±0.07	0.91	±0.11
	Linear	0.9551[z]		0.1483		0.0607		0.1764		0.0001	
	Quadratic	0.9469		0.3543		0.1752		0.379		0.0001	
3	13.1	0.29	±0.03	0.53	±0.11	0.48	±0.09	0.47	±0.06	0.62	±0.04
	16.0	0.36	±0.06	0.59	±0.15	0.45	±0.07	0.45	±0.06	0.58	±0.09
	19.0	0.36	±0.05	0.58	±0.14	0.48	±0.10	0.43	±0.06	0.46	±0.08
	22.7	0.36	±0.06	0.57	±0.14	0.53	±0.13	0.46	±0.06	0.58	±0.07
	26.0	0.30	±0.05	0.67	±0.18	0.60	±0.16	0.51	±0.08	0.53	±0.07
	29.0	0.32	±0.05	0.66	±0.18	0.58	±0.17	0.47	±0.07	0.53	±0.06
	33.4	0.33	±0.05	0.75	±0.21	0.70	±0.19	0.54	±0.08	0.65	±0.06
	37.2	0.40	±0.09	0.78	±0.23	0.75	±0.23	0.57	±0.11	0.72	±0.07
	41.8	0.40	±0.10	0.86	±0.26	0.67	±0.19	0.57	±0.08	0.79	±0.04
	Linear	0.3351		0.0791		0.0640		0.0630		0.0052	
	Quadratic	0.5204		0.2083		0.1800		0.1571		0.0007	

Table 2 continued

6	13.1	0.35	±0.03	0.69	±0.16	0.49	±0.06	0.44	±0.06	0.63	±0.06
	16.0	0.44	±0.09	0.68	±0.16	0.46	±0.04	0.47	±0.06	0.64	±0.07
	19.0	0.42	±0.06	0.66	±0.15	0.52	±0.08	0.50	±0.09	0.62	±0.07
	22.7	0.45	±0.10	0.71	±0.17	0.59	±0.14	0.47	±0.08	0.53	±0.05
	26.0	0.41	±0.07	0.71	±0.19	0.68	±0.16	0.51	±0.07	0.58	±0.05
	29.0	0.50	±0.10	0.74	±0.20	0.71	±0.20	0.56	±0.11	0.54	±0.06
	33.4	0.42	±0.10	0.78	±0.21	0.75	±0.22	0.57	±0.09	0.74	±0.06
	37.2	0.40	±0.07	0.82	±0.24	0.72	±0.18	0.57	±0.06	0.64	±0.04
	41.8	0.51	±0.13	0.93	±0.29	0.61	±0.15	0.55	±0.07	0.70	±0.05
	Linear	0.3941		0.2410		0.1130		0.0957		0.1961	
	Quadratic	0.6898		0.4475		0.1583		0.2259		0.1035	

[z] ***Pr>F***

Rate

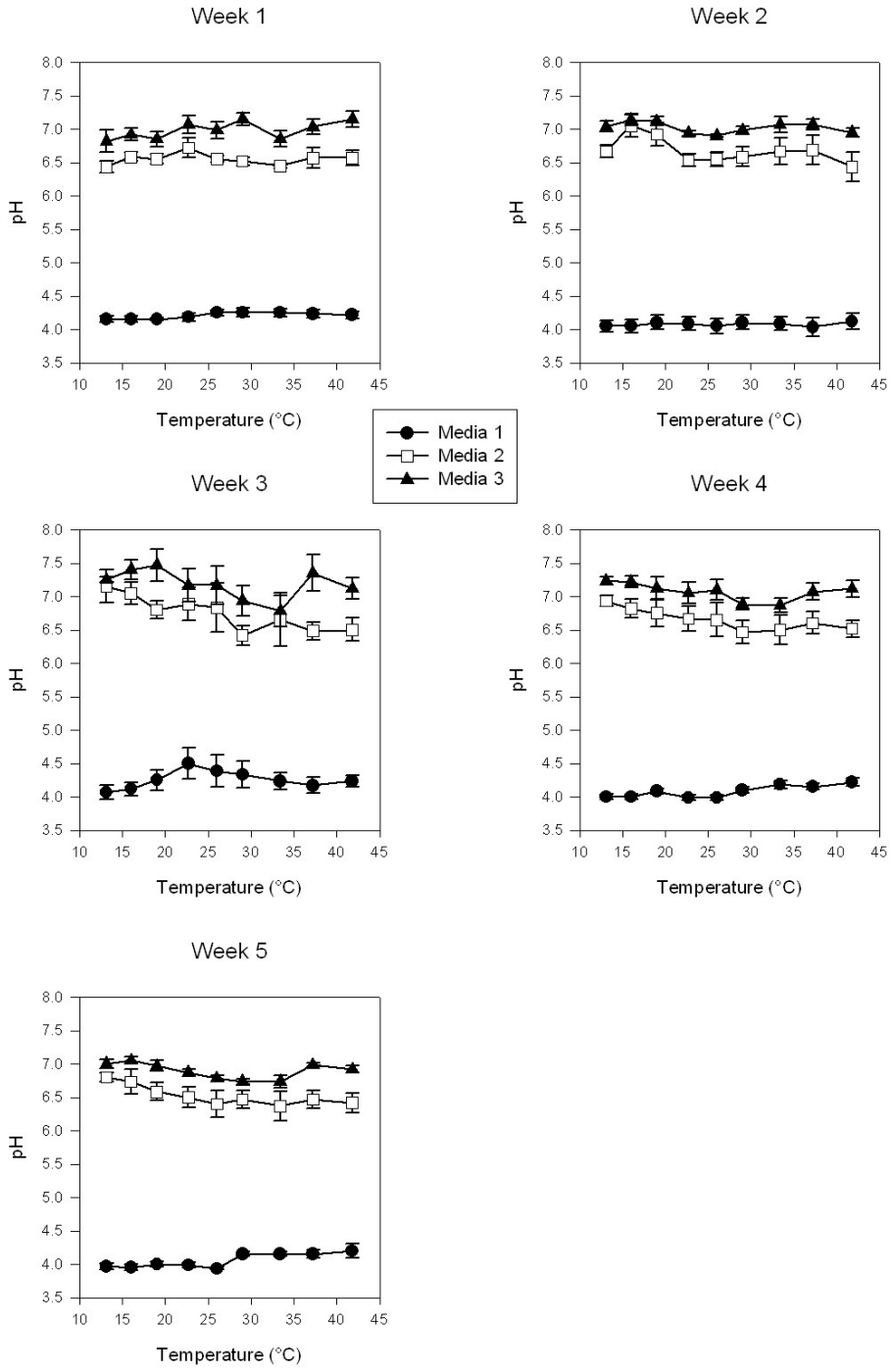

Figure 6. The effects of limestone rate and root zone medium temperatures on leachate pH collected weekly for five weeks after transplanting for New Guinea impatiens 'Celebration Orange' (Media 1, 0 kg/m3; Media 2, 3 kg/m3; Media 3, 6 kg/m3.)

Rate

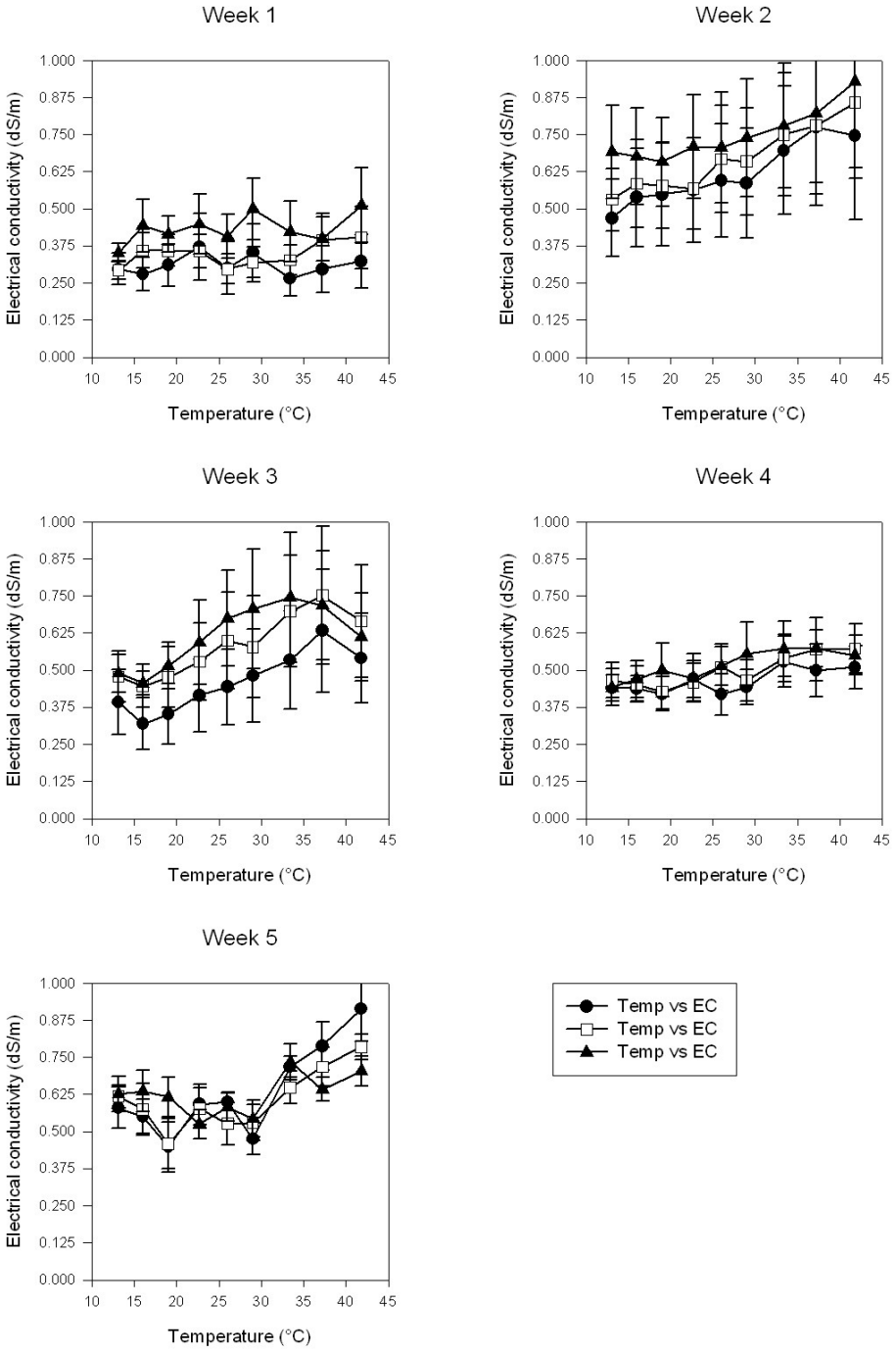

Figure 7. The effects of limestone rate and root zone medium temperatures on leachate EC collected weekly for five weeks after transplanting for New Guinea impatiens 'Celebration Orange' (Media 1, 0 kg/m3; Media 2, 3 kg/m3; Media 3, 6 kg/m3.)

Table 3. The effects of limestone rate and root zone medium temperatures on the height of New Guinea impatiens 'Celebration Orange' (± values represent the standard error of the mean).

Root zone Medium Temperature (°C)	Limestone rate (kg/m^3)					
	0		3		6	
	Height (cm)					
13.1	8.27	±0.93	8.43	±0.89	8.88	±1.13
16.0	10.38	±1.48	9.97	±0.79	10.42	±1.03
19.0	9.63	±1.36	9.92	±1.34	10.00	±1.11
22.7	9.75	±1.20	10.62	±1.11	10.57	±1.2
26.0	11.48	±1.43	11.22	±1.42	10.53	±1.28
29.0	10.13	±1.26	10.87	±1.08	11.23	±1.44
33.4	9.75	±1.65	10.93	±1.64	10.67	±1.56
37.2	9.62	±1.44	10.28	±1.58	9.58	±1.16
41.8	6.27	±0.73	6.87	±0.61	6.55	±0.55
Linear	0.2728[z]		0.6187		0.2253	
Quadratic	0.0195		0.0092		0.0084	

[z] $Pr>F$

Table 4. The effects of limestone rate and root zone medium temperatures on the dry weight of New Guinea impatiens 'Celebration Orange' (± values represent the standard error of the mean).

Root zone Medium Temperature (°C)	Limestone rate (kg/m^3)					
	0		3		6	
	Dry weight (g)					
13.1	5.09	±1.57	5.19	±1.58	5.28	±1.57
16.0	5.02	±1.59	5.20	±1.57	5.13	±1.58
19.0	5.19	±1.52	5.24	±1.60	5.25	±1.56
22.7	5.03	±1.62	5.04	±1.63	5.22	±1.63
26.0	5.10	±1.55	5.34	±1.55	5.22	±1.60
29.0	5.16	±1.55	5.28	±1.57	5.17	±1.57
33.4	5.02	±1.51	5.19	±1.54	5.25	±1.52
37.2	5.15	±1.51	5.10	±1.53	5.08	±1.54
41.8	4.77	±1.55	4.77	±1.59	4.80	±1.58
Linear	0.9141[z]		0.8626		0.8444	
Quadratic	0.9852		0.9664		0.9704	

[z] $Pr>F$

Table 5. The effects of limestone sieve size and root zone medium temperatures on leachate pH collected weekly for six weeks after transplanting for New Guinea impatiens 'Celebration Orange' (± values represent the standard error of the mean).

Limestone Sieve (µm)	Root zone Temperature (°C)	Weeks After Transplant											
		1		2		3		4		5		6	
		Leachate pH											
45	12.4	6.63	±0.04	6.78	±0.15	6.72	±0.09	6.73	±0.09	6.83	±0.07	6.67	±0.08
	14.9	6.60	±0.04	6.95	±0.13	6.58	±0.08	6.58	±0.09	6.70	±0.17	6.68	±0.14
	18.0	6.80	±0.08	6.93	±0.11	6.60	±0.14	6.48	±0.09	6.83	±0.30	6.65	±0.19
	22.3	6.67	±0.06	6.82	±0.13	6.48	±0.11	6.32	±0.18	6.75	±0.34	6.65	±0.28
	25.8	6.72	±0.09	6.77	±0.15	6.60	±0.22	6.30	±0.19	6.63	±0.26	6.63	±0.26
	29.6	6.73	±0.12	6.77	±0.15	6.32	±0.13	6.20	±0.19	6.65	±0.23	6.62	±0.28
	34.1	6.60	±0.11	6.68	±0.13	6.20	±0.09	6.35	±0.18	6.52	±0.16	6.72	±0.30
	37.5	6.73	±0.16	6.65	±0.13	6.18	±0.09	6.50	±0.12	6.53	±0.14	6.97	±0.28
	42.3	6.63	±0.11	6.72	±0.14	6.08	±0.10	6.52	±0.04	6.63	±0.16	6.82	±0.22
	Linear	0.9993 [z]		0.0891		0.0001		0.2356		0.2146		0.3636	
	Quadratic	0.6778		0.2390		0.0001		0.0073		0.4407		0.5578	
75-150	12.4	6.40	±0.08	6.85	±0.13	6.67	±0.16	6.62	±0.14	6.80	±0.17	6.68	±0.13
	14.9	6.58	±0.09	6.93	±0.18	6.68	±0.20	6.65	±0.12	6.70	±0.18	6.82	±0.29
	18.0	6.62	±0.11	6.88	±0.18	6.62	±0.18	6.55	±0.20	6.87	±0.36	6.67	±0.33
	22.3	6.53	±0.09	6.82	±0.13	6.48	±0.19	6.37	±0.23	6.65	±0.34	6.53	±0.26
	25.8	6.58	±0.12	6.73	±0.17	6.35	±0.15	6.25	±0.22	6.57	±0.27	6.70	±0.29
	29.6	6.43	±0.13	6.63	±0.15	6.37	±0.20	6.22	±0.20	6.55	±0.25	6.52	±0.25
	34.1	6.48	±0.05	6.57	±0.18	6.32	±0.20	6.52	±0.24	6.52	±0.16	6.72	±0.26
	37.5	6.42	±0.11	6.70	±0.14	6.12	±0.16	6.42	±0.20	6.47	±0.14	6.70	±0.24
	42.3	6.42	±0.14	6.58	±0.19	6.05	±0.13	6.52	±0.22	6.55	±0.22	6.80	±0.23
	Linear	0.2810		0.0309		0.0003		0.4329		0.1667		0.8920	
	Quadratic	0.3404		0.0959		0.0017		0.1861		0.3569		0.7370	

Table 5 continued

250-1,200	12.4	4.32	±0.03	4.58	±0.07	4.62	±0.13	4.77	±0.21	5.07	±0.23	5.37	±0.24
	14.9	4.37	±0.06	4.65	±0.07	4.63	±0.17	4.75	±0.25	4.93	±0.23	5.13	±0.21
	18.0	4.35	±0.05	4.65	±0.04	4.90	±0.20	4.92	±0.25	5.30	±0.32	5.45	±0.22
	22.3	4.40	±0.04	4.67	±0.04	4.83	±0.14	4.90	±0.23	5.37	±0.27	5.58	±0.24
	25.8	4.38	±0.08	4.67	±0.12	4.72	±0.20	4.87	±0.30	5.33	±0.44	5.82	±0.48
	29.6	4.42	±0.05	4.68	±0.07	4.70	±0.18	4.72	±0.22	5.12	±0.24	5.53	±0.28
	34.1	4.35	±0.04	4.52	±0.04	4.50	±0.13	4.70	±0.13	4.93	±0.17	5.52	±0.34
	37.5	4.33	±0.07	4.50	±0.03	4.38	±0.19	4.77	±0.11	4.95	±0.16	5.42	±0.26
	42.3	4.38	±0.09	4.55	±0.10	4.77	±0.18	4.82	±0.24	5.30	±0.24	5.97	±0.40
	Linear	0.7074		0.1079		0.3872		0.8044		0.9776		0.1508	
	Quadratic	0.6593		0.1089		0.6540		0.9584		0.9229		0.3567	

[z] *Pr>F*

Table 6. Effects of limestone sieve size and root zone medium temperatures on leachate electrical conductivity collected weekly for six weeks after transplanting for New Guinea impatiens 'Celebration Orange' (± values represent the standard error of the mean).

Limestone Sieve Size (µm)	Root zone Temperature (°C)	Weeks After Transplant											
		1		2		3		4		5		6	
		Leachate Electrical Conductivity (dS/m)											
45	12.4	0.30	±0.01	0.22	±0.01	0.37	±0.02	0.51	±0.05	0.44	±0.08	0.39	±0.08
	14.9	0.26	±0.02	0.20	±0.02	0.32	±0.02	0.46	±0.05	0.43	±0.11	0.30	±0.08
	18.0	0.28	±0.01	0.22	±0.02	0.36	±0.06	0.53	±0.07	0.54	±0.16	0.41	±0.12
	22.3	2.25	±0.01	0.21	±0.02	0.34	±0.05	0.50	±0.08	0.46	±0.13	0.34	±0.11
	25.8	0.25	±0.02	0.21	±0.03	0.32	±0.03	0.52	±0.06	0.49	±0.15	0.43	±0.13
	29.6	0.24	±0.01	0.22	±0.01	0.32	±0.02	0.58	±0.06	0.50	±0.14	0.42	±0.14
	34.1	0.32	±0.01	0.27	±0.02	0.36	±0.04	0.50	±0.04	0.47	±0.13	0.48	±0.16
	37.5	0.29	±0.01	0.27	±0.02	0.41	±0.03	0.59	±0.04	0.54	±0.08	0.43	±0.12
	42.3	0.29	±0.01	0.28	±0.01	0.43	±0.04	0.56	±0.04	0.57	±0.04	0.41	±0.10
	Linear	0.2811		0.0004		0.0684		0.1806		0.4242		0.4209	
	Quadratic	0.0295		0.0008		0.0151		0.4106		0.7197		0.6927	
75-150	12.4	0.31	±0.03	0.27	±0.02	0.37	±0.02	0.51	±0.05	0.51	±0.08	0.50	±0.13
	14.9	0.29	±0.02	0.23	±0.02	0.32	±0.03	0.50	±0.07	0.46	±0.12	0.40	±0.12
	18.0	0.29	±0.02	0.25	±0.02	0.34	±0.02	0.55	±0.06	0.50	±0.12	0.44	±0.11
	22.3	0.25	±0.03	0.21	±0.03	0.31	±0.03	0.48	±0.03	0.47	±0.12	0.38	±0.11
	25.8	0.24	±0.02	0.22	±0.02	0.35	±0.04	0.48	±0.06	0.46	±0.12	0.43	±0.13
	29.6	0.26	±0.02	0.25	±0.03	0.32	±0.03	0.50	±0.02	0.42	±0.10	0.42	±0.13
	34.1	0.30	±0.02	0.27	±0.02	0.37	±0.03	0.54	±0.04	0.45	±0.08	0.45	±0.13
	37.5	0.25	±0.01	0.22	±0.03	0.35	±0.02	0.55	±0.03	0.54	±0.08	0.42	±0.11
	42.3	0.27	±0.02	0.28	±0.02	0.43	±0.05	0.63	±0.09	0.57	±0.12	0.39	±0.11
	Linear	0.1515 [z]		0.5856		0.0696		0.1053		0.6346		0.7259	
	Quadratic	0.1048		0.2177		0.0130		0.0887		0.5103		0.9273	

Table 6 continued

250-1,200	12.4	0.23	±0.03	0.14	±0.01	0.30	±0.03	0.45	±0.06	0.40	±0.07	0.33	±0.10
	14.9	0.20	±0.01	0.12	±0.01	0.32	±0.03	0.49	±0.09	0.43	±0.12	0.36	±0.09
	18.0	0.21	±0.03	0.13	±0.01	0.22	±0.02	0.39	±0.08	0.32	±0.11	0.25	±0.07
	22.3	0.16	±0.02	0.13	±0.01	0.22	±0.02	0.39	±0.03	0.30	±0.09	0.24	±0.08
	25.8	0.19	±0.02	0.13	±0.01	0.27	±0.02	0.42	±0.02	0.37	±0.13	0.33	±0.11
	29.6	0.17	±0.02	0.12	±0.01	0.23	±0.02	0.48	±0.04	0.36	±0.10	0.35	±0.10
	34.1	0.22	±0.03	0.21	±0.04	0.33	±0.02	0.52	±0.06	0.46	±0.09	0.40	±0.13
	37.5	0.19	±0.01	0.20	±0.03	0.37	±0.04	0.61	±0.08	0.53	±0.12	0.37	±0.11
	42.3	0.20	±0.01	0.28	±0.07	0.40	±0.04	0.76	±0.17	0.61	±0.17	0.39	±0.13
	Linear	0.5814		0.0001		0.0020		0.0024		0.0760		0.3582	
	Quadratic	0.1719		0.0001		0.0001		0.0004		0.0548		0.5756	

[z] *Pr>F*

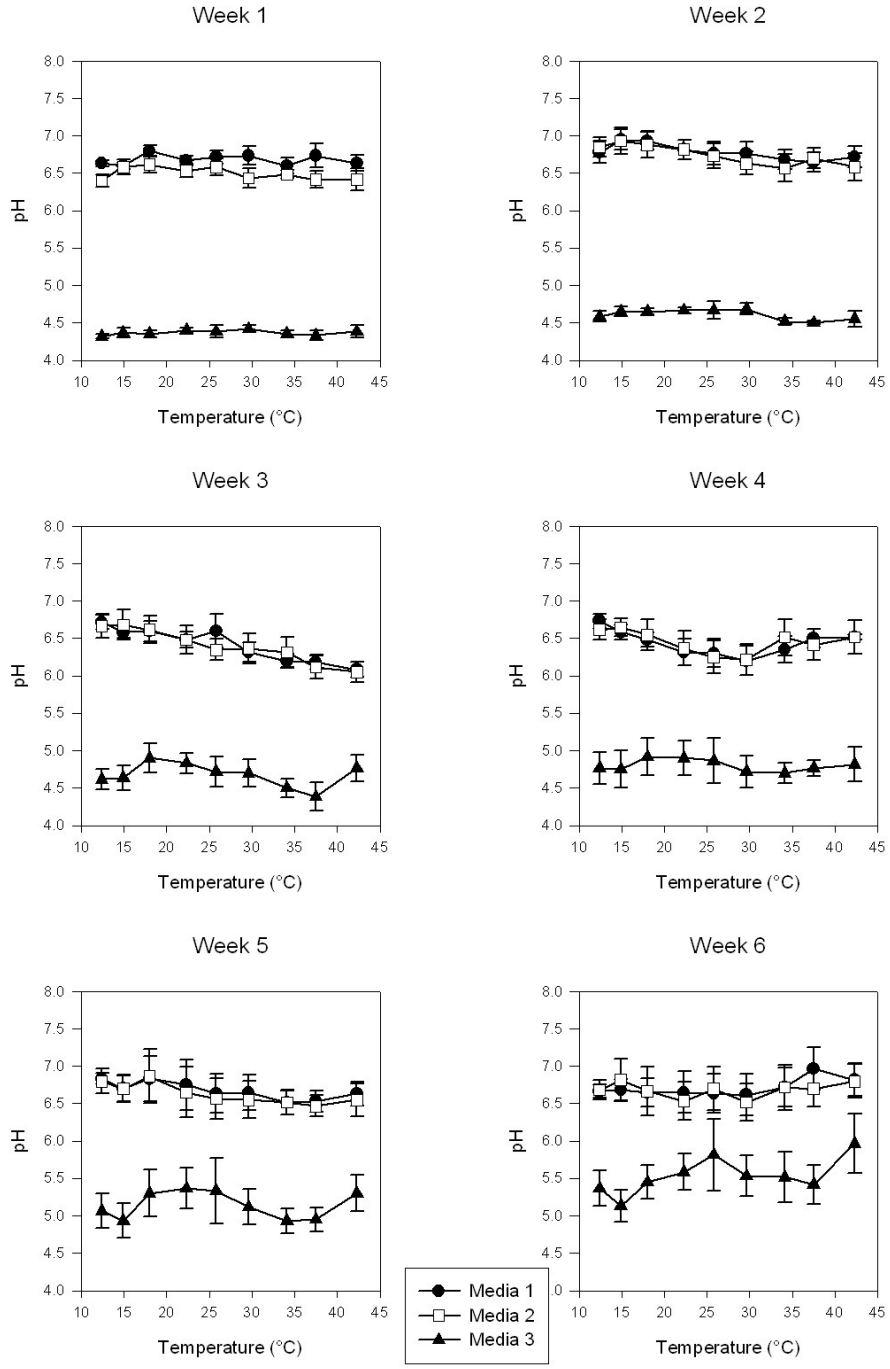

Figure 8. The effects of limestone grind size and root zone medium temperatures on leachate pH collected weekly for six weeks after transplanting for New Guinea impatiens 'Celebration Orange' (Media 1, 45 µm; Media 2, 75-150 µm; Media 3, 250-1,200 µm.)

Grind Size

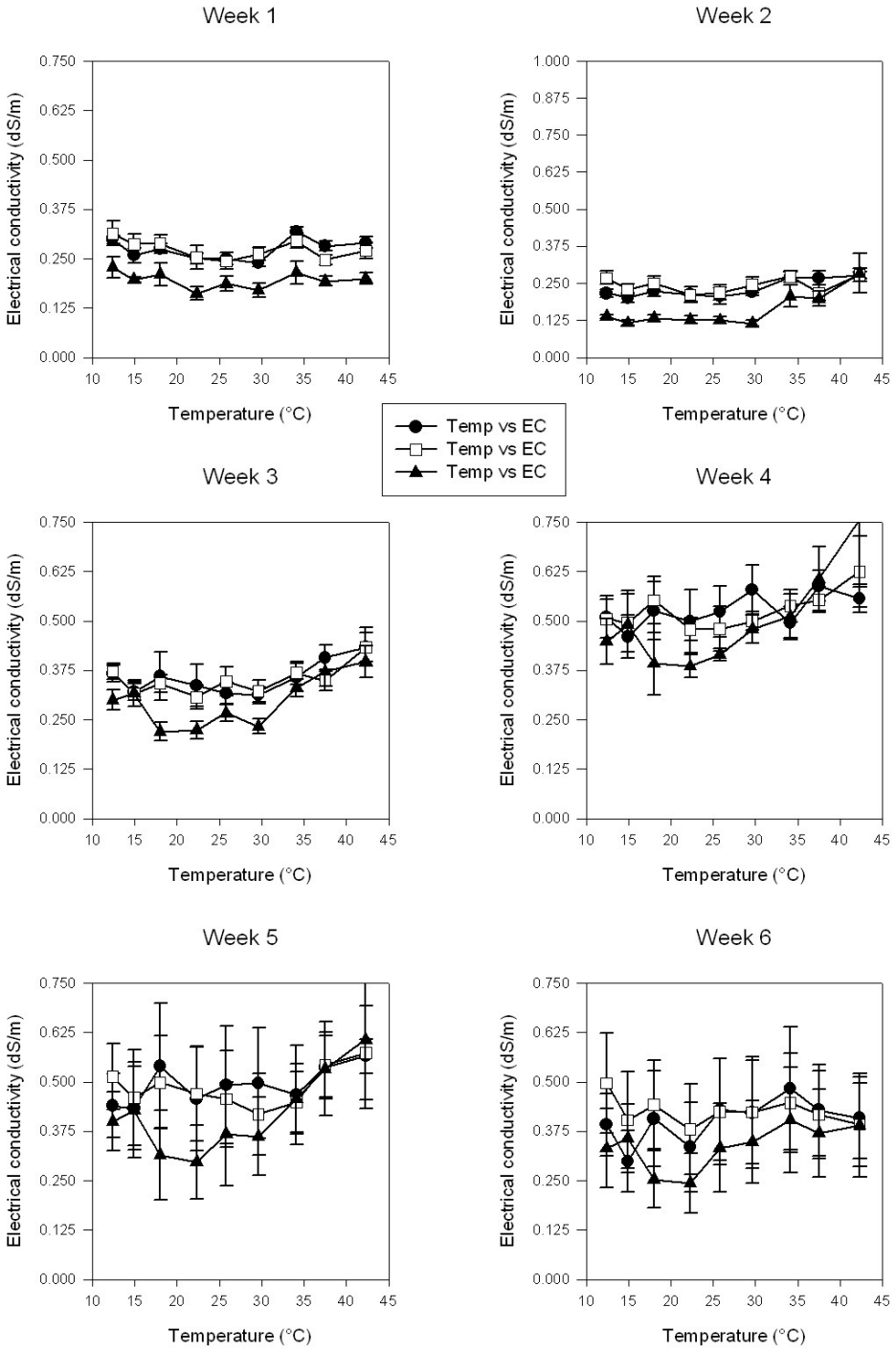

Figure 9. The effects of limestone grind size and root zone medium temperatures on leachate EC collected weekly for six weeks after transplanting for New Guinea impatiens 'Celebration Orange' (Media 1, 45 µm; Media 2, 75-150 µm; Media 3, 250-1,200 µm.)

Table 7. The effects of limestone sieve size and root zone medium temperatures on the height of New Guinea impatiens 'Celebration Orange' (± values represent the standard error of the mean).

Root zone Medium Temperature (°C)	Limestone Sieve Size (µm)					
	45		75-150		250-1,200	
	Height (cm)					
12.4	10.10	±0.55	9.98	±0.75	10.65	±0.60
14.9	12.22	±1.00	11.87	±0.75	12.18	±0.90
18.0	12.33	±0.85	12.83	±0.55	11.40	±0.85
22.3	11.58	±0.63	13.30	±0.22	11.62	±0.92
25.8	12.75	±0.91	13.07	±0.80	12.93	±0.73
29.6	12.37	±0.94	12.37	±0.76	12.68	±0.49
34.1	12.50	±0.39	12.12	±0.37	11.23	±0.67
37.5	11.65	±0.46	12.12	±0.24	10.88	±0.61
42.3	8.85	±0.23	9.02	±0.56	8.25	±0.26
Linear	0.2751[z]		0.2365		0.0290	
Quadratic	0.0002		0.0001		0.0001	

[z] $Pr>F$

Table 8. The effects of limestone sieve size and root zone medium temperatures on the dry weight of New Guinea impatiens 'Celebration Orange' (± values represent the standard error of the mean).

Root zone Medium Temperature (°C)	Limestone Sieve Size (μm)					
	45		75-150		250-1,200	
	Dry weight (g)					
12.4	5.09	±1.79	5.21	±1.79	5.07	±1.83
14.9	5.31	±1.79	5.37	±1.79	5.08	±1.70
18.0	5.32	±1.68	5.37	±1.70	5.21	±1.83
22.3	5.15	±1.71	5.32	±1.71	4.97	±1.69
25.8	5.14	±1.77	5.32	±1.71	5.18	±1.67
29.6	5.25	±1.73	5.35	±1.61	5.07	±1.69
34.1	5.26	±1.58	5.41	±1.72	6.12	±1.97
37.5	5.49	±1.77	5.48	±1.73	5.61	±1.77
42.3	5.20	±1.59	5.13	±1.58	4.95	±1.60
Linear	0.9436[z]		0.9972		0.8310	
Quadratic	0.9975		0.9946		0.9686	

[z] $Pr>F$

Chapter 5: Conclusions

When growing New Guinea impatiens it is important to closely monitor the pH of the crop and keep it in the ideal range, 5.8-6.5 (Hartley, 1995). Maintaining a root-zone medium pH in this range is a management tool for preventing the plants from taking up iron and manganese at rates that are too high and that can lead to issues with micronutrient toxicity. As previously mentioned the foliar damage caused by iron and manganese toxicity is irreversible and if it becomes severe may cause the plants to be unsalable. Even thought the New Guinea impatiens plants used in these experiments didn't express cupping, curling or distortion of the leaves, some plants exhibited slight marginal chlorosis. Perhaps in 5 to 6 weeks the iron and manganese content increased in the leaves but had yet to achieve the toxic levels that would cause severe leaf distortion symptoms.

The addition of limestone to a sphagnum peat moss based root-zone medium is necessary to provide a pH in the desired range of 5.8-6.5 for growing New Guinea impatiens (Hartley, 1995). Without any limestone added the pH never went above 4.5, which is not acceptable for producing floriculture crops. Keeping the calcitic limestone incorporation rate at 3 kg/m^3 and maintaining a root-zone temperature between 22.7 to 29.0°C provided a pH to best fit the desired range. The 6 kg/m^3 incorporation rate was simply too high, the lowest average pH recorded for was 6.73, which too high and does not fall into the ideal pH range for New Guinea impatiens.

The 250-1,200 μm calcitic limestone grind size is not a good choice for New Guinea impatiens production, the pH never went above a 5.97. Incorporating 45 or 75-150 μm grind size calcitic limestone at the rate of 3 kg/m^3 and maintaining a root-zone medium temperature 22.3 to 29.6°C provided a root-zone medium pH to best meet the desired the pH range.

It is important that a grower makes an informed decision when selecting the root-zone medium for growing a crop of New Guinea impatiens. Use a finer calcitic limestone and keep the incorporation rate in the 3 kg/m^3 range and strive to maintain a root-zone medium temperature in the 22.0 to 29.0°C temperature range. Following these guidelines will help a grower produce a quality crop of New Guinea impatiens that will please the customer.

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Appendix

Analysis of Variance Tables (ANOVA)

Table 9. Analysis of variance for root zone leachate pH for New Guinea impatiens 'Celebration Orange' grown under nine medium temperatures and three limestone rates. Leachate was collected at five 1-week intervals and analyzed as a repeated measures design.

Source of Variation	dF	Type III Sums of Squares	Pr>F
Limestone Rate	2	1329.59	<0.0001
Temperature	8	1.93	0.6963
Rate*Temp	16	4.92	0.5950
Block*Rate*Temp (Error A)	26	9.06	<0.0001
Week	4	4.73	<0.0001
Week*Rate	8	1.40	0.0155
Week*Temp	32	3.77	0.0202
Week*Rate*Temp (Error B)	64	3.83	0.8500

Table 10. Analysis of variance for root zone leachate electrical conductivity for New Guinea impatiens 'Celebration Orange' grown under nine medium temperatures and three limestone rates. Leachate was collected at five 1-week intervals and analyzed as a repeated measures design.

Source of Variation	dF	Type III Sums of Squares	Pr>F
Limestone Rate	2	1.16	<0.0001
Temperature	8	3.05	<0.0001
Rate*Temp	16	0.20	0.9934
Block*Rate*Temp (Error A)	26	1.10	0.9008
Week	4	9.42	<0.0001
Week*Rate	8	0.58	0.3373
Week*Temp	32	1.64	0.7780
Week*Rate*Temp (Error B)	64	0.55	1.0000

Table 11. Analysis of variance for plant height for New Guinea impatiens 'Celebration Orange' grown under nine medium temperatures and three limestone rates. Measurements were taken at the end of five weeks. The study was repeated twice over time serving as a blocking effect.

Source of Variation	dF	Type III Sums of Squares	Pr>F
Limestone Rate	2	5.54	0.2196
Temperature	8	278.80	<0.0001
Rate*Temp	16	13.94	0.9521
Block	1	998.05	<0.0001

Table 12. Analysis of variance for dry weight for New Guinea impatiens 'Celebration Orange' grown under nine medium temperatures and three limestone rates. Plants were harvested after five weeks and placed in a drying oven at 70°C for 48 hours. After 48 hours the bags were removed, weighed and dry weights recorded. The study was repeated twice over time serving as a blocking effect.

Source of Variation	dF	Type III Sums of Squares	Pr>F
Limestone Rate	2	0.3170	0.0098
Temperature	8	2.725	<0.0001
Rate*Temp	16	0.4568	0.6136
Block	1	1979.32	<0.0001

Table 13. Analysis of variance for root zone leachate pH for New Guinea impatiens 'Celebration Orange' grown under nine medium temperatures and three limestone sieve sizes. Leachate was collected at six 1-week intervals and analyzed as a repeated measures design. The study was repeated twice over time serving as a blocking effect.

Source of Variation	dF	Type III Sums of Squares	Pr>F
Sieve Size	2	654.46	<0.0001
Temperature	8	3.61	0.1670
Sieve*Temp	16	4.18	0.5422
Block*Sieve*Temp (Error A)	26	7.25	<0.0001
Week	5	29.14	<0.0001
Week*Sieve	10	29.39	<0.0001
Week*Temp	40	7.27	<0.0001
Week*Sieve*Temp (Error B)	80	3.24	0.9898

Table 14. Analysis of variance for root zone leachate electrical conductivity for New Guinea impatiens 'Celebration Orange' grown under nine medium temperatures and three limestone sieve sizes. Leachate was collected at six 1-week intervals and analyzed as a repeated measures design. The study was repeated twice over time serving as a blocking effect.

Source of Variation	dF	Type III Sums of Squares	Pr>F
Sieve Size	2	0.91	<0.0001
Temperature	8	1.12	0.0004
Sieve*Temp	16	0.51	0.2875
Block*Sieve*Temp (Error A)	26	0.65	0.3415
Week	5	11.60	<0.0001
Week*Sieve	10	0.09	0.9526
Week*Temp	40	0.57	0.9699
Week*Sieve*Temp (Error B)	80	0.39	1.0000

Table 15. Analysis of variance for plant height for New Guinea impatiens 'Celebration Orange' grown under nine medium temperatures and three limestone sieve sizes. Height measurements were taken at the end of six weeks. The study was repeated twice over time serving as a blocking effect.

Source of Variation	dF	Type III Sums of Squares	Pr>F
Limestone Rate	2	7.791	0.2017
Temperature	8	247.3	<0.0001
Rate*Temp	16	24.46	0.8499
Block	1	41.41	<0.0001

Table 16. Analysis of variance for dry weight for New Guinea impatiens 'Celebration Orange' grown under nine medium temperatures and three limestone sieve sizes. Plants were harvested after six weeks and placed in a drying oven at 70°C for 48 hours. After 48 hours the bags were removed, weighed and dry weights recorded. The study was repeated twice over time serving as a blocking effect.

Source of Variation	dF	Type III Sums of Squares	Pr>F
Limestone Rate	2	0.7224	0.0140
Temperature	8	2.537	0.0004
Rate*Temp	16	0.7394	0.9057
Block	1	2358.68	<0.0001