COMPARING THE EFFECT OF CONTROLLED-RELEASE, SLOW-RELEASE, AND WATER-SOLUBLE FERTILIZERS ON PLANT GROWTH AND NUTRIENT LEACHING

Thesis

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ABSTRACT

This thesis describes the effect of slow-release, controlled-release, and water-soluble fertilizers on plant growth and nutrient leaching. In the first experiment, four different fertilizers were applied at three rates each in order to investigate their effect on growth and quality of New Guinea Impatiens (NGI) (*Impatiens hawkeri* Bull.) 'Paradise New Red.' Fertilizer treatments included 1) Peters Peat-Lite 20-4.4-16.6 water-soluble fertilizer (WSF), 2) Daniels 10-1.8-2.5 soybean-based fertilizer (SBF), 3) Osmocote Plus 15-4-10, 3- 4 month longevity controlled-release fertilizer (CRF), 4) and Contec-DG 15-4-10, 5-month slow-release turf fertilizer (AGT). SPAD readings, plant dry weight (DW), consumer preference ratings (CP), and cumulative flower number (CFN) were measured and used to calculate a total quality index and select 'optimal' application rates for experiment two. SPAD, DW, and CP were significantly affected by increased application rates of all treatments. CFN was significantly affected by increased fertilization rate of SBF and AGT. High electrical conductivity (EC) in WSF plants had a negative effect on growth when EC exceeded 3.0 $dS{\cdot}m^{-1}$ at harvest. SBF applied at equivalent rates of N fertilization resulted in higher dry weight and significantly lower EC than WSF. 'Optimal' rates were determined to be 1) AGT at 2.14 $kg{\cdot}m^{-3}$, 2) CRF at 7.11 $kg{\cdot}m^{-3}$, 3) SBF at 150 $mg{\cdot}L^{-1}$ N, and 4) WSF at 75 $mg{\cdot}L^{-1}$ N. In experiment two, the effect of these 'optimal' rates on plant growth, nutrition, and nutrient leaching were compared. One or

more nutrient deficiencies were detected in every treatment except CRF, but were most detrimental on quality of AGT and SBF. While SBF plants appeared healthy, necrotic spotting occurred due to K deficiency. AGT plants were rated the lowest by consumers, grew the least, had lower SPAD, and were generally less floriferous than other treatments. CRF leached the most nutrients, most notably N (94-524% more total N), especially early in the production period. N, P, K, and Mg losses were the most affected by leaching with clear water to reduce supraoptimal substrate EC. SBF and WSF leached much less N than CRF, but did result in higher P leaching. While SBF leached similar amounts of N as WSF even though it was fertigated at twice the rate, higher N leaching may have occurred due to unmeasured urea in leachate. Based on these results, three-month longevity CRF and AGT may not be suitable for NGI fertilization. Further investigation into the effect of SBF on growth and nutrient leaching is needed. In experiment three, the effect of temperature on nutrient leaching at a 0.25 target leaching fraction was investigated during an eight-week period. Three fertilizers, 1) AGT, 2) Osmocote Plus 15-4-10, 5 to 6 month longevity controlled-release fertilizer (CRF2), and 3) MagAmp K 7-17.7-5 slow-release fertilizer (MAP), were applied at a standard N rate 0.54 $kg{\cdot}m^{-3}$. Treatments were incubated in growth chambers at constant temperatures of 18°C, 22°C and 26°C. The effects of temperature, irrigation amount, week, and the interaction between temperature and week on leaching of all nutrients were examined. With the exception of N, most nutrients from AGT were quickly solubilized and lost from the substrate, regardless of temperature. Methylene urea in AGT caused acidification of the substrate between 22-26°C and increased the solubility of Mn and

Mg. Nitrification reactions may have contributed to increased dissolution of some nutrients above 22°C for MAP. Temperature didn't have a large total overall effect on nutrient leaching from CRF2, but P and Ca leaching was higher at 18°C, possibly due to higher substrate moisture content. In general, when using controlled or slow-release fertilizers, mean temperatures at or below 18°C should be avoided as release and availability of some nutrients may be either reduced or not matched with plant nutritional requirements.

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Fields of Study

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1. Floriculture as an Industry

Floriculture is a multi-billion dollar per year industry that contributes significantly to total gross agricultural domestic product in the United States. The U.S. Department of Agriculture (2010) reported that in 2009, floriculture crop sales topped approximately US $3.69 billion, drawn from the 15 major production states. Floriculture crop categories included annual bedding plants, herbaceous perennial plants, potted flowering plants, indoor plants, cut flowers, and propagative floriculture materials. Out of all categories, forty-nine percent of total floriculture sales were attributed to bedding plants, with sales near $1.81 billion. The top bedding plant crops included begonias, geraniums, impatiens, marigolds, pansies, and petunias. Ohio ranked sixth nationally with floriculture sales reaching $192 million, behind California, Florida, Michigan, Texas, and North Carolina. In California, 2009 sales of large operations neared $1 billion.

Floriculture, like much of US agriculture, has become more centered on the expansion and maintenance of large, efficient operations. While the number of growers has decreased, sales per grower have increased. This is shown by a steady increase in average sales per acre, which increased by 4% in 2006 alone to $88,411 (Jerardo, 2007).

Additionally, a steady increase in total sales per large grower occurred in every crop category since 1992. Average sales per operation have nearly doubled since 1993, to $1.28 million. It is becoming more challenging as time progresses for small operations to remain sustainable and be profitable. In light of this fact, two thirds of cut flowers in the US were imported, primarily from South American countries such as Colombia and Ecuador, up at least ten percent since 2002. Unrooted cuttings are a large portion of imports, and are critical in keeping annual bedding and garden plant prices low. Prices, on the other hand, are increasing, with imported flowers rising by 22% since 2002, due to higher energy costs of fertilizer production and natural gas usage. Based on these challenges, growers must make changes if they have not already done so to reduce fertilizer use and increase efficiency. Fertilization practices not only significantly affect crop quality, but also profitability and may have substantial environmental consequences (Tyler et al., 1996).

1.2. Sustainability

For the purpose of this thesis, the term sustainability will be defined and placed into context. This term was first notably addressed in the Food, Agriculture, Conservation, and Trade Act of 1990 (FACTA), and focused on a long-term site-specific approach, by which livestock is integrated with crop production. The FACTA focused on the following goals of sustainability: satisfaction of food and fiber needs, enhanced environmental quality, efficient use of on-site and off-site resources along with appropriate use of "biological cycles and controls," continued economic viability, and enhancement of the "quality of life for farmers and society as a whole" (Gold, 1999; Poincelot, 2003). On the other hand, prevailing systems of agriculture are commonly referred to as “conventional or industrial and are generally viewed as input-intense operations that may vary widely throughout the world. The following characteristics, according to Gold (1999) represent the majority of current operations in agriculture: a tendency toward “rapid technological innovation; large capital investments in order to apply production and management technology; large scale farms;” monoculture; high yield and high value crops; “extensive” fertilizer, pesticide, and energy use; “high labor efficiency; and dependency on agribusiness.” While large-scale operations are not necessarily the problem, the focus on minimizing costs while maximizing production does not go without consequences. Stewart (2007) examined the industrialization of the floriculture industry and explained how it has largely followed the model presented by Gold (2007). Floriculture is facing many equivalent challenges as that of large scale agriculture and needs to address these factors influencing sustainability.

Implementation of sustainable practices is a challenging process. Naturally, operations are concerned with increasing costs and how to lower them while maximizing profit. However, an overall long rather than short-term approach to the matter is essential if true maximization of efficiency, and thus profit, is to be realized. It is important to first understand that complete sustainability is, in fact, not the goal – but rather maximization of effort toward this goal. A key factor is awareness that sustainability involves a union amongst elements of the environment, economy, and people (Doxon, 1991). All of these elements work together to define the market and what makes a product profitable and valuable. This is a modest starting point for operations, as product markets may vary across the industry. No matter the starting point, growers should be able to find ways to continually improve the sustainability of their operation. Sustainability is certainly not a static issue and will vary depending on changes in the market, economy, and resource availability. Such a program will focus on limiting negative effects of production on the environment, conserving energy, maintaining productivity, and promoting a positive presence amongst the public and local community (Lopez et al., 2008). Within this model, reductions in fertilizer use and nutrient losses by leaching are considered positive sustainable practices as components of limiting a grower's carbon foot-print (Lopez et al., 2008). Proper marketing of sustainability to consumers (Hall et al., 2009) will also determine which operations can take full advantage of early adoption of sustainable practices in addition to environmental benefits.

A notable certification program for potted plant and cut flower producers, VeriFlora 'Certified Sustainably Grown', defines stringent standards for producers in an effort "to provide a uniform standard and assessment matrix that can be applied when evaluating the sustainability performance of a diverse array of agricultural production approaches . . ." (SCS, 2007). There are eight unifying elements to the standardization process: 1) sustainable crop production, 2) ecosystem management and protection, 3) resource conservation and energy efficiency, 4) integrated waste management, 5) fair labor practices, 6) community benefits, 7) product quality, and 8) product safety and purity. These are all subcategories of the main framework for environmental sustainability, social and economic sustainability, and product integrity. For growers, VeriFlora can function as a positive marketing tool to highlight the value of sustainable products to consumers, and are expected to become more popular in the future (Dennis et al., 2010).

1.3. Fertilization and Environmental Quality

The relationship between fertilization practices and the environment has progressed further towards concern of reducing environmental contamination. One of the first documented mentions of environmental concern from fertilization practices was put forth by the Clean Water Act of 1972, which dealt with P and N – N holding the greatest risk for contamination due to its high usage (Merhaut et al, 2006). Nitrogen, being the most limiting nutrient in most systems (Vitousek et al, 1997; Mikkelsen and Bruulsema, 2005), happens to be often discussed in relation to losses and waste during production. Several studies still focus on N because it is the primary nutrient most prone to leaching and groundwater contamination (Engelsjord et al, 1997; Blythe et al, 2002; Morgan et al, 2009). It is also important to reduce N consumption because of its high cost (Morgan et al, 2009; Simonne and Hutchinson, 2005). Depending on the crop and fertility program, a large portion of the N applied may be lost through leaching into the soil profile or disposal into sewer systems and consequently rivers and streams (Broschat, 1995). Nutrient leaching occurs especially under production conditions of high rainfall or heavy irrigation (Vendrame et al., 2004). N leaching can lead to groundwater contamination, and may eventually enter surface watersheds, eventually dispersing into the ocean (Mosier et al, 1998). Groundwater contamination can result in levels in excess of the maximum N concentration of 10 $mg \cdot L^{-1}$ allowed by the EPA (Mosier et al., 1998). P is also problematic because it has the ability to contaminate surface water and is also easily leached from the soilless substrates commonly utilized in the floriculture industry (Godoy and Cole, 2000). Excessive fertilization practices may also result in ammonia volatilization, nitrous oxide emission (and thus ozone destruction), degradation of soils, algal growth, eutrophication, and other related forms of pollution (Shaviv and Mikkelsen, 1993).

Indoor greenhouse or glasshouse production is still connected to the surrounding outdoor environment. Completely or partially closed greenhouse systems, while highly efficient, are initially expensive and are often not implemented unless made compulsory by law (Opdam et al., 2005). They require a good water source and high value crops to be grown to be successful (Stanghellini et al, 2007). Policies also continue to change and are becoming more strict on growers, especially in Europe. In the Netherlands, stricter regulations have been put in place and are being enforced by court orders to decrease leaching of fertilizer and water into the environment, decreasing the number of crops that can be grown profitably (Stanghellini et al., 2007; Van Os, 1999). It could be inferred, that governments such as the United States may soon impose more strict guidelines for growers in relation to fertilization and leaching into the environment. Growers who do not pay attention to recommended practices to reduce leaching of nutrients into the environment may be eventually forced to do so by legal action.

1.4. Controlled and slow-release fertilizers

Controlled and slow-release fertilizers (C/SRFs) are described as materials that slowly release soluble nutrients over an extended period of time (Shaviv and Mikkelsen, 1993). These fertilizers are easily contrasted against water-soluble fertilizers (WSFs), which are instantly soluble and leachable when applied to media (Vendrame et al, 2004). Similarly, granular fertilizers (or dry, soluble fertilizer pellets) are also quickly soluble when exposed to moisture, can cause plant injury, quickly solubilize in media, and cause considerable leaching (Broschat, 1995). Likelihood of plant injury and nutrient leaching is reduced with C/SRFs (Broschat, 1995). C/SRFs are used primarily in specialty markets such as nursery (woody-plant) production and compose only 0.15% of the current fertilizer market with demand rising by approximately 5% annually (Medina et al., 2009; Morgan et al., 2009). These fertilizers are often utilized in a nursery setting in order to reduce nutrient losses due to high irrigation or rainfall and a wide variability in temperature (Broschat, 1995). In contrast, such conditions are not likely to be encountered in a greenhouse setting, which is under constant environmental control (Merhaut et al., 2006). In this context, it may be more difficult for greenhouse growers to recognize the potential advantages of fertilization with CRFs.

Controlled-release fertilizers (CRFs) consist of encapsulated solutions in a semi-permeable membrane, surrounded by a hydrophobic polymeric or sulfur coating (Birrenkott et al, 2005; Morgan et al, 2009; Shaviv and Mikkelsen, 1993). The coating on CRFs assists in limiting exposure of the core of the capsule to moisture, allowing for slow release of nutrients by diffusion (Morgan et al, 2009; Shaviv and Mikkelsen, 1993). Sulfur-based coatings consisting of sulfur-coated urea are relatively inexpensive, have low solubility, and allow for release through imperfections and small pore openings based on coating thickness (Morgan et al, 2009). On the other hand, the most advanced of the CRF products contain polymer coatings, which allow for even longer longevity and the ability to maintain constant release by adjusting not only coating thickness but composition as well (Morgan et al, 2009). A thicker polymeric coating will result in a product with a more extended longevity. A linear release rate of nutrients often does not occur due to differences in temperature, moisture content, and variability in coating thickness and granule size (Birrenkott et al., 2005).

SRFs also slowly release nutrients, but this occurs primarily due to microbial activity and/or chemical hydrolysis (Morgan et al., 2009). In order for adequate release to occur, sufficient moisture and warm temperatures (generally above 20°C) must be present in order to initiate and encourage microbial activity. SRF substances are only slightly soluble and require additional time for mineralization, thereby giving them slow-release properties. SRF materials may be organic or inorganic, and unlike CRFs are uncoated (Shaviv and Mikkelsen, 1993). A primary example of an organic slow-release fertilizer is compost. Inorganic examples include urea-based fertilizers (such as urea formaldehyde, isobutylidene diurea, and triazone), magnesium ammonium phosphates (MagAmps) and other materials which degrade biologically and aren't easily soluble (Guertal, 2009; Shaviv and Mikkelsen, 1993).

The use of C/SRFs in crop production has demonstrated much success. There are many advantages to using C/SRFs in bedding plant production and other agricultural crops.

C/SRFs have demonstrated the following advantages: 1) Nutrients are better utilized when slowly released throughout a season rather than applied in “bursts” or instantly soluble applications such as is the case in WSF (water-soluble fertilizer) application, thus increasing nutrient use efficiency and perhaps more closely synchronizing release rates with plant demand (Engelsjord et al, 1997; Merhaut et al, 2006; Morgan, et al, 2009, Mikkelsen and Bruulsema, 2005); 2) The quantity of fertilizer used is also reduced, leading to less of a risk for plant injury through high soluble salt levels (Engelsjord et al, 1997; Broschat, 1995); 3)Nutrient leaching is greatly reduced when using C/SRFs as compared to water-soluble fertilizers (WSFs) (Vendrame et al., 2004; Engelsjord et al., 1997; Blythe et al., 2002); 4) One fertilizer application may meet the seasonal need of the crop, reducing the need for additional labor (Mikkelsen and Bruulsema, 2005); and 5) Crops such as poinsettia, begonia, and new guinea impatiens produced using CRFs are shown to be of comparable or better quality than those produced with WSFs (Blythe et al, 2002; Richards and Reed, 2004).

Cost may be the issue that causes many growers to be reluctant in purchasing, and using CRFs in production (Medina et al, 2009; Mikkelsen and Bruulsema, 2005). However, each operation would benefit from conducting an in-house cost-benefit analysis. Due to a wide variability in formulations, crop demand, and necessitated application rates, this should be done on an operation-specific basis. Another concern growers may have is the current inability of CRFs, while they may constantly release nutrients, to match periods of high N demand (Simonne and Huchinson, 2005; Guertal, 2009). On the other hand, CRFs of different longevities exhibit different release patterns during bedding plant production, thus highlighting the importance of selecting the proper product (Andiru, 2010). Additionally, environmental conditions may dictate a higher N release pattern or loss based on high rates of leaching, constant moisture or saturation, and high temperature and humidity (Broschat, 1995; Shaviv and Mikkelsen, 1993). The consequence of such release characteristics may equate to the loss of control of a fertility program for some growers.

1.5. Soybean-based fertilizer

The idea of using alternative organic or waste-based sources of fertilizer is becoming more common as sustainability and concern for the environment grows. The majority of fertilizers are synthetically produced, and their nutrients are instantly available once applied (Guertal, 2009). Daniels 10-1.8-2.5 soybean-based fertilizer (SBF) (DP Foods, Sherman, TX) contains a biodegradable organic base derived from oilseed extract (Nelson et al., 2010). After oil extraction and additional extraction of the high quality oil for cooking purposes, the remaining material is separated for either animal feed or oilseed extract. This material is the water-soluble fraction containing sugars, amino acids, and organic acids (Nelson et al., 2010). The remaining organic material after extraction is commonly classified as waste (therefore requiring disposal), and contains small but notable amounts of nitrogen, phosphorous, potassium, and other minerals (Nelson et al., 2010).

Preliminary research suggests that SBF produces similar if not "better" quality bedding plants than commonly used water-soluble (WSF) sources of fertilizer such as 20N-4.4P-

16.6K (Nelson et al., 2009). Ammonium toxicity did not occur in SBF treatments containing equivalent concentrations of reduced N as WSF. In regard to plant nutrition, K concentrations were sufficient with no deficiency symptoms. Additionally, SBF acted as a pH buffer while maintaining lower EC and vigorous plants. The buffering ability of SBF may explain the result of the fertilizer's resistance to ammonium toxicity through the maintenance of higher pH (Nelson et al., 2010).

SBF should be further examined in its ability to 1) produce quality plants at equal to or lower concentrations than traditional water-soluble fertilizers, 2) reduce substrate EC and 3) maintain higher pH, in crops other than petunia, vinca, pansy, and cyclamen. The organic matter contained in the fertilizer may give it slow-release properties allowing for a smaller release rate of nutrients to be leached from media – thereby explaining the observed lower EC. While plant tissue nutrient concentration has been studied comparing SBF to WSF, nutrient and micronutrient concentration in leachate has not, and should be examined in order to determine if it is an environmental hazard.

1.6. New Guinea Impatiens

Impatiens were discovered in the 1800s and rose dramatically in popularity during the 1900s when collections and hybridization of the genus were made (Benjamin, 1990). After destruction of early impatiens collections by begonia mite infestations in the early 1900s, the USDA and Longwood Gardens funded a collection initiative headed by John Creech and Russell Siebert in the 1970s (Benjamin, 1990). This initiative was central to the promotion and discovery of a genus that would in the future become a very important crop to the floriculture industry and public (Cathey, 1995). NGI were produced from seed after their initial introduction into the U.S. The first commercially significant variety was 'Tango' in 1989 (Benjamin, 1990; Cathey, 1995). Today, new guinea impatiens (NGI) have risen to become a very popular landscape plant, often used in basked arrangements and can thrive for long periods of time under ideal conditions (Dole and Wilkins, 2005).

Before talking at all about nutrition, one fact should be made universally known about NGI. NGI are low fertility plants which are highly sensitive to soluble salts, especially before root establishment (Hartley, 1995). Ideally, no fertilizer should be applied within the first two to three weeks depending on environmental conditions and not until roots have filled to the sides of the container (Hartley, 1995). Substrate pH and EC should be closely monitored in an NGI fertility program. After establishment, plants are less sensitive to high soluble salts and should not be allowed to have an EC over 2.0 $dS \cdot m^{-1}$, and ideally less than 1.5 $dS \cdot m^{-1}$ (Judd and Cox, 1992). If the preferred method of nutrient delivery is fertigation, a rate of 100-200 $mg \cdot L^{-1}$ N is sufficient, or around 250-350 $mg \cdot L^{-1}$ N every third watering with a fertilizer such as 20-4.4-16.6 or 15-7-14.1 (Hartley, 1995). If EC exceeds 2.0 $dS \cdot m^{-1}$ during establishment, the media should be leached with clear water to allow excess soluble salts to escape (Hartley, 1995). Substrate pH should remain in the 5.8 to 6.5 range (Hartley, 1995). NGI are very efficient in their ability to uptake micronutrients such as Mn and Fe, resulting in higher sensitivity to micronutrient toxicities when pH drops below 5.8 (Hartley, 1995). If over-fertilization occurs, NGI grow poorly and can be stunted, develop large dark green leaves with a wavy or cupped appearance, and may have leaf tip burn and edge browning (Hartley, 1995). Under-fertilization results in chlorosis, purplish leaves, leaf drop and yellowing, and a reduction in flower size (Hartley, 1995).

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CHAPTER 2: IDENTIFYING OPTIMAL FERTILITY RATES FOR NEW GUINEA IMPATIENS

2.1. Introduction

New Guinea Impatiens (NGI) is an important crop for the floriculture industry. Of the $1.9 billion in sales of bedding and flowering plants in 2009, NGI sales surpassed $54 million (U.S. Dept. Agr., 2010). While NGI may be a significant source of income to growers, the issue of fertility management presents challenges. During establishment, NGI have been shown to be sensitive to soluble salts (Judd and Cox, 1992), highlighting the importance of constant control over the amount of nutrients applied and its monitoring of substrate electrical conductivity (EC). Substrate EC should not exceed 2.6 $dS{\cdot}m^{-1}$ during production, and EC above 1.5 $dS{\cdot}m^{-1}$ has been shown to inhibit growth (Cavins et al., 2000; Judd and Cox, 1992). Thus, fertilization rates are dictated based on substrate EC during production and inorganic water-soluble fertilizers (WSF) are often used to meet NGI nutritional requirements. However, other fertilizer types and application methods, such as controlled-release fertilizers have been demonstrated to be effective for NGI production (Richards and Reed, 2004). The issue of concern is the current inability of CRFs, while they may constantly release nutrients, to match nutritional demands for some crops (Simonne and Huchinson, 2005; Guertal, 2009).

Another fertilizers of probable interest in bedding plant production is soybean-based fertilizer (SBF) and slow-release turf fertilizer (AGT). In contrast to WSF, SBF contains a biologically-derived component from oilseed extract, and has been demonstrated to be successful in petunia, vinca, pansy, and cyclamen production (Nelson et al., 2010). Additionally, no work has been done evaluating AGT outside of the turf industry (OBIC, 2011). AGT contains granules that disperse into the substrate when water is applied, thus allowing for less fertilizer waste as a consequence of irrigation practices (OBIC, 2011). These fertilizers require additional research of their efficacy in floriculture production in general and NGI in particular.

Most studies dealing with bedding plants determine ideal fertilization rates based solely on aspects of growth, such as height, dry weight, or leaf area (James and van Iersel 2001; Kang and van Iersel, 2009; Kent and Reed, 1996, Richards and Reed, 2004). While growth is an essential element of plant quality, no studies have determined ideal rates also based on consumer opinion, as the consumer makes the determination of whether or not a plant is sold (Conover, 1986). There are many aspects of plant quality that are not related to plant size that may be more important factors when consumers decide to purchase a plant. Such aspects of quality include overall health and greenness, the presence of flowers, lack of insect damage, and crop uniformity (Conover, 1986).

The objectives of this study were to determine the effect of various rates of four different fertilizers on growth of New Guinea Impatiens (*Impatiens hawkeri* Bull.) ‘Paradise New

Red') and to identify their respective ideal rates based on three plant growth characteristics and consumer preference.

2.2. Materials and Methods

Substrate preparation. Substrate for this experiment consisted of a 7:3 ratio of peat (Sunshine Peat Moss, SunGro Horticulture, Bellevue, WA) to perlite (Thermo-Rock East, Inc., New Eagle, PA) mixture (by volume) with no pre-plant nutrient charge. Calcitic lime was added to the mix at a rate of 3.0 $kg \cdot m^{-3}$. A 1.0 L tap water solution of a wetting agent (AquaGro, Scotts Co., Marysville, OH) was also applied at a rate of 7.6 $mL \cdot L^{-1}$. The substrate was prepared and placed in sterile plastic bags ready for planting in 700 cm^3, 11.4 cm diameter plastic containers.

Crop selection and fertilizer treatments. Plugs of New Guinea Impatiens (*Impatiens hawkeri* Bull.) 'Paradise New Red' (Ecke Ranch, Encinitas, CA) were transplanted into 4.5" containers. Four fertilizers were selected for application at three rates each (not including the control group) with seven replications. Fertilizer treatments included Peters Peat-Lite 20-4.4-16.6 WSF (Scotts Co., Marysville, OH), Daniels 10-1.8-2.5 SBF (DP Foods, Sherman, TX), Osmocote 15-4-10, 3-month CRF (Scotts Co., Marysville, OH), and Contec-DG 15-4-10, 5-month slow release turf fertilizer (AGT) (The Andersons Co., Maumee, OH). AGT is used as a turf fertilizer and is not utilized in the floriculture industry. It was selected as a slow-release (non-encapsulated) fertilizer. CRF was applied at 1x, 0.75x, and 0.5x label rate, which resulted in the following rates: 7.11, 5.33, and 3.56 $kg \cdot m^{-3}$. These CRF rates of application are in line with previous experiments using this type of fertilizer on NGI (Richards and Reed, 2004; Vendrame et al., 2004). AGT was applied at rates of 3.57, 2.14, and 1 $kg{\cdot}m^{-3}$. WSF and SBF fertigation rates of 75, 150, and 250 $mg{\cdot}L^{-1}$ N were used based on a common range of fertigation rates in a greenhouse setting from what is considered relatively low, moderate, and high during NGI production (Hamrick, 2003; Hartley, 1995). The granular fertilizers (AGT and CRF) were evenly top-dressed on the surface of the substrate following transplanting of rooted cuttings. Fertigated treatments (SBF and WSF) were prepared immediately preceding irrigation events. Control plants had no fertilizer applied. Plants were placed and labeled based on a completely randomized design with seven replications in a greenhouse with a double layer acrylic roof at temperature settings of 22°C day and 18°C night, along with an allotted growing area of approximately 0.093 m^2 (1 ft^2) per plant.

Irrigation, substrate and crop monitoring. Plants were irrigated by hand every 1-5 days as needed and supplied either ~300 mL tap water or ~300 mL prepared fertilizer solution to allow the substrate to reach a target leaching fraction (LF) range of 0.2-0.3. Irrigation volume in experiments is often determined based on the leaching fraction (LF), which is defined as the effluent volume (volume of water leached) divided by the influent volume (volume of water applied) (Owen et al., 2008). EC measurements were taken using the pour-through nutrient extraction procedure (Cavins et al., 2000) at 9, 31, and 71 days after planting (DAP). Leachate EC and pH were measured using an EC/pH meter (Accumet Model AP85 pH/Conductivity meter, Fisher Scientific, Pittsburgh, PA) within two hours following collection. Once flowering ensued, flower number was recorded at

56, 63, 65, 70, 72, 77, 79, and 84 DAP and summed to obtain a cumulative flower number (CFN). Only fully open, non-senescent flowers were recorded.

Consumer preference survey. Chadwick Arboretum volunteers, students, and staff of the Department of Horticulture and Crop Science, The Ohio State University, Columbus, OH, were asked to evaluate plants shortly before harvest. This occurred at 76, 77, and 78 DAP. Before consumer preference evaluations, plants were organized by treatment and then treatments were completely randomized on a greenhouse bench. Volunteers were asked to evaluate plants in each treatment group based on four criteria: foliage and plant vigor, flower number, and uniformity. Participants were given a rating scale of one to five with one being poor or unacceptable, two being fair, three being good, four being very good, and five being excellent (Figure B.2). A total of 22 individuals anonymously participated in the survey.

Plant measurements. At harvest (84 DAP), plants were analyzed for relative chlorophyll content using a SPAD-502 meter (Konica Minolta Sensing, Tokyo, Japan) by taking an average reading from three fully expanded leaves at the upper most point of the plant. After obtaining SPAD readings, plants were cut at the crown directly above the substrate surface, placed in paper bags and located in a forced air oven (GS, Blue M Electric, Williamsport, PA) for 48 hours at 57°C to measure plant dry weight (DW).

Quality Indices. In order to determine ideal rates of fertilization based on all data obtained from the experiment, growth characteristics were transformed to a scale of 0-5 in order to equally represent a total quality index (QI) for each of the fertilizer treatments at the various rates. Four plant growth characteristics were used for this analysis: DW, CFN, SPAD, and overall consumer preference (CP). Measurements of each characteristic were transformed by dividing the replicate by the maximum observed value for each fertilizer treatment (hypothetical example: SPAD is 74 for a replicate, maximum observed SPAD value of CRF is 80, therefore $74/80 = 0.9 \times 5 = 4.6$). By transforming these measurements, each was equally weighed in the calculation of the total QI (QI = CP + SPAD + CFN + DW) of each replicate, thus allowing for a QI that represented all four growth characteristics. It is important to note, however, that total QI were solely means of representation of quality between rates of each fertilizer rather than between multiple rates and fertilizers as a means to determine any differences between the rates tested.

Data Analysis. PROC GLM was used for statistical analysis of DW, CFN, SPAD, CP, EC and pH across rates of fertilization using polynomial contrasts, quality indices with one-way ANOVA analysis and the least significant difference (LSD), and separation of all treatment means with Tukey's Honest Significant Difference (HSD) (SAS v.9.1, SAS Institute, Cary, NC). The format used for presentation of data in tables analyzed using polynomial contrasts was modeled from Bi et al. (2010).

2.3. Results

Substrate pH and electrical conductivity. Substrate pH did not vary significantly with increasing rates of fertilization at 9, 31, and 71 DAP (Table 2.1). pH usually remained within or slightly below the recommended pH range of 5.4-6.5 for bedding plant production (Nelson, 2003), especially near harvest (71 DAP). Substrate EC was significantly affected by increasing fertilization rate of all treatments at 9, 31, and 71 DAP with the exception of SBF treated substrate at 71 DAP. EC responded linearly and quadratically to CRF treated substrate at 9, 31, and 71 DAP, as well as WSF treated substrate at 71 DAP. EC of all other treatments responded linearly to increasing fertilization rate. In general, suggested substrate EC during NGI production is 1.0 to 2.6 $dS \cdot m^{-1}$ (Hamrick, 2003; Hartley, 1995). On 9 DAP, AGT substrate treated with 2.14 and 3.57 $kg \cdot m^{-3}$ were above the recommended EC range, as well as WSF treated substrate at 250 $mg \cdot L^{-1}$ N on 31 and 71 DAP. Substrate EC decreased over time for AGT, CRF, and SBF treated substrates but notably increased for WSF treated substrate 250 $mg \cdot L^{-1}$ N rate.

Plant Growth and Flowering. Increasing fertilization rates resulted in higher SPAD readings and DW (Table 2.2). SBF and WSF treated plants had higher SPAD readings than CRF and AGT treated plants. AGT treated plants had the lowest SPAD readings. SPAD readings responded linearly to increasing rates of AGT, SBF, and WSF; while responding quadratically for CRF. DW responded linearly and quadratically to increasing fertilizer rates with the exception of WSF treated plants, for which it only responded quadratically. Response of CFN with increasing fertilizer rates was significant for AGT and SBF treated plants; while CFN responded both quadratically and linearly to increasing AGT rates, and linearly only to SBF (Table 2.2). There were no differences in flowering with increasing CRF and WSF rates.

Consumer preference ratings. Consumer ratings of plant foliage and vigor, flower number, uniformity, and overall ratings were significant across increasing fertilizer rates with the exception of flower number for AGT and SBF treated plants (Table 2.3). Foliage and plant vigor ratings responded linearly and quadratically in all treatments, except for AGT, which only responded linearly. Plants with the highest foliage and vigor ratings were those treated with SBF and WSF. Flower number ratings responded linearly with increased fertilization rates of CRF and WSF. Flower number consumer ratings of AGT and SBF treated plants did not differ across rates. AGT, SBF, and WSF treated plant uniformity ratings responded linearly to increased fertilization rate, while CRF responded quadratically. Uniformity did not differ among most treatments. Overall CP ratings responded linearly to increased fertilization rate for AGT, SBF, and WSF, and quadratically for CRF. Overall ratings increased with increasing fertilization rate for AGT and SBF, and decreased for WSF and CRF. Consumers most preferred plants treated with AGT at 3.57 kg·m^{-3}, CRF at 3.56 and 7.11 kg·m^{-3}, SBF at 150 and 250 mg·L^{-1} N, and WSF at 75 and 150 mg·L^{-1} N with no significant differences.

Ideal fertility rates. There were significant differences in total QI for all fertilizer types except WSF (Table 2.2). Ideal rates of each fertilizer were determined as: 1) AGT at 2.14 kg·m^{-3}, 2) CRF at 7.11 kg·m^{-3}, 3) SBF at 150 mg·L^{-1} N, and 4) WSF at 75 mg·L^{-1} N.

2.4. Discussion

SPAD readings are a useful representation of overall plant health. SPAD readings have been highly correlated with chlorophyll content, and thus N and micronutrient status of bedding plants (Smith et al., 2004). Higher SPAD readings (Table 2.2) were due to higher N application rates (Table 2.4). Foliage and vigor ratings (Table 2.3) and SPAD readings (Table 2.2) were the lowest at lower N application rates, indicating that consumers recognized plants in poorer health. Consumers did not notice a difference in foliage and vigor when more than 337.5 mg total N was applied, suggesting this is the minimum amount of N to be applied in circumstances similar our experiment in order to produce a quality NGI plant.

EC was an effective tool to indicate whether growth inhibition occurred due to excessive substrate soluble salts. While many of the treatments exceeded 1.5 $dS{\cdot}m^{-1}$, WSF at 250 $mg{\cdot}L^{-1}$ N was the only treatment exceeding the maximum EC recommendation of 2.6 $dS{\cdot}m^{-1}$ for bedding plants classified as “light feeders,” based on the pour-through method (Cavins et al., 2000). Fertigating with WSF at 250 $mg{\cdot}L^{-1}$ N produced average EC values of 3.42 and 4.97 $dS{\cdot}m^{-1}$ at 31 and 71 DAP, respectively, explaining the significant growth suppression in comparison to the 150 $mg{\cdot}L^{-1}$ N WSF treatment, which remained below 2.08 $dS{\cdot}m^{-1}$ (Table 2.1). Substrate EC values from CRF treatments indicate that nutrient release may have been fairly constant and did not result in excessive soluble salt buildup at a 0.2-0.3 LF, even at the 7.11 $kg{\cdot}m^{-3}$ rate. Substrate treated with CRF during NGI production has been demonstrated to not exceed recommended levels even above this rate during subirrigation (Richards and Reed, 2004). Since NGI are light feeders, growth is less affected by low EC than high EC. AGT plants had the highest EC early in production, most likely due to rapid nutrient solubility (not measured), which suppressed plant growth early in production and reduced growth in the latter part of the experiment due to lack of nutrients (Table 2.2). Lack of nutrients during growth likely promoted flowering of AGT plants later on (Haver and Schuch, 1996). A significant linear and quadratic decrease in CFN with increased AGT fertilization rate (Table 2.2) is an indication of nutritional stress promoting earlier and more pronounced flowering during production (Haver and Schuch, 1996). On the other hand, while these plants may have had signs of stress, consumers highly rated plants at the 2.14 and 3.57 $kg{\cdot}m^3$ rates (Table 2.3). While consumers noticed significant differences in the foliage, flowering was more pronounced causing the overall ratings to be higher and comparable to other treatments. Making some adjustments in the release pattern of the AGT fertilizer may make its use in floriculture possible.

In contrast to WSF, SBF had a “buffering effect” on EC. These results are similar to those obtained by Nelson et al. (2010). In this experiment, SBF plants grew more than WSF treated plants at a rate of 250 $mg{\cdot}L^{-1}$ N (Table 2.2). This difference in DW was likely a result of lower EC and no growth suppression at high N fertigation concentrations. Consumers recognized the overall differences in these plants, as SBF plants at 250 $mg{\cdot}L^{-1}$ N were significantly preferred to WSF plants at the same rate (Table 2.3). These findings may be explained by how the biologically derived component in SBF reacts when it is added to the substrate, possibly acting as a “slow-release” fertilizer (Nelson, P.V., personal communication). This fertilizer contains nutrients that must undergo conversion to either nitrate (organic N, 0.75%) or ammonium (urea, 3.65%) to become available. As hypothesized in Nelson et al. (2010), the presence of a biologically derived component and ureaform N may explain the lower EC of SBF substrate.

Consequently, there may have been more N available during the latter part of the experiment when plant uptake was the highest.

Optimal fertility rates for CRF and WSF determined in this research were generally within accepted ranges for NGI production with fertilizers currently on the market (Hamrick, 2003; Hartley, 1995). Previous research has identified CRF as producing quality NGI plants at or above our ideal rate of 7.11 $kg \cdot m^{-3}$ (Richards and Reed, 2004). The determined ideal rate of WSF (75 $mg \cdot L^{-1}$ N) was the result of no significant differences in overall quality between rates. SBF plants at 75 $mg \cdot L^{-1}$ N and AGT plants at 1.00 $kg \cdot m^{-3}$ had noticeable symptoms of chlorosis, explaining why these rates resulted in significantly lower QI, due a reduction in DW, SPAD (Table 2.2) and CP (Table 2.3).

To our knowledge, this study provides consumer preference data that has not been previously acquired. There are no other studies evaluating the effects of different fertilizer types at varying rates on consumer preference ratings. It should be noted that while consumer preference ratings in this experiment are useful, they are not necessarily representative of the entire population. This rating system could be further developed and used in the future with a larger population size to more concretely identify differences in plants with several treatments applied. Also, future studies should be conducted in order to determine the minimum consumer preference ratings required to produce marketable plants for sale.

2.5. Conclusion

Different fertilizers applied at varying rates affected growth of New Guinea Impatiens (*I. hawkeri* Bull.) ‘Paradise New Red’ plants. Growers should be weary when changing fertility regimes and should closely monitor EC when growing NGI. When using WSF, substrate EC in excess of 3.0 $dS{\cdot}m^{-1}$ may result in suppressed NGI growth. CRF and SBF fertilizers did not exceed the recommended substrate EC at any rate. Unlike WSF, SBF fertilizer did not suppress growth when fertigated at a rate over 150 $mg{\cdot}L^{-1}$ N. While there is no published work in using AGT and SBF during NGI production, WSF and CRF ideal rates were in agreement with recommended ranges. While AGT at 3.57 $kg{\cdot}m^{-3}$ was one of the highest rated treatments overall by consumers, use of AGT to fertilize NGI is questionable due to high EC early in the experiment. Finally, further research on consumer preference of plants treated with different fertilizers is needed in order to identify important trends in preference and marketability of bedding plants.

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		9 DAP		31 DAP		71 DAP	
Fertilizer	**Application Rate**	pH	EC	pH	EC	pH	EC
Control	0	5.07	0.91	5.37	0.73	5.36	0.88
AGT	1.00 kg·m^{3}	5.78	1.50	5.90	0.90	5.79	0.84
AGT	2.14 kg·m^{3}	5.76	3.10	5.81	1.27	5.50	0.99
AGT	3.57 kg·m^{3}	5.71	5.30	5.97	1.98	5.43	1.09
CRF	3.56 kg·m^{3}	5.31	0.86	5.73	0.71	5.53	0.56
CRF	5.33 kg·m^{3}	5.53	0.92	6.11	0.91	5.96	0.64
CRF	7.11 kg·m^{3}	5.43	1.11	6.25	1.37	5.60	1.13
SBF	75 mg·L^{-1} N	5.08	1.27	5.49	0.96	5.46	0.70
SBF	150 mg·L^{-1} N	4.76	1.45	5.13	1.37	5.09	0.91
SBF	250 mg·L^{-1} N	5.10	2.01	5.34	2.10	5.29	1.02
WSF	75 mg·L^{-1} N	4.60	1.02	5.00	1.07	5.31	0.87
WSF	150 mg·L^{-1} N	5.18	1.28	5.39	2.08	5.05	2.06
WSF	250 mg·L^{-1} N	5.07	1.69	5.26	3.42	4.83	4.97
	HSD	1.30	0.68	1.26	0.51	1.13	0.92
				Fertilizer Rate Response			
AGT		NS	L***	NS	L***	NS	L*
CRF		NS	L***Q*	NS	L***Q*	NS	L***Q*
SBF		NS	L***	NS	L***	NS	NS
WSF		NS	L***	NS	L***	NS	L***Q***

NS, *, **, or *** non-significant, or significant at p ≤ 0.05, 0.01, or 0.001 respectively

Table 2.1. Average pH and EC (dS·m^{-1}) from three collection dates (7, 31, and 71 DAP) measured using the pour-through extraction method. Plants were treated with varying rates of AGT, SBF, CRF, and WSF. DAP = Days after planting. HSD = Tukey Honest Significant Difference between all treatment means (n=7, $P \leq 0.05$). Fertilizer rate response identified using significant quadratic (Q) or linear (L) polynomial contrasts.

Fertilizer	**Application Rate**	CP	SPAD	TV	CFN	TV	DW	TV	Total QI
Control	0	1.6	24.6	-	0.3	-	1.8	-	-
AGT	1.00 kg·m^{3}	2.7	38.0	2.8	28.1	3.5	6.1	3.1	12.2
AGT	2.14 kg·m^{3}	3.2	54.1	4.0	33.3	4.2	8.5	4.3	**15.7**
AGT	3.57 kg·m^{3}	3.7	63.6	4.8	17.7	2.2	8.6	4.4	15.1
CRF	3.56 kg·m^{3}	3.9	53.5	3.7	23.6	2.4	9.6	3.4	13.5
CRF	5.33 kg·m^{3}	3.2	56.5	3.9	24.0	2.4	10.0	3.6	13.1
CRF	7.11 kg·m^{3}	3.9	67.9	4.7	28.0	2.9	12.6	4.5	**15.3**
SBF	75 mg·L^{-1} N	3.0	56.7	3.6	12.3	1.5	11.1	2.5	10.5
SBF	150 mg·L^{-1} N	3.6	68.7	4.3	24.1	2.9	17.6	4.0	**14.7**
SBF	250 mg·L^{-1} N	3.8	73.3	4.6	26.6	3.2	19.0	4.3	15.8
WSF	75 mg·L^{-1} N	4.1	67.4	4.1	22.1	2.8	14.1	3.7	**14.7**
WSF	150 mg·L^{-1} N	3.9	73.1	4.5	29.1	3.6	16.7	4.3	16.3
WSF	250 mg·L^{-1} N	3.0	78.8	4.8	24.0	3.0	12.6	3.3	14.1
	HSD	0.7	6.9	-	21.0	-	2.4	-	-
					Fertilizer Rate Response				LSD
	AGT	L***	L***Q*		L*Q**		L***Q**		1.3
	CRF	Q***	L***Q*		NS		L***		0.8
	SBF	L***	L***		L*		L***Q**		1.1
	WSF	L***	L***		NS		Q**		2.4

NS, *, **, or *** non-significant, or significant at p ≤ 0.05, 0.01, or 0.001 respectively

Table 2.2. Average consumer preference overall rating (CP), SPAD readings, cumulative flower number (CFN), plant dry weight (DW) (g), and total quality index (QI). Plants were treated with varying rates of AGT, SBF, CRF, and WSF. TV represents the transformed values to a scale of 1 to 5 of the preceding (left to right) growth variables. Least Significant Difference (LSD) of the means was used to choose ideal rates ($P \leq 0.05$). Total QI is the sum of the TV values for all variables measured. Total QI (highlighted in bold) represent the optimal rate of each fertilizer. Values are the mean of seven replications. HSD = Tukey Honest Significant Difference between all treatment means (n=7, $P \leq 0.05$). Fertilizer rate response identified using significant quadratic (Q) or linear (L) polynomial contrasts.

Fertilizer	**Application Rate**	**Foliage and Vigor**	**Flower Number**	**Uniformity**	**Overall**
Control	0	1.10	1.20	2.50	1.60
AGT	1.00 kg·m^3	1.75	3.60	2.85	2.73
AGT	2.14 kg·m^3	2.40	3.95	3.10	3.16
AGT	3.57 kg·m^3	3.35	3.90	3.85	3.72
CRF	3.56 kg·m^3	3.75	3.95	4.05	3.93
CRF	5.33 kg·m^3	2.85	3.55	3.10	3.16
CRF	7.11 kg·m^3	4.30	3.40	3.90	3.87
SBF	75 mg·L^{-1} N	3.10	2.60	3.20	2.98
SBF	150 mg·L^{-1} N	4.30	2.70	3.65	3.55
SBF	250 mg·L^{-1} N	4.50	2.95	3.80	3.75
WSF	75 mg·L^{-1} N	4.40	3.75	4.25	4.14
WSF	150 mg·L^{-1} N	4.70	2.85	4.00	3.85
WSF	250 mg·L^{-1} N	3.60	2.10	3.30	3.01
	HSD	0.80	0.96	1.04	0.71
			Fertilizer Rate Response		
AGT		L***	NS	L**	L***
CRF		L*Q***	L*	Q***	Q***
SBF		L***Q*	NS	L*	L***
WSF		L***Q***	L***	L***	L***

NS, *, **, or *** non-significant, or significant at $p \leq 0.05$, 0.01, or 0.001 respectively

Table 2.3. Average consumer preference ratings. Survey conducted 76, 77, and 78 DAP. Ratings of foliage and vigor, flower number, and uniformity are based on a scale of 1-5, with 1 representing poor and 5 representing excellent. Overall ratings are a mean of the three aforementioned ratings. HSD = Tukey Honest Significant Difference between all treatment means (n = 22, $P \leq 0.05$). Fertilizer rate response identified using significant quadratic (Q) or linear (L) polynomial contrasts.

Fertilizer	Application Rate	N applied (mg)
AGT	1.00 kg-m^3	105.0
	2.14 kg-m^3	224.7
	3.57 kg-m^3	374.9
CRF	3.56 kg-m^3	373.6
	5.33 kg-m^3	559.7
	7.11 kg-m^3	746.6
WSF and SBF	75 mg-L^{-1} N	337.5
	150 mg-L^{-1} N	675.0
	250 mg-L^{-1} N	1125.0

Table 2.4. Total N (mg) applied. WSF and SBF total N applied is estimated based on approximate irrigation volumes of 300 mL per irrigation per plant and average frequency (3 irrigations per week) in an 11.4 cm diameter plastic container (700 mL).

CHAPTER 3: EFFECT OF FOUR DIFFERENT FERTILIZERS ON NEW GUINEA IMPATIENS GROWTH AND NUTRIENT LEACHING

3.1. Introduction

In containerized plant production, fertilizer nutrients are often lost from the substrate by leaching (Mikkelsen and Bruulsema, 2005) and fertilizer type has been demonstrated to significantly affect nutrient leaching (Broschat, 1995; Shaviv and Mikkelsen, 1993). Examples of different fertilizer types include water-soluble (WSF), slow or controlled-release (S/CRF), and granular fertilizers (Mikkelsen and Bruulsema, 2005). In New Guinea Impatiens (NGI) production, nutrients are usually delivered via fertigation (mixing of soluble nutrients in irrigation water) with water-soluble fertilizers (WSF) (Hartley, 1995). WSFs provide substantial control over the fertility regime. However, controlled-release fertilizers (CRF) have been demonstrated successfully for NGI production as an alternative to water-soluble fertilization, and can reduce nutrient leaching and increase fertilizer use efficiency (Richards and Reed, 2004; Haver and Schuch, 1996).

Most leaching studies have focused on N leaching due to its high usage and mobile nature in the soil and organic substrates (Cabrera et al., 1993; Hershey and Paul, 1982; Merhaut et al., 2006). P leaching is also of special concern due to its surface water contamination potential (Godoy and Cole, 2000). Leaching of other nutrients (such as Ca, Mg, Fe, Mn, Zn, and Cu) from container substrates in a greenhouse environment has been examined, but only from controlled-release fertilizers with no plants present (Blythe et al., 2006; Broschat and Moore, 2007). These nutrients have been shown to leach at concentrations above those recommended as safe by the EPA (Blythe et. al, 2006). Broschat (1995) examined N, P, and K leaching during outdoor production of foliage plants fertilized by several methods but did not measure leaching of other nutrients. To our knowledge, there are no studies available providing data on nutrient leaching of all nutrients during greenhouse production of bedding plants fertilized by several methods. Further investigation on the effect of different fertilization methods on bedding plant nutrition and leaching of nutrients is needed.

The objective of this study was to measure the effect of four different fertilizers on 1) plant growth, 2) nutrition, and 3) nutrient leaching in New Guinea Impatiens (*Impatiens hawkeri* Bull.) ‘Paradise New Red’.

3.2. Materials and Methods

Substrate preparation. Substrate for this experiment consisted of a 7:3 ratio of peat (Sunshine Peat Moss, SunGro Horticulture, Bellevue, WA) to perlite (Thermo-Rock East Inc., New Eagle, PA) mixture (by volume) with no pre-plant nutrient charge. Calcitic lime was added to the mix at a rate of 3.0 $kg \cdot m^{-3}$. A 1.0 L tap water solution of a wetting agent (AquaGro, Scotts Co., Marysville, OH) was also applied at a rate of 7.6 $mL \cdot L^{-1}$.

The substrate was prepared and placed in sterile plastic bags ready for planting in 700.0 cm^3, 11.4 cm diameter plastic containers.

Crop selection and fertilizer treatments. Plugs of New Guinea Impatiens (*Impatiens hawkeri* Bull.) 'Paradise New Red' (Ecke Ranch, Encinitas, CA) were transplanted into containers on January 20, 2010. Fertilizer treatments included 1) Peters Peat-Lite 20-4.4-16.6 (WSF) at a rate of 75 $mg{\cdot}L^{-1}$ N (Scotts Co., Marysville, OH); 2) Daniels 10-1.8-2.5 soybean-based fertilizer (SBF) at a rate of 150 $mg{\cdot}L^{-1}$ N (DP Foods, Sherman, TX); 3) Osmocote Plus 15-4-10, 3-4 month longevity (CRF) at a rate of 7.11 $kg{\cdot}m^{-3}$ (Scotts Co., Marysville, OH); and 4) Contec-DG 15-4-10, 5-month slow-release turf fertilizer (AGT) at a rate of 2.14 $kg{\cdot}m^{-3}$ (The Andersons Co., Maumee, OH). The above rates are 'optimal rates' obtained in Chapter 2. AGT and CRF were evenly top-dressed on the surface of the substrate following transplanting of rooted cuttings. Control plants had no fertilizer applied.

Irrigation, substrate and crop monitoring. On average, plants were hand watered every 3.2 ± 0.33 days, at a leaching fraction (LF) of 0.27 ± 0.01 (mean ± SE). Water volume averaged 251 ± 13 mL at each irrigation. In order to collect leachate for analysis, 300 mL plastic bowls were placed below the containers before the application of water to the substrate. Plastic mesh allowed for the containers to remain above the collection bowls to avoid container contact with the collected leachate. After measurement of the total amount of water leached, leachate aliquots were filtered with filter paper, stored in 20 mL plastic vials, and frozen at -10°C for later nutrient analysis. Leachate NO_3^--N and NH_4^+-N were measured using ion selective electrodes (ISE) (Scotts Testing Laboratory, Lincoln, NE). Inductively coupled plasma optical emission spectroscopy (ICP-OES, model IRIS Intrepid II, Thermo Electron, Waltham, MA) was used for analysis of leachate P, K, Ca, Mg, S, Na, Si, Fe, Mn, Zn, B, and Cu concentrations at the USDA-ARS Laboratory (University of Toledo, Toledo, OH). Substrate EC and pH of one test block (not used for analysis) was measured using the pour-through method (Cavins et al., 2000) at 16, 29, 36, and 66 DAP. EC and pH were measured using an EC/pH meter (Accumet Model AP85 pH/Conductivity meter, Fisher Scientific, Pittsburgh, PA). Pour-through pH was determined to be supra-optimal (Nelson, 2003) at 16 DAP (Table 3.1) and was lowered by application of a 95% sulfuric acid solution at a rate of 0.16 $mL \cdot L^{-1}$ at 21, 26, 31, and 34 DAP (Bishko et al., 2003). The solution was increased to 0.24 $mL \cdot L^{-1}$ at 46, 48, 52, 55, 58, 66, and 68 DAP. At 38 DAP, plants were leached with 432 ± 9 mL distilled water at a LF of 0.50 ± 0.01 because the pour through EC (Table 3.1) measurements were over 1.5 $dS \cdot m^{-1}$ (Hartley, 1995; Judd and Cox, 1992).

Consumer preference survey. Chadwick Arboretum volunteers, students, and staff of the Department of Horticulture and Crop Science, The Ohio State University, Columbus, OH, were asked to evaluate plants shortly before harvest. This occurred at 76, 77, and 78 DAP. Before consumer preference evaluations, plants were organized by treatment and then treatments were completely randomized on a greenhouse bench. Volunteers were asked to evaluate plants in each treatment as a group and identified with a number based on four criteria: foliage and plant vigor, flower number, and uniformity. Participants were given a rating scale of one to five with one being poor or unacceptable, two being fair, three being good, four being very good, and five being excellent (Figure B.2). A total of 21 individuals anonymously participated in the survey.

Plant analysis. At harvest (77 DAP), plant leaves were analyzed for relative chlorophyll content using a SPAD-502 meter (Konica Minolta Sensing, Tokyo, Japan) by taking an average reading from three fully expanded leaves at the upper most point of the plant. Flowers were collected and their diameter (FD) measured at harvest. Once flowering ensued (average days to flower: 68.4 ± 2.4), flower number was recorded at 59, 68, 70, 72, 74, and 76 DAP and summed to acquire a cumulative flower number (CFN). Only fully open, non-senescent flowers were counted for CFN and measured for FD. Plant shoots were cut at the crown directly above the growing media and flowers were removed to be placed separately in paper bags for placement in a forced air oven for 48 hours at 57°C to obtain plant shoot dry weight (SDW) and flower dry weight (FDW) (GS, Blue M Electric, Williamsport, PA). Photographs of plants with visible nutrient deficiencies were taken at harvest using a digital camera (Sony Cybershot DSC-T20, Sony Corp., Tokyo, Japan). In preparation for nutrient analysis, plant tissues were ground (Thomas Scientific Grinder, Swedesboro, NJ), passed through a mesh screen, and digested using a microwave digester (MARS Express, CEM Corp, Phoenix, AZ). USEPA method 3051 was used for measurement of tissue P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn (USDA-ARS Laboratory, University of Toledo, Toledo, OH). A combustion analyzer was used for measurement of tissue N (Model 2400, Perkin Elmer, Covina, CA).

Data Analysis. Plants were organized following a randomized complete block design with six replications in a greenhouse with temperature settings of 22°C day/18°C night, with an allotted growing area of approximately 0.093 m^2 (1 ft^2) per plant. Preliminarily data analysis was conducted by regressing nutrient cumulative leaching data against time, blocking, and fertilizer type using a general linear model (PROC GLM). All remaining data were analyzed using ANOVA with mean separations by the least significant difference (LSD) in PROC GLM (SAS v.9.1, SAS Institute, Cary, NC). Graphs of cumulative leaching over time were created using SigmaPlot v.11.0 (Sistat Software, Chicago, IL).

3.3. Results

pH and EC. Substrate EC increased up to 36 DAP before all substrates were treated with distilled water at a LF of 0.50 ± 0.01 on 38 DAP (Table 3.1). CRF EC early in the experiment was very high, and reached above 2.6 $dS·m^{-1}$, with a maximum of 3.38 $dS·m^{-1}$ at 36 DAP. EC was measured again before harvest at 66 DAP, at which point EC was within the acceptable range (<1.5 $dS·m^{-1}$) for the test block. Initial substrate pH was high (>6.5) but decreased over time to acceptable ranges for most fertilizer treatments by 36 DAP and all treatments by 66 DAP, excluding the control, which remained above pH 7.

Plant growth and flowering. SPAD readings, CFN, FDW, FD and SDW of NGI plants were all significantly affected by fertilizer type (Table 3.2). AGT plants had the lowest SPAD, FD, and SDW out of all fertilized plants. There was no difference in SPAD and FD of WSF, CRF, and SBF grown plants. CRF and WSF plants had the highest CFN, while AGT and SBF plants had the lowest. FDW was highest when plants were treated with WSF, lowest in AGT, and similar between CRF and SBF treated plants. WSF and SBF plants were the largest, followed by the CRF and AGT treated plants. Control plants had the lowest SPAD, CFN, FD, and SDW.

Tissue macronutrient concentrations. Fertilizer type significantly affected shoot macronutrient concentrations (Table 3.3). N concentrations were highest in SBF treated plants and lowest in AGT treated plants. P in shoot tissue of plants treated with WSF and SBF was higher than those treated with CRF and AGT. K concentrations were highest for WSF and CRF plants, and below the recommended range (Mills and Jones, 1996) for SBF and AGT plants. SBF plants had the lowest shoot K concentrations and developed typical K deficiency symptoms (Gibson et al., 2008) exhibiting necrotic spots on leaves (Figure 3.1). AGT plants had some necrotic spotting as well but it was not as pronounced (Figure 3.2). Shoot Ca concentrations were highest in control and SBF plants and lowest for AGT, CRF, SBF, and WSF fertilized plants. Mg concentration in tissue did not differ except for being highest in plants treated with SBF. S concentrations in tissue of most plants were similar except slightly lower in AGT fertilized plants. Control plants were N, P, and K deficient.

Tissue micronutrient concentrations. Fertilizer type significantly affected shoot micronutrient concentrations (Table 3.4). Shoot B concentrations were highest in CRF plants and lowest in AGT and SBF plants. Cu concentrations of AGT treated plants were below the sufficiency range and lowest when compared to other fertilizers (Mills and

Jones, 1996). AGT plants did develop noticeable symptoms of Cu deficiency (Gibson et al., 2008) with chlorosis, upward cupping, and rolling at the leaf margins of younger leaves (Figure 3.2). Cu concentrations of CRF plants were the highest. Fe was deficient (Mills and Jones, 1996) and total Fe concentration were lowest in plants treated with AGT and WSF (Table 3.4). Control plants were Cu and Fe deficient. While WSF tissue concentrations of Fe were below sufficiency standards, visual Fe deficiency symptoms (Gibson et al., 2008) were not apparent (Figure 3.3). Also, Fe deficiency symptoms were not distinctly apparent for AGT (Figure 3.2). Fe tissue nutrient concentrations were highest in plants treated with SBF and CRF fertilizers. AGT plants had the highest Mn (excluding the control), while CRF, SBF, and WSF had the lowest. Shoot Zn concentrations were highest in CRF and SBF plants, followed by WSF plants, and lowest in AGT plants. Tissue of CRF plants did not contain any nutrient concentrations below the sufficiency range (Table 3.4) and no nutrient deficiency symptoms were observed (Figure 3.4).

Macronutrient leaching. Fertilizer type significantly affected the total macronutrients leached (Table 3.5). CRF leached significantly more N than other treatments. There were no differences in total N leached from WSF and SBF, even though N applications for SBF were twice as high as WSF (150 and 75 $mg \cdot L^{-1}$ N, respectively).P leaching was the highest in WSF and SBF; however, the total P leached from WSF, CRF, and AGT plants was similar. CRF, AGT, and WSF leached comparable amounts of K while SBF leached the least K. SBF leached 26-151% less K than other fertilizers. AGT and CRF leached the most Mg, while SBF and WSF leached lower amounts.AGT leached the most S and WSF, CRF, and SBF plants leached similar total amounts during the experiment.

Cumulative N (Figure 3.5), P (Figure 3.6), and K (Figure 3.7) leached gradually increased over time for WSF and SBF. Additionally, cumulative N leached was nearly identical for WSF and SBF (Figure 3.5). CRF leached the most N early in the production period with 83% of total N leached before the leaching event (LE) at 38 DAP, and 81%, 94%, and 524% more N than WSF, SBF, and AGT, respectively. Unlike with other treatments, cumulative N leached from AGT increased by only 9% after the LE. AGT and CRF cumulative P (Figure 3.6) and K (Figure 3.7) leached increased up to the LE with a minor increase thereafter. Once the LE occurred, 88% and 76% of total P leached was lost from AGT and CRF, versus 47% and 43% from WSF and SBF. In addition, at this point in time, cumulative K leached from AGT and CRF considerably increased to 87% and 96% of the total K leached during the experiment.

Mg (Figure 3.8) and S (Figure 3.9) leached increased over time for all fertilizers. There was a noticeable surge in Mg leached after the LE, when 38% of total Mg leached was lost, on average (Figure 3.8). WSF and SBF followed a parallel cumulative Mg leaching pattern, with lower cumulative leaching than AGT and CRF. Similarly, cumulative Mg leached from AGT and CRF was not significantly different. AGT had a considerably higher increase in S cumulative leaching than other fertilizers at the LE when about 46% of the total S leached was lost versus 32% on average for other fertilizers (Figure 3.9).

Micronutrient leaching. Fertilizer type significantly affected the amount of Fe, Zn, and B leached (Table 3.6). There were no significant differences in Mn and Cu leached when fertilizer was added. AGT leached the least Fe and Zn, while CRF, SBF, and WSF leached the most. CRF leached more B than AGT, while there were no differences in B leached between other treatments. In general, cumulative micronutrient leaching increased over time. There were noticeable increases in Fe leached after the LE for CRF and WSF, at which point 40% and 20% of total Fe leached was lost, respectively (Figure 3.10). CRF leached more Mn early in the experiment with 54% of total Mn leached by the LE, while SBF cumulative leaching increased noticeably more than other fertilizers with 76% of total Mn leached after the LE (Figure 3.11). SBF cumulative Mn leached eventually surpassed all other treatments and leached more total Mn during the experiment than other fertilizers (Table 3.6). CRF cumulative Zn (Figure 3.12) and Cu (Figure 3.13) leached increased noticeably more than other treatments at the LE. At this point, 30% of total Zn (Figure 3.12) and 76% of total Cu (Figure 3.13) leached was lost in contrast to 9-14% and 47-55% for other fertilizers, respectively. Cumulative B leached followed a similar trend for all the treatments with a 59-65% of total B leached by the LE, followed by a minimal increase thereafter (Figure 3.14).

Consumer preference ratings. Fertilizer type significantly affected consumer preference ratings (Table 3.7). Amongst the fertilizer treatments, AGT plants had the lowest foliage and vigor ratings with no difference between CRF, WSF, and SBF plants, which received the highest consumer ratings. CRF, SBF, and WSF plants were perceived as having the most flowers, while AGT plants received the lowest flower number rating among fertilizers. Consumers viewed AGT plants as the least uniform while WSF and CRF plants were the most uniform, with SBF plants in between. Overall consumer ratings were the highest for WSF and CRF plants, intermediate for SBF plants, and lowest for AGT plants. Overall ratings did not differ between SBF and WSF plants, but CRF plants were more highly rated than SBF plants.

3.4. Discussion

SBF and WSF plants had the highest SDW (Table 3.2) probably due to the constant application of soluble N and thus constant availability of the nutrient to the plants. This result was obtained even though they received less total N than CRF (Table 3.8). In contrast, high EC (>1.5 $dS \cdot m^{-1}$) early in the experiment (Table 3.1) in addition to high N release as identified by leaching (Figure 3.7), may have suppressed growth of CRF treated plants (Judd and Cox, 1992) (Table 3.2). The release of N from CRF during this period was likely not synchronized with nutritional demands of the plant, which is an issue of concern when using CRF in bedding plant production (Simonne and Huchinson, 2005; Guertal, 2009). These results are similar to those demonstrated by Hershey and Paul (1982), where CRF of 3-4 month longevity leached more N than WSF at a 0.27 LF. It should be noted, however, that in a production setting, different results in total leaching of N may occur due to the irrigation method. In our experiment, WSF was applied directly to the substrate. If overhead watering with a hose occurs, CRF is likely to result in significantly lower leaching of N and other nutrients (Andiru, 2010).

AGT plants were the smallest likely due to less total N applied (Table 3.4), high EC early in the experiment (Table 3.1), and very early losses of N shown by cumulative leaching leveling off by the middle of the experiment (Figure 3.5). Similarly, AGT plants were significantly smaller and had higher substrate EC in Chapter 2. Due to less N being applied and lack of availability later in the experiment, AGT N shoot tissue concentrations were the lowest of any fertilizer treatment (Table 3.2). On the other hand, SPAD readings only differed for AGT plants suggesting that CRF, SBF, and WSF treatments all had similar chlorophyll levels.

Consumers were able to visually identify what the SPAD meter quantified (Table 3.5), with no differences in foliage and vigor ratings between CRF, SBF, and WSF plants. These results are in agreement with previous research suggesting that SPAD is a good indicator of overall plant health and color (Smith et al., 2004). Additionally, plant color and overall health may be an aspect of quality more attractive to the consumer than size (DW) alone, since CRF plants were significantly smaller than SBF and WSF plants (Table 3.2).

SBF plants were K deficient (Table 3.3; Figure 3.1) most likely due to the low proportion of K (2.5%) provided by the fertilizer. SBF plants at the same rate in Chapter 2, while not conclusively determined by tissue analysis, also exhibited K deficiency symptoms. These results are different from those obtained by Nelson et al. (2010) suggesting that fertilization of bedding plants with SBF does not cause K deficiency. The presence of necrotic spots on some SBF plants (Figure 3.1), while unsightly, were not so common to cause a significant difference in consumer ratings of foliage and vigor in comparison to WSF and CRF plants (Table 3.5). However, SBF plants were rated lower for uniformity, possibly because the necrotic spotting was more pronounced on some plants than others. Similarly, chlorosis of AGT leaves due to Cu deficiency (Figure 3.2) may have contributed to lower consumer uniformity ratings (Table 3.5). Since SBF plants were K deficient (Table 3.3), addition of supplemental K during production may be needed to grow plants of acceptable quality. AGT plants had a yellowish green color and lower SPAD readings, due to N deficiency (Gibson et al., 2008). WSF plants did not manifest Fe deficiency symptoms (Figure 3.3) and the lack of Fe deficiency symptoms could be explained by the fact that NGI are Fe efficient plants (Hartley, 1995).

The water LE at 38 DAP caused large losses of K (Figure 3.7), P (Figure 3.6), and Mg (Figure 3.8) from the CRF and AGT treatments because these nutrients were already present in the substrate in large quantities before leaching. These results are in contrast to the losses of fertigation treatments at constant rates for the entire production period for SBF and WSF. These treatments had minimal increases in cumulative K (Figure 3.7), P (Figure 3.6), and Mg (Figure 3.8) leaching after the water LE because lower concentrations of total soluble nutrients were present in the substrate.

Total N leached and N leaching over time was not significantly different between SBF and WSF due to the high proportion of urea and organic-N in SBF (44%). Urea in its chemical form ($(NH_2)_2CO$) is highly soluble in water but it does not have a chemical charge. Therefore, urea and organic-N not converted to ammonium was immediately leached and not detected by ISE. When comparing total N applied as a representation of NH_4^+ + NO_3^-, 499.0 mg·N^{-1} and 448.5 mg·N^{-1} was applied to SBF and WSF plants, respectively. While SBF plants did not have higher SDW than WSF plants, they had significantly higher shoot N concentrations due to the proportion of urea and organic N that remained in the substrate after irrigation and underwent conversion into NH_4^+. This would suggest that there were additional total N losses from SBF that were not quantified by the method used to detect N in leachates. If SBF is used in a setting where leaching losses occur, the urea portion will eventually be naturally converted into NH_4^+ and could be environmentally problematic. Since SBF has been demonstrated to cause significantly lower substrate EC than WSF (see Chapter 2) due to its high urea and organic-N concentration (Nelson et al., 2010), it may have applications in zero leaching or subirrigation systems. It should be reiterated, however, that plants treated with 75 mg·L^{-1} N in the previous chapter were found to have significantly lower quality (as represented by the quality index) than the 150 mg·L^{-1} N rate. Nelson (2010) also recommended that SBF not be used at low concentrations (less than 100 mg·L^{-1} N) because it did not supply sufficient quantities of macronutrients. Therefore, the applicability of SBF in the environmentally conscious setting requires further investigation, as necessitated higher rates of fertigation may result in greater nutrient leaching at the expense of maintaining plant quality.

3.5. Conclusion

Fertilizer type significantly affected growth, nutrient leaching, and nutrition of NGI ‘Paradise New Red’ plants. Plants grew more when fertigation was used as a method of fertilizer application. AGT treated plants grew the least, had lower SPAD, less flowers, were rated the lowest overall by consumers, and were K, Cu, and Fe deficient. SBF plants were K deficient both visibly and based on tissue K concentrations. CRF plants, while smaller than WSF and SBF plants, were comparable if not superior overall in regard to flowering and consumer preference ratings. Also, CRF plants, unlike other treatments, did not produce tissue below nutrient sufficiency levels suggested for NGI. WSF plants did not exhibit Fe deficiency symptoms even though Fe tissue concentrations were below industry standards. Overall, CRF leached the most nutrients (especially N) due to release that did not match plant requirements early in the production period. These results were unexpected. A three-month release CRF like that used in this experiment may not be ideal for NGI due to high EC and N leaching early in the production period, even though production of these plants occurred over a shorter period of time than three months. On the other hand, WSF and SBF resulted in larger plants and less waste of nutrients by leaching. SBF leached similar amounts of N (N = NH_4^+ + NO_3^-) as WSF; however, SBF leachates may have had higher total N concentrations due to unmeasured urea in leachate. Further investigation on the impact of SBF and CRF of varying longevities on N leaching and growth of bedding plants may be needed.

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		16DAP		29DAP		36DAP		66DAP	
		pH	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**
Fertilizer	**Application Rate**								
Control	0	7.28	0.66	7.11	0.97	7.15	1.40	7.03	1.15
AGT	2.14 kg·m^3	6.81	1.85	6.78	1.60	6.31	2.35	6.16	1.38
CRF	7.11 kg·m^3	6.61	2.02	6.48	2.93	6.11	3.38	5.41	1.36
SBF	150 mg·L^{-1} N	7.06	0.94	6.72	1.00	6.56	1.93	5.94	1.35
WSF	75 mg·L^{-1} N	6.66	1.03	6.57	1.27	6.16	1.98	5.42	1.68

Table 3.1. Substrate pH and EC (dS·m^{-1}) of one test block. The pour-through method was used to measure EC and pH at 16, 29, 36, and 66 DAP, following application of irrigation water or prepared fertilizer solution.

Fertilizer	Application Rate	SPAD	CFN	FDW (g)	FD (cm)	SDW (g)
Control	0	41.5c	1.8c	1.3b	5.4c	2.3d
AGT	2.14 $kg \cdot m^3$	56.8b	17.8b	1.0b	6.7b	7.2c
CRF	7.11 $kg \cdot m^3$	65.0a	27.7a	1.9ba	7.1a	9.9b
SBF	150 $mg \cdot L^{-1}$ N	69.3a	18.3b	1.5ba	7.1a	11.4a
WSF	75 $mg \cdot L^{-1}$ N	65.0a	24.8ba	2.0a	7.0a	11.2a
	LSD	4.6	7.0	0.7	0.3	1.2
	Significance	***	**	*	***	***

*, **, or *** significant at $p \leq 0.05$, 0.01, or 0.001 respectively

Table 3.2. Plant SPAD readings, cumulative flower number (CFN), total dry weight of all flowers at harvest (g) (FDW), flower diameter (cm) (FD) and shoot dry weight (g) (SDW). Means with the same letter in each column are not significantly different. Values represent a mean of six replications.

		N	P	K	Ca	Mg	S
Fertilizer	**Application Rate**	*Macronutrient (% of Dry Weight)*					
Control	0	1.36e^z	0.07c^z	0.73d^z	1.23a	1.07b	0.39c
AGT	2.14 kg·m^3	1.92d^z	0.38b	1.25c^z	1.11b	1.01b	0.66b
CRF	7.11 kg·m^3	3.29b	0.38b	1.60b	1.06b	1.02b	0.75a
SBF	150 mg·L^{-1} N	3.66a	0.51a	0.94d^z	1.15ba	1.28a	0.76a
WSF	75 mg·L^{-1} N	2.84c	0.48a	2.16a	1.12b	0.99b	0.74a
	LSD	0.33	0.05	0.24	0.11	0.10	0.06
	Significance	***	***	***	*	***	***

, or * significant at $p \leq 0.01$, or 0.001 respectively

^{z} = below recommended nutrient sufficiency range (Mills and Jones, 1996)

Table 3.3. Shoot tissue macronutrient (% of dry weight) concentrations. Values represent a mean of six replications. Means with the same letter in a column are not significantly different.

		B	Cu	Fe	Mn	Zn
Fertilizer	**Application Rate**			*Micronutrient ($mg \cdot kg^{-1}$)*		
Control	0	25.48b	2.01d[z]	44.68c[z]	210.73a	26.37c
AGT	2.14 $kg \cdot m^3$	16.97c	2.58dc[z]	55.66bc[z]	187.42b	30.16c
CRF	7.11 $kg \cdot m^3$	36.88a	6.42a	71.73ba	98.19c	53.17a
SBF	150 $mg \cdot L^{-1}$ N	19.43c	4.20bc	77.90a	112.31c	53.58a
WSF	75 $mg \cdot L^{-1}$ N	27.48b	5.00ba	56.12bc[z]	100.19c	44.57b
	LSD	5.90	1.95	17.98	21.86	6.24
	Significance	***	**	**	***	***

, or * significant at $p \leq 0.01$, or 0.001 respectively

[z] = below recommended nutrient sufficiency range (Mills and Jones, 1996)

Table 3.4. Shoot tissue micronutrient ($mg \cdot kg^{-1}$) concentrations. Values represent a mean of six replications. Means with the same letter in a column are not significantly different.

		N	P	K	Ca	Mg	S
Fertilizer	**Application Rate**			*Macronutrient (mg)*			
Control	0	2.22c	0.03c	0.16c	3.53b	4.72c	7.57c
AGT	2.14 $kg{\cdot}m^3$	25.85c	0.96b	7.47a	9.00a	12.08a	24.74a
CRF	7.11 $kg{\cdot}m^3$	161.26a	0.90b	5.91a	11.55a	12.67a	20.88ba
SBF	150 $mg{\cdot}L^{-1}$ N	82.90b	2.20a	2.97b	9.89a	9.44b	18.37b
WSF	75 $mg{\cdot}L^{-1}$ N	89.34b	1.58ba	5.41ba	8.74a	9.13b	17.78b
LSD		56.59	0.87	2.21	3.20	2.63	4.86
Significance		**	**	**	**	**	**

NS, *, or ** non-significant or significant at $p \leq 0.05$, or 0.01 respectively

Table 3.5. Total macronutrients leached (mg). Values represent a mean of three replications. Means with the same letter or no letter in a column are not significantly different.

Fertilizer	Application Rate	Fe	Mn	Zn	B	Cu
		Micronutrient (mg)				
Control	0	0.00b	0.00b	0.00b	0.01c	0.00b
AGT	2.14 kg·m^{3}	0.00b	0.02a	0.02b	0.03bc	0.02a
CRF	7.11 kg·m^{3}	0.04a	0.02a	0.06a	0.04ba	0.03a
SBF	150 mg·L^{-1} N	0.03a	0.02a	0.04a	0.05a	0.02ba
WSF	75 mg·L^{-1} N	0.04a	0.02a	0.05a	0.04ba	0.03a
LSD		0.02	0.01	0.02	0.02	0.02
Significance		**	*	**	*	*

*, or ** significant at $p \leq 0.05$, or 0.01 respectively

Table 3.6. Total micronutrients leached (mg). Values represent a mean of three replications. Means with the same letter or no letter in a column are not significantly different.

Fertilizer	Application Rate	Foliage and Vigor	Flower Number	Uniformity	Overall
Control	0	1.5c	1.3c	2.4d	1.8d
AGT	2.14 kg·m^{3}	2.6b	3.8b	3.2c	3.2c
CRF	7.11 kg·m^{3}	4.6a	4.6a	4.6a	4.6a
SBF	150 mg·L^{-1} N	4.4a	4.2ba	3.9b	4.1b
WSF	75 mg·L^{-1} N	4.5a	4.5a	4.2ba	4.4ab
	LSD	0.5	0.5	0.6	0.5
	Significance	***	***	***	***

*** significant at $p \leq 0.001$

Table 3.7. Consumer preference ratings at 74-76 days after planting. Values are a mean of 21 replications. Means with the same letter in each column are not significantly different.

Fertilizer	Application Rate	Irrigation volume (L)	N applied (mg)	P applied (mg)	K applied (mg)
Control	0	3.39	0	0	0
AGT	2.14 kg·m^{3}	5.28	224.7	59.3	149.2
CRF	7.11 kg·m^{3}	5.94	746.6	197.1	495.7
SBF	150 mg·L^{-1} N	5.80	891.0	156.8	221.9
WSF	75 mg·L^{-1} N	5.98	448.5	98.7	372.3

Table 3.8. Total N (mg), P (mg), K (mg), and irrigation volume (L) applied to plants.

Figure 3.1. Photograph of plant fertilized with SBF. Plant is exhibiting K deficiency symptoms as characterized by the necrotic spotting of leaves (Gibson et al., 2008). Photograph taken at 77 DAP.

Figure 3.2. Photograph of plant fertilized with AGT. Plant is exhibiting Cu and K deficiency symptoms as characterized by upward cupping of leaves and rolling of leaf margins, as well as some necrotic spotting (Gibson et al., 2008). Photograph taken at 77 DAP.

Figure 3.3. Photograph of plant fertilized with WSF. Plant is exhibiting no noticeable nutrient deficiency symptoms. Photograph taken at 77 DAP.

Figure 3.4. Photograph of plant fertilized with CRF. Plant is exhibiting no noticeable nutrient deficiency symptoms. Photograph taken at 77 DAP.

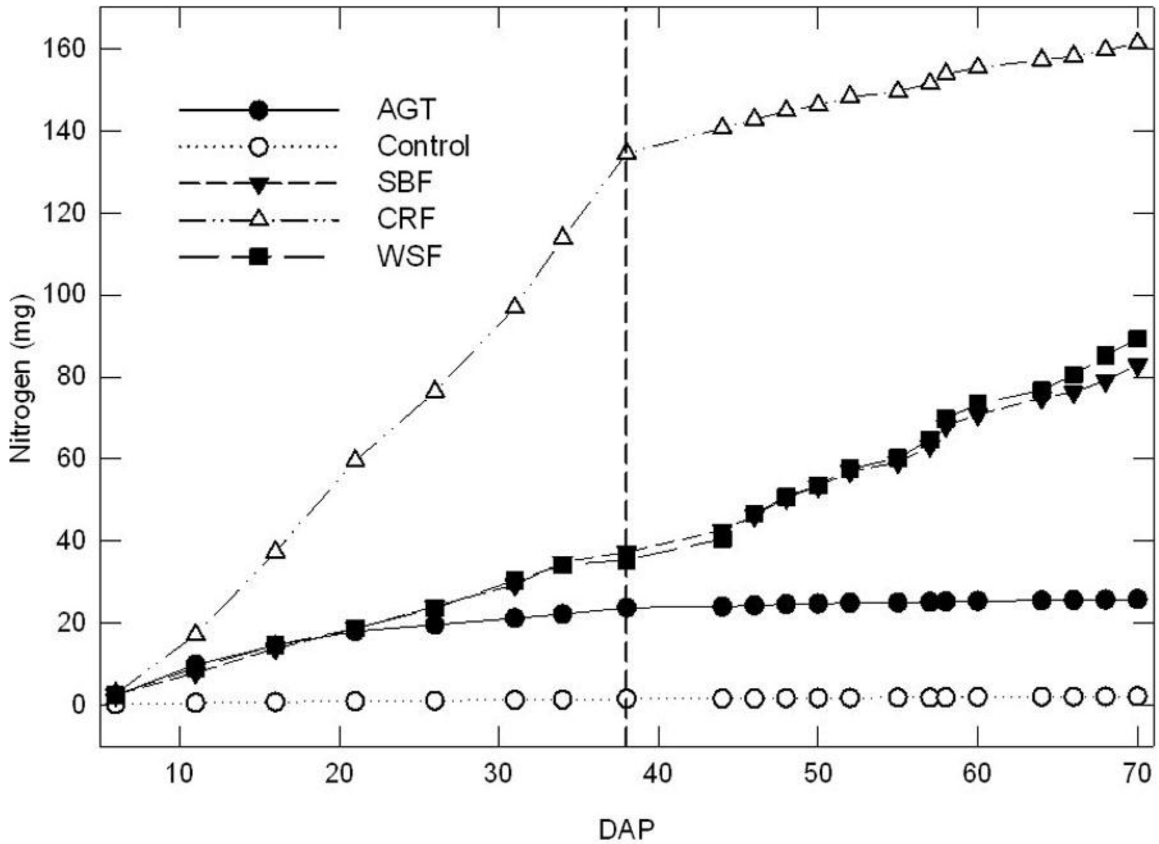

Figure 3.5. Cumulative nitrogen (NH_4^+-N + NO_3^--N) leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

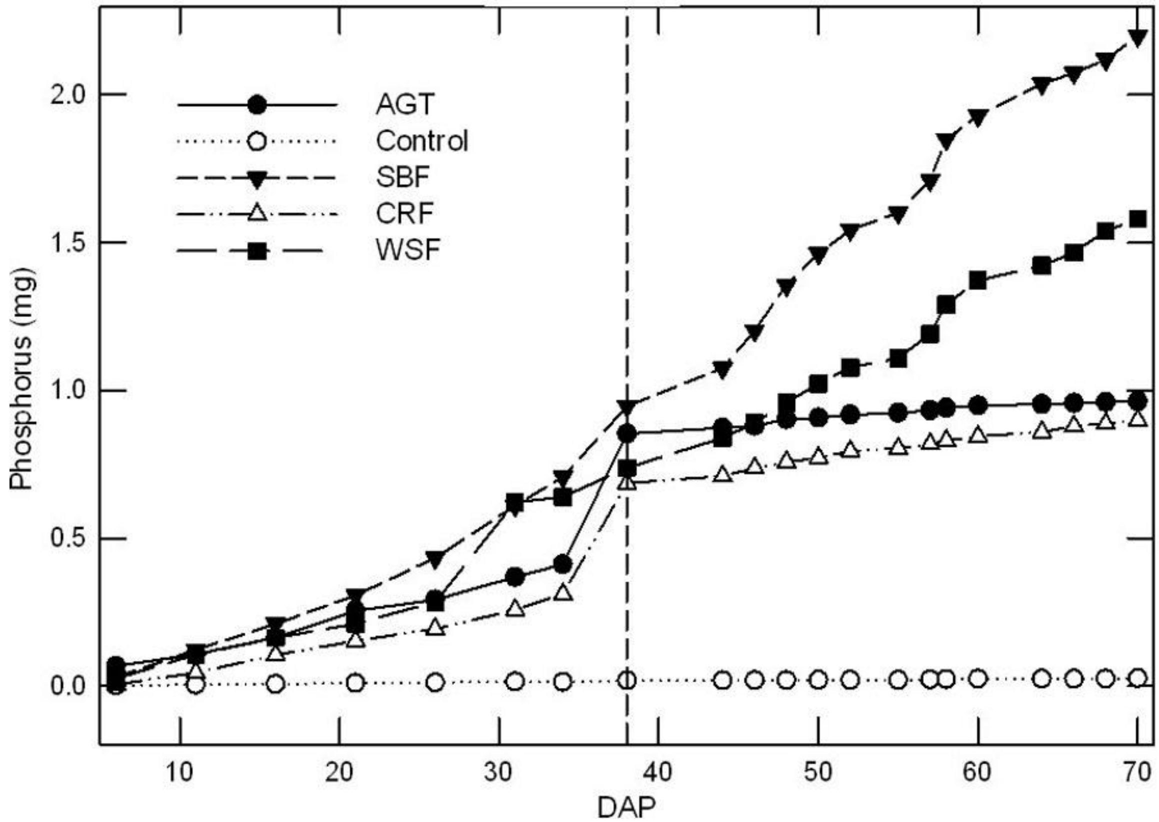

Figure 3.6. Cumulative phosphorus leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

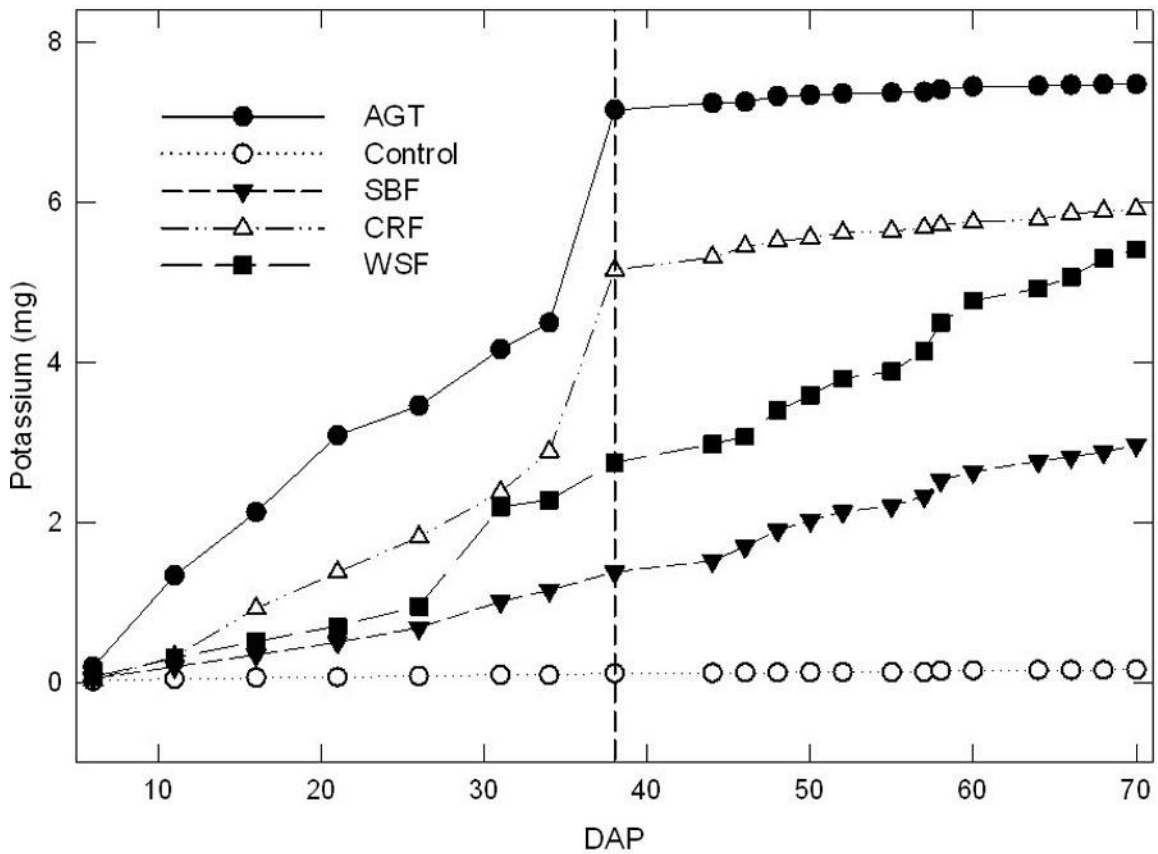

Figure 3.7. Cumulative potassium leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

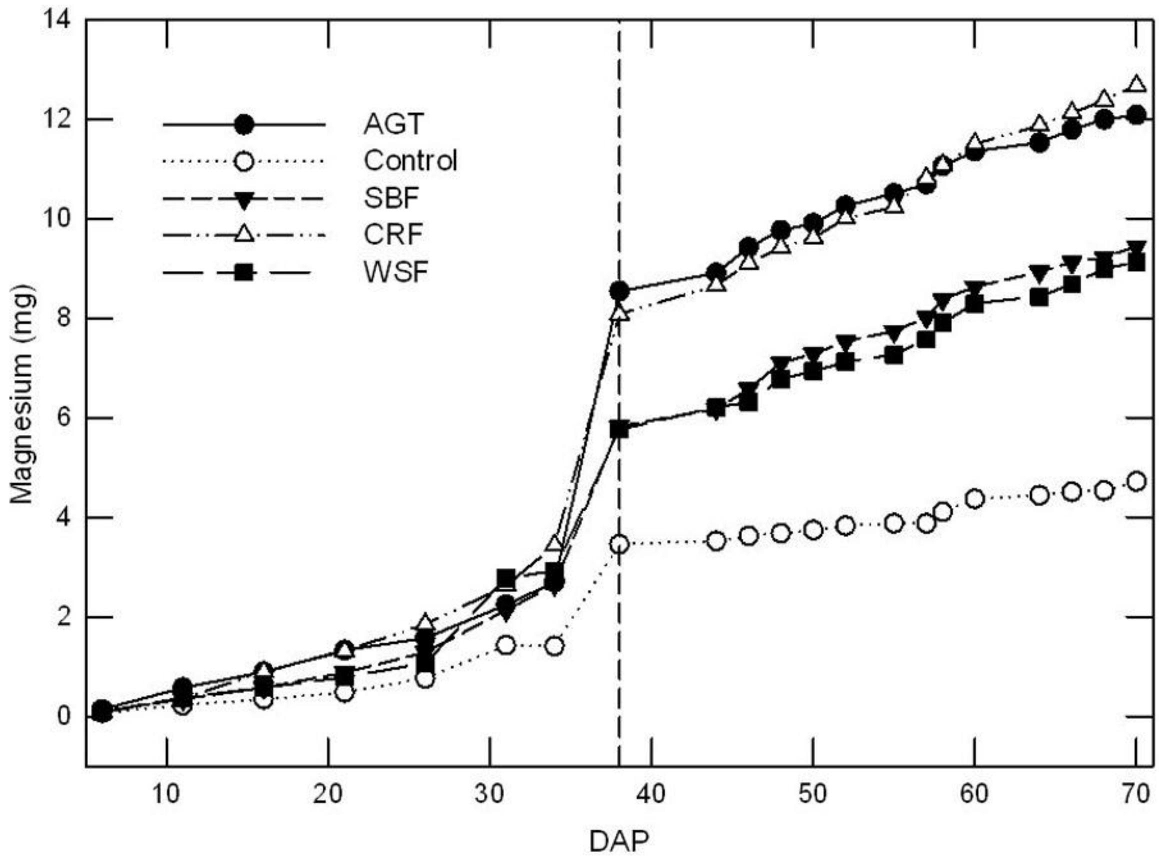

Figure 3.8. Cumulative magnesium leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

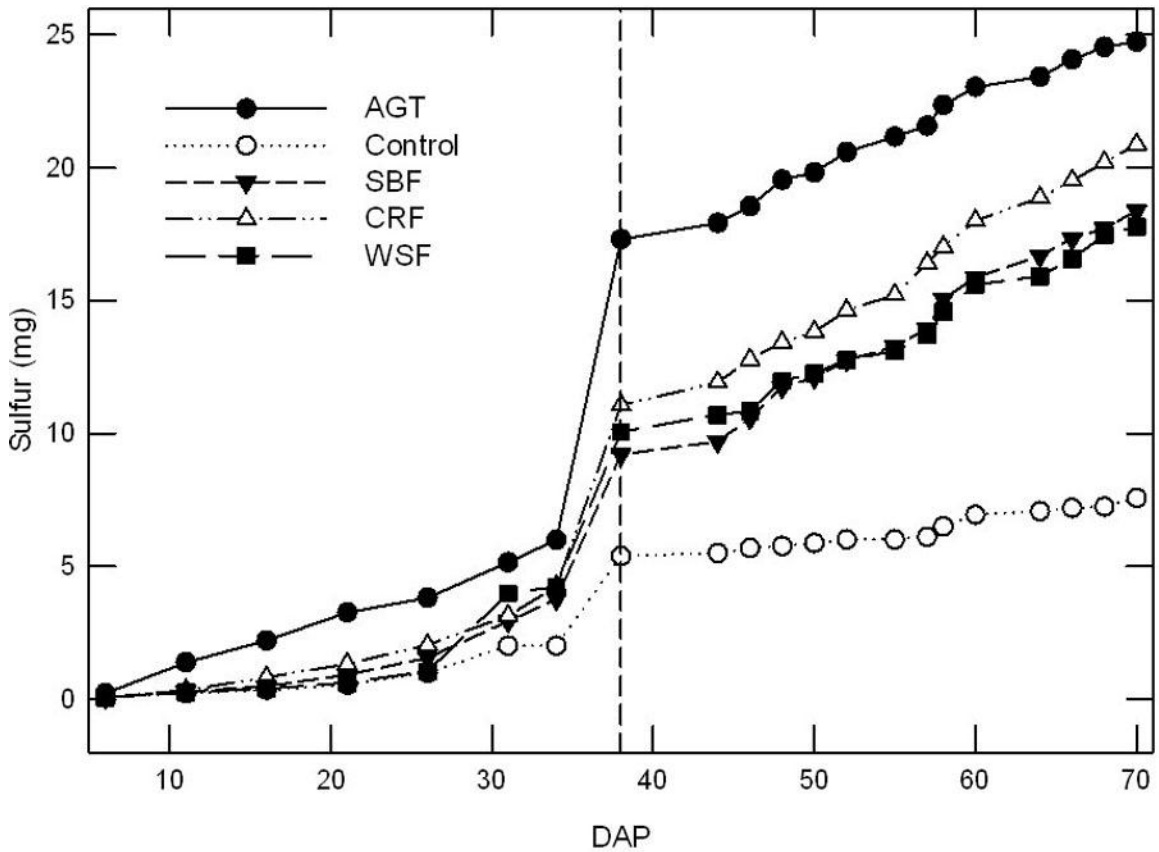

Figure 3.9. Cumulative sulfur leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

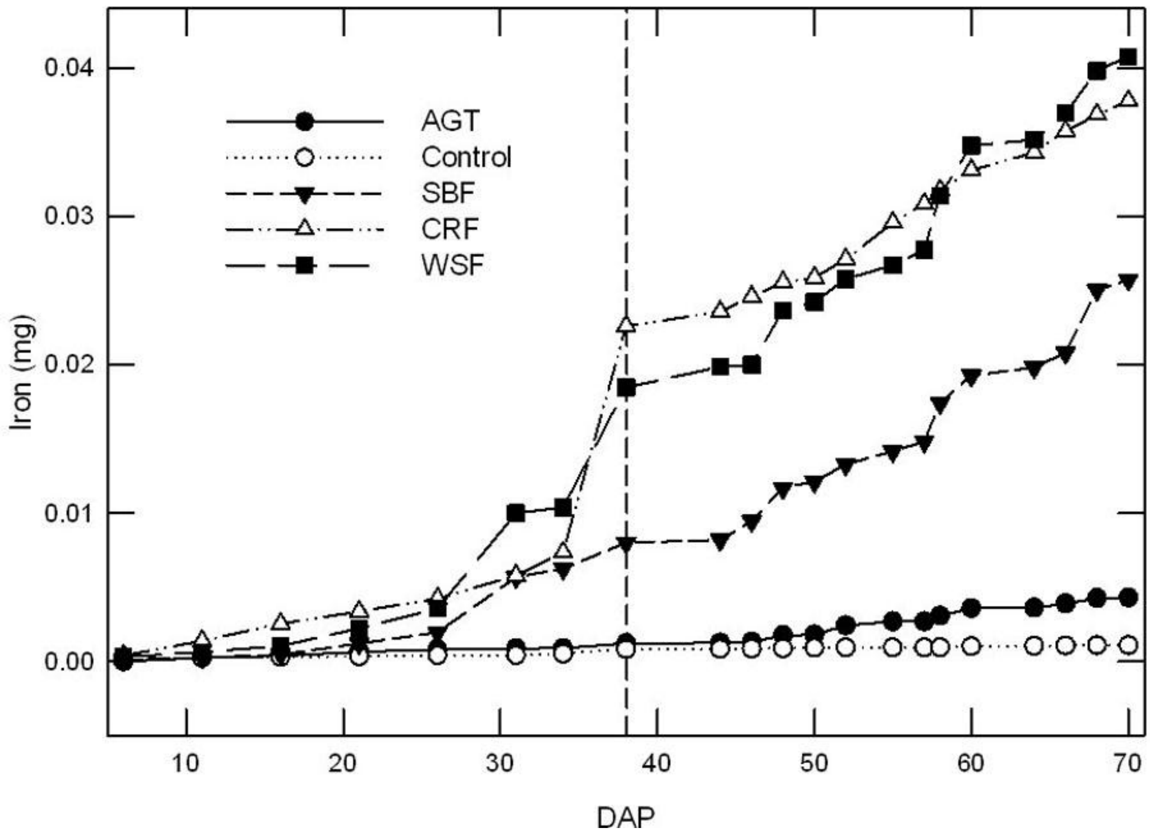

Figure 3.10. Cumulative iron leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

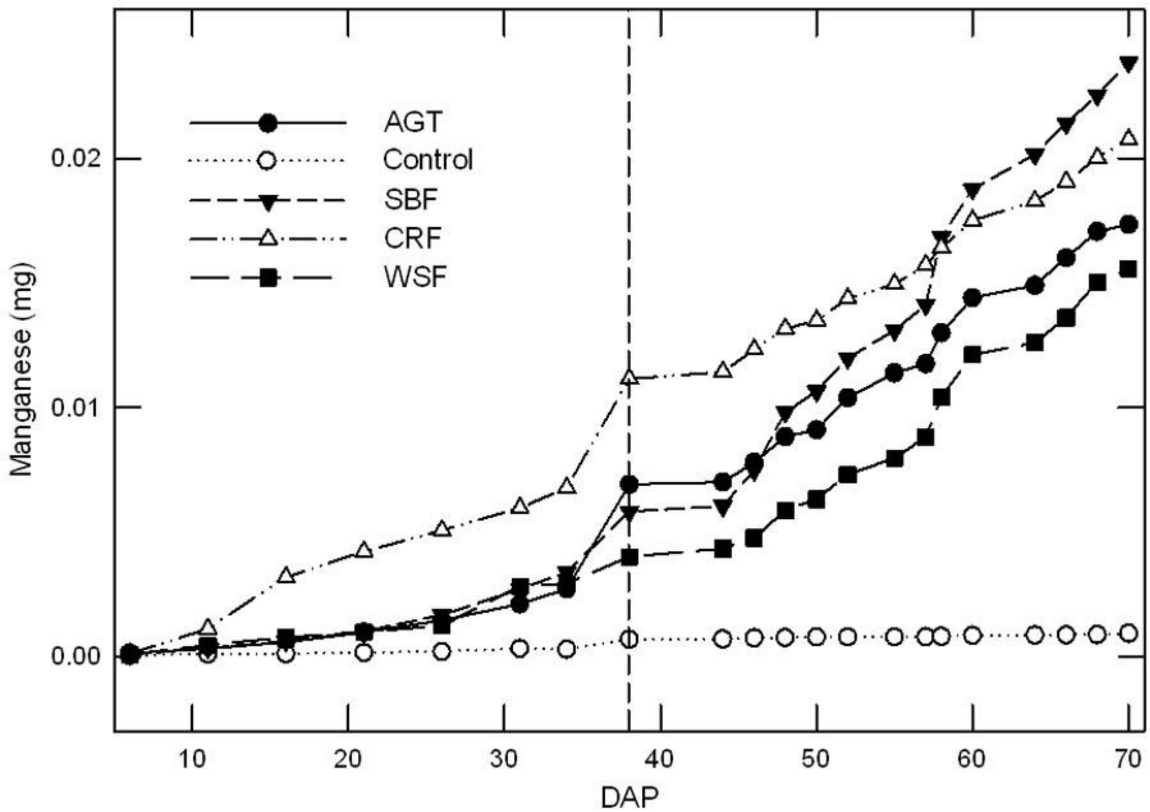

Figure 3.11. Cumulative manganese leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

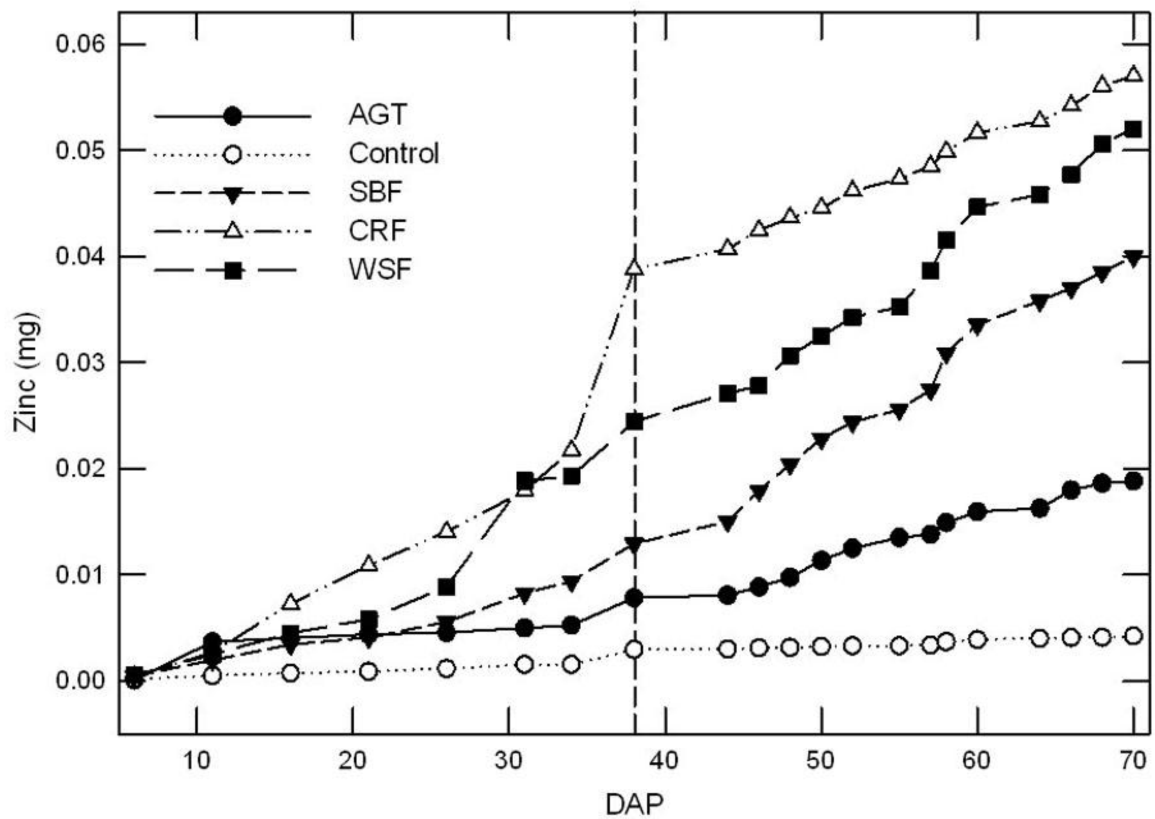

Figure 3.12. Cumulative zinc leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

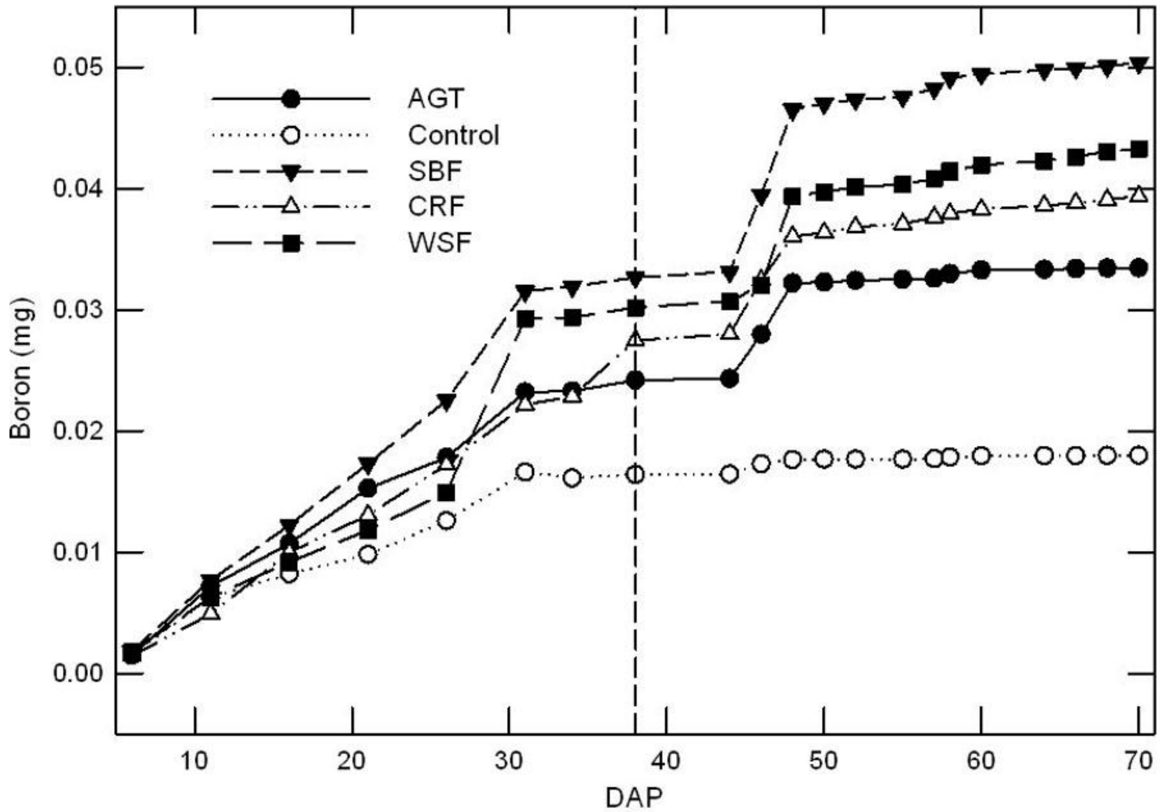

Figure 3.13. Cumulative boron leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

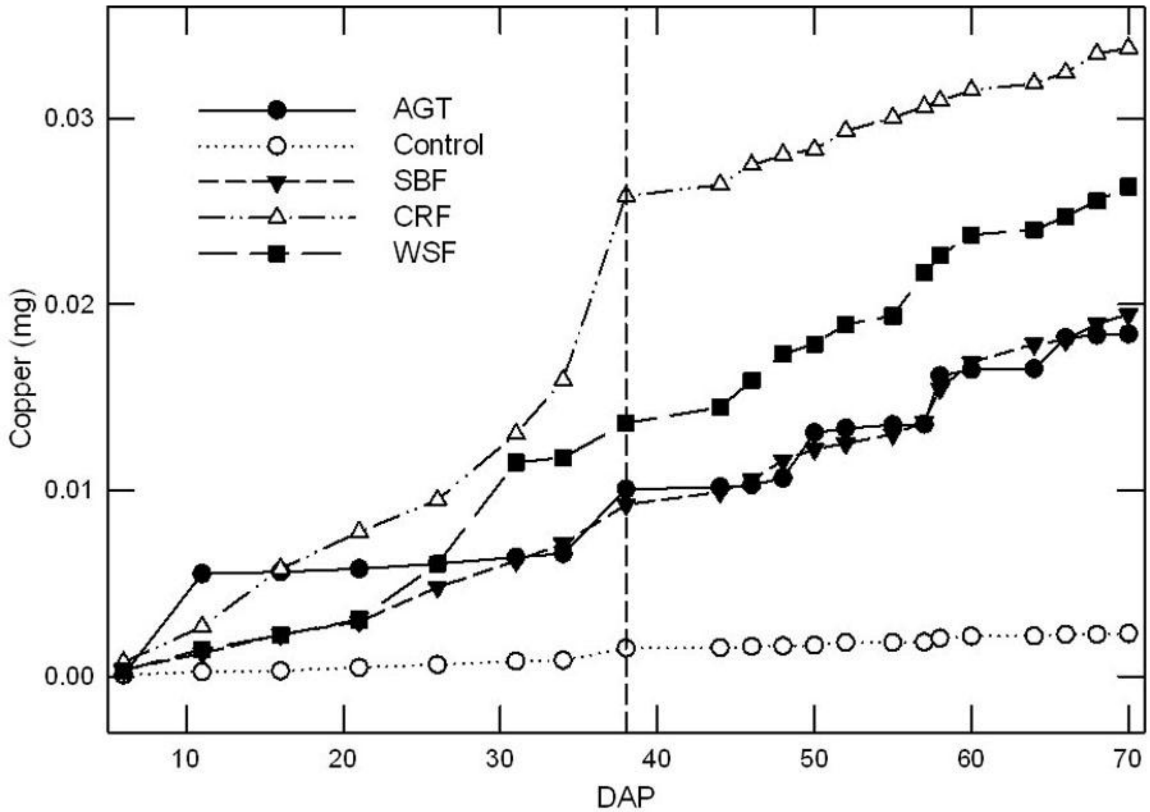

Figure 3.14. Cumulative copper leached (mg). Leaching was quantified over a period of 70 days after planting (DAP). Values are a mean of three replications. Dashed line represents the leaching event on 38 DAP, when plants were irrigated at a 0.50 leaching fraction.

CHAPTER 4: EFFECT OF TEMPERATURE ON NUTRIENT LEACHING FROM THREE FERTILIZERS

4.1. Introduction

Significant relationships between nutrient loss from controlled and slow-release fertilizers (C/SRFs) and temperature have been demonstrated in both greenhouse and laboratory settings in which temperature was either controlled or variable (Cabrera 1997; Husby et al, 2003; Sharma, 1979). There is more certainty as to the relation of N release to temperature than that of other nutrients, especially micronutrients (Broschat and Moore, 2007). Additionally, release differs between slow-release and controlled-release fertilizers due to the mechanism of release (Shaviv, 2001). Slow-release fertilizers are generally less soluble and require moisture for dissolution, and nutrient release may be slow to occur (Shaviv, 2001). In contrast, controlled-release fertilizers are less affected by variability in moisture, temperature, and media properties (Shaviv, 2001). In contrast, granular fertilizers are not generally predictable with respect to leaching and are instantly solubilized once water is introduced (Broschat, 1995; Shaviv and Mikkelsen, 1993).

The impact of irrigation practices should be considered when focusing on the effect of different fertilizer types on nutrient release and leaching from soilless substrates.

Irrigation volume in experiments is often determined based on the leaching fraction (LF), which is defined as the effluent volume (volume of water leached) divided by the influent volume (volume of water applied) (Owen et al., 2008). In practice, a wide variability in the influent and effluent volumes of water can still result in the same LF. Evapotranspiration from container substrates affects the amount of water required to maintain a particular LF at an irrigation event (Ku and Hershey, 1992). A medium LF (0.2-0.3) is ideal during production because it can result in increased nutrient and irrigation use efficiency, and reducing fertilizer waste (Tyler et al., 1996). In practice, this LF range is realistic if a grower is attempting to minimize leaching.

While it has been established that temperature affects nutrient release from different fertilizers, no work has been done evaluating the combined effect of varying temperatures and a constant LF on nutrient leaching. Also, it is desirable to investigate whether or not temperatures common to floriculture (18-26°C) would affect leaching from substrates at a constant LF. The objective of this experiment was to compare nutrient leaching from unplanted containers treated with three fertilizers and irrigated at a constant LF while incubated at three different temperatures. Containers were unplanted in order to realistically measure nutrient release (and plant availability) as identified by leaching, similar to Blythe et al. (2006) and Newman et al. (2006).

4.2. Materials and Methods

Media preparation. Substrate for this experiment consisted of a 7:3 ratio of peat (Sunshine Peat Moss, SunGro Horticulture, Bellevue, WA) to perlite (Thermo-Rock East, Inc., New Eagle, PA) mixture (by volume), with no pre-plant nutrient charge. Perlite was slowly added to attain the desired ratio, followed by calcitic lime at a rate of 2.0 $g{\cdot}L^{-1}$ substrate. After thoroughly mixed, 1.0 L of a wetting agent solution (AquaGro, Scotts Co., Marysville, OH) was applied with a hand sprayer at a rate of 7.6 $mL{\cdot}L^{-1}$ water, followed by approximately 5.0 L tap water to ensure media hydration. Media was prepared and placed in plastic bags ready for immediate placement in 700.0 cm^3, 11.4 cm diameter containers.

Fertilizer treatments. 1) Osmocote Plus 15-4-10, 5-6 month controlled-release fertilizer (CRF2) (Scotts Co., Marysville, OH), 2) Contec-DG 15-4-10, 5-month slow-release turf fertilizer (AGT) (The Andersons Co., Maumee, OH), and 3) MagAmp K 7-17.7-5, medium-particle size, 6-month slow release fertilizer (MAP) (Sumitomo Corp., Tokyo, Japan) were selected and applied at a standard rate of 375 $mg{\cdot}N^{-1}$ per container (0.54 $kg{\cdot}m^{-3}$). This resulted in the following application rates: 1) AGT at 3.57 $kg{\cdot}m^{-3}$ (100.0 $mg{\cdot}P^{-1}$, 250.0 $mg{\cdot}K^{-1}$), CRF2 at 3.57 $kg{\cdot}m^{-3}$ (100.0 $mg{\cdot}P^{-1}$, 250.0 $mg{\cdot}K^{-1}$), and MAP at 7.65 $kg{\cdot}m^{-3}$ (948.2 $mg{\cdot}P^{-1}$, 401.8 $mg{\cdot}K^{-1}$). CRF2 was the label chosen for the CRF in this experiment, as it has a different longevity than the CRF used in Chapters 2 and 3. This longevity was chosen to more closely match MAP and AGT suggested longevities. The control treatment had no fertilizer applied. Containers were placed in growth chambers and labeled based on a randomized complete block 3×4 factorial design with six replications at three constant temperature settings of 18°C, 22°C, and 26°C. These temperatures covered an appropriate range of greenhouse production settings for a wide variety of crops (Hamrick, 2003). Constant rather than variable night and day temperatures were selected in order to more accurately identify differences in leaching between temperatures. No supplemental lighting was provided.

Irrigation and substrate monitoring. Containers were hand watered once per week for eight weeks at a target LF of 0.25. Irrigation volumes during the study totaled 1.1 L water at 18°C, 2.47 L at 22°C, and 2.72 L at 26°C and did not differ among fertilizer treatments. Actual leaching fractions were 0.297 ± 0.005 at 18°C, 0.243 ± 0.004 at 22°C, and 0.242 ± 0.003 at 26°C (mean ± SE). In order to collect leachate for analysis, 300 mL plastic bowls were placed below the containers before the application of water to the substrate. Plastic mesh allowed for the containers to remain above the collection bowls to avoid container contact with extracted leachate. Leachate volume was measured and transferred from collection bowls to 50 mL centrifuge tubes for lab analysis. Within two hours of collection, leachate EC and pH were measured using an EC/pH meter (Accumet Model AP85 pH/Conductivity meter, Fisher Scientific, Pittsburgh, PA). Aliquots were then filtered with filter paper and stored in 20 mL plastic vials to be frozen at -10°C for later nutrient analysis. Leachate NO_3^--N and NH_4^+-N were measured using ion selective electrodes (ISE) (Scotts Testing Laboratory, Lincoln, NE). Inductively coupled plasma optical emission spectroscopy (ICP-OES, model IRIS Intrepid II, Thermo Electron, Waltham, MA) was used for analysis of leachate P, K, Ca, Mg, S, Fe, Mn, Zn, B, and Cu concentrations at the USDA-ARS Laboratory (University of Toledo, Toledo, OH).

Data analysis. Model effects (temperature and week as fixed effects, and water applied as a random effect) on nutrient leaching at each collection over time were analyzed using a general linear model (GLM). Differences in total nutrients leached between temperatures for each fertilizer treatment were analyzed using least significant difference (LSD) and differences between all treatment means with Tukey's honest significant difference (HSD) (PROC GLM, SAS v.9.1, SAS Institute, Cary, NC). Figures of pH, EC, and nutrient leaching over time were created using SigmaPlot v.11.0 (Sistat Software, Chicago, IL).

4.3. Results

Leachate pH and EC. At 18°C, pH was always lower for MAP and CRF2 leachates (Figure 4.1). AGT leachate pH was variable, with pH at 18°C increasing early in the experiment and then remaining fairly constant after week three. At 22°C and 26°C, AGT leachate pH increased until week three, then decreased up to week six by 0.6-0.7 units. At the end of the experiment, leachate pH at 18°C was higher than at 22°C and 26°C. During the majority of the experiment, leachate EC was higher at 18°C for AGT and CRF2 (Figure 4.2). MAP leachate EC was higher at 18°C for the first half of the experiment. During the second half of the experiment, MAP leachate EC was lower at 18°C than at 22°C and 26°C. MAP leachate EC at 18°C also remained fairly constant during the experiment after week one, while leachate EC gradually increased at 22°C and 26°C. AGT leachate EC increased more during the first week than any other fertilizer. At 18°C, AGT had the highest observed leachate EC of any treatment. CRF2 leachate EC gradually increased at 22°C and 26°C during the experiment. At 18°C, CRF2 leachate EC increased more during the first half of the experiment than at other temperatures and leveled off and remained fairly constant thereafter.

Nitrogen. Temperature had a significant effect on N leaching over time for AGT and MAP (Table 4.1). Temperature had no effect on leaching of N over time from CRF2. N leaching was significantly affected by week for MAP and CRF2. Irrigation volume significantly affected N leaching over time for MAP. Leaching of N over time from MAP was significantly affected by an interaction between temperature and collection week. Total N leaching at the end of the experiment was higher for AGT and MAP at 22°C and 26°C (Table 4.2). Also, AGT and MAP both leached the most N at these temperatures. AGT leached the most N overall, especially at 22°C, and MAP leached the least N out of any fertilizer treatment. AGT leached the most N on week at 22°C and 26°C, and N leaching remained relatively constant afterward (Figure 4.3). The initial surge in N leaching from AGT did not occur, however, at 18°C. N leaching remained fairly constant for MAP at 18°C, but generally increased over time at 22°C and 26°C.

Phosphorus. Temperature significantly affected P leaching over time from all fertilizers (Table 4.1). P leaching was significantly affected by week and irrigation volume over time for AGT and MAP. There was a significant interaction in P leaching by week and temperature for MAP over time. Week also significantly affected P leaching from CRF2. Temperature significantly affected total P leaching for all fertilizers (Table 4.2). The trend was for higher P leaching at lower temperatures as AGT and CRF2 leached the most P at 18°C and MAP leached the most P at 18°C and 22°C. MAP at 18°C leached the most P out of any treatment and CRF2 leached the least P.AGT P leaching followed the trend of being high early in the experiment and decreasing over time (Figure 4.4). P leaching from MAP was erratic and varied between 4 and 12 mg per week after week one, often being lower at 26°C than 18°C and 22°C.

Potassium. Temperature and week significantly affected K leaching over time from all fertilizers (Table 4.1).Irrigation volume significantly affected K leaching over time from MAP and CRF2. There was an interaction between week and temperature over time only for MAP. There were significant differences in total K leached for MAP which leached the most K at 22°C and 26°C (Table 4.2). While the linear model was significant, total leaching did not differ for AGT and CRF2. AGT leached significantly more K than any other fertilizer. At 22°C and 26°C, MAP leached more total K than CRF2. Much like with N and P, K was heavily leached from AGT early in the experiment (Figure 4.5). Also, K leaching followed a similar trend to N leaching from MAP, with fairly constant K leaching at 18°C, and a gradual increase over time at 22°C and 26°C.

Calcium. Temperature had a significant effect on Ca leaching over time for MAP and CRF2 (Table 4.1). Week significantly affected Ca leaching from all fertilizers. Irrigation volume only significantly affected Ca leaching over time from AGT. There were no significant interactions between temperature and week on Ca leaching over time. There were no differences in total Ca leached from individual fertilizer treatments at the three temperatures tested (Table 4.2). AGT at 18°C and 22°C leached more Ca than any other treatment except CRF2 at 18°C. Similar to other macronutrients, Ca leaching from AGT was highest early in the experiment, with the majority of Ca leached before week five (Figure 4.6).

Magnesium. Temperature had a significant effect on Mg leaching over time only for AGT and MAP (Table 4.1). Week and irrigation volume significantly affected Mg leaching over time during the experiment for all fertilizers. A temperature by week interaction significantly affected Mg leaching over time for AGT and MAP. Temperature significantly affected total Mg leached for AGT and MAP but not for CRF (Table 4.2). AGT leached the most Mg at 26°C and MAP leached the most at 22°C and 26°C. The majority of treatments leached similar amounts of Mg, with AGT leaching higher totals of Mg on average. Mg leaching over time from MAP was similar across all temperatures until week four, when leaching continued to increase for the remainder of the experiment at 22°C and 26°C and remained below 1 mg per week at 18°C (Figure 4.7). Leaching of Mg from AGT was high during the first few weeks, decreased up to week five, then steadily increased for the remainder of the experiment at 22°C and 26°C. At 18°C, Mg leaching from AGT did not increase but rather decreased slightly until the end of the experiment.

Sulfur. Temperature significantly affected S leaching over time only from MAP (Table 4.1). Week only had an effect on S leaching for CRF and AGT. Irrigation volume significantly affected S leaching over time from AGT and MAP. There were no interactions between temperature and week on S leaching over time. Temperature significantly affected total S leached from MAP, where there was significantly less S leached at 18°C than at 22°C and 26°C (Table 4.2). When comparing all treatments, AGT leached significantly more total S than any other treatments. S leaching from AGT was very high between weeks one through three, when 10-20 mg S was leached per week, decreasing over time (Figure 4.8).

Iron. Temperature and week significantly affected Fe leaching from AGT and CRF over time (Table 4.3). Irrigation volume and the interaction between temperature and week significantly affected Fe leaching over time from AGT. Week was the only main effect significantly affecting Fe leaching from MAP. In contrast to differences in Fe leaching over time (Table 4.3), temperature did not affect total Fe leached for all fertilizers tested (Table 4.4). CRF leached more total Fe at all temperatures than any other treatment. Total Fe leaching did not differ among all other treatments.

Manganese. For all fertilizers, temperature, week, irrigation volume, and the interaction between temperature and week significantly affected Mn leaching over time (Table 4.3). Temperature significantly affected total Mn leaching from AGT and MAP, where AGT leached the most Mn at 22 and 26°C, and MAP leached similar amounts of Mn at 22°C and 26°C (Table 4.4). Also, MAP leached similar amounts of Mn at 26°C and 18°C. AGT at 22°C and 26°C leached significantly more Mn than any other treatment. For AGT, the trend of Mn leaching per week was nearly identical to Mg, with leaching beginning high at the beginning of the experiment, decreasing, and then increasing again at 22°C and 26°C with no increase at 18°C (Figure 4.9).

Zinc. Temperature had a significant effect on Zn leaching over time from all fertilizers (Table 4.3). Irrigation volume only significantly affected Zn leaching over time from AGT and MAP. CRF2 was the only fertilizer in which Zn leaching was significantly affected by week. The temperature by week interaction significantly affected Zn leaching over time from AGT. In regard to the effect of temperature on total Zn leached for each individual treatment, there were no significant differences (Table 4.4). CRF2 at 18°C leached the most Zn out of any treatment and CRF2 leached the most Zn, on average. There were no differences in total Zn leached between AGT and MAP. Total Zn leached from all fertilizers was not significantly different at 22°C and 26°C.

Boron. Temperature and week significantly affected B leaching over time from all fertilizers (Table 4.3). B leaching was affected by irrigation volume over time for AGT and MAP. The interaction between temperature and week significantly affected B leaching over time from AGT. Total B leached was significantly affected by temperature for MAP and AGT, where the most B was leached at 22°C and 26°C (Table 4.4). Total B leached did not differ between AGT and MAP treatments at 22°C and 26°C, but was higher in CRF2 than AGT and similar between CRF2 and MAP.

Copper. Temperature significantly affected Cu leaching over time from all fertilizers (Table 4.3). Week, irrigation volume, and the interaction between week and temperature affected Cu leaching over time from AGT only. Temperature significantly affected total Cu leached from AGT (Table 4.4). AGT leached the most Cu at 22°C and 26°C. When comparing all treatment means, there were some differences with CRF2 at 22°C and 26°C leaching the most total Cu.

4.4. Discussion

There was a tendency for AGT to heavily leach nutrients such as P, K, Ca, and S during the early part of the eight-week period at all temperatures (Figures 4.4, 4.5, 4.6, 4.8). The leaching trend of these nutrients closely follows that of granular fertilizers, which are quickly solubilized and leached when water is added to a substrate (Broschat, 1995; Shaviv, 2001). Supporting this conclusion, AGT had very high leachate EC during the first few weeks (Figure 4.2). Leachate EC was highest at 18°C due to the fact that a smaller volume of water was applied, causing the collected leachate to have a much higher concentration of soluble salts (Cole and Dole, 1997).Unlike K, Ca, and S, the reason for much higher total P leached at 18°C is unknown (Figure 4.4, Table 4.2). Further investigation is needed. While nutrients were quickly solubilized from AGT, it may not necessarily be problematic since it is a fertilizer normally used for the turf industry. Nutrient leaching may differ in an environment with plants and mineral soil present.

N leaching did not follow a similar leaching trend to P, K, Ca, and S because the majority of N in AGT is in the form of methylene urea (Table A.1). The cold-water soluble portion of the N (CWSN) contained in the product was more readily leached at temperatures above 18°C, explaining the initial burst of nitrogen on week one (Figure 4.3). Additionally, the remaining hot-water soluble portion (HWSN) is the less soluble form, which was slow-release for the remainder of the experiment. Release of these types of urea-form nitrogen is shown to be dependent on temperature, especially the HWSN portion (Shaviv, 2001). Release of more soluble urea at 22°C and 26°C and the consequential conversion of N to ammonium likely caused acidification of AGT substrate as shown by the decrease in leachate pH (Figure 4.1). It is valid, therefore, to conclude that N release from AGT is highly affected by temperatures of 22°C-26°C, and that release is significantly slower at 18°C.

The differences in Mn and Mg leaching over time from AGT at 22°C and 26°C are due to changes in substrate pH over time, as reflected by leachate pH. Solubility of Mn becomes increasingly higher at lower pH in soilless substrates (Peterson, 1982). The increase in

Mn leaching from AGT (Figure 4.9) occurs along with the decrease AGT leachate pH (Figure 4.1).The similar trend in leaching of Mg (Figure 4.7) can also be explained by changes in substrate pH and solubility of the nutrient. There is a significant fluctuation in solubility of Mg between pH 5 and 6 (Peterson, 1982). At pH 5.17, Mg solubility is nearly equivalent to that of pH 6.03, however, it decreases by approximately 225% at pH 5.58 (Peterson, 1982). As pH decreased between 5.6 and 5.2, Mg solubility and thus leaching also increased. While instantly soluble portions of Mn and Mg in the fertilizer were leached early in the experiment, release later in the experiment of both nutrients was highly dependent on pH and solubility of the two nutrients. Therefore, while temperature was a significant factor in leaching of these nutrients, it was more a cumulative result of acidification of the substrate by ammonification that caused the variability in their release.

Differences in total nutrient leaching from MAP at 18°C versus 22°C and 26°C could be either a result of substrate moisture content or accelerated dissolution by microbial reactions related to nitrification (Rothbaum and Rhode, 1976; Lunt et al., 1964). Leaching trends of N, K and Mg from the fertilizer were similar over time, suggesting that the mechanism of release was related (Figures 4.3, 4.5, and 4.7). Unlike with other fertilizers tested in this study, all of these nutrients had a significant interaction of week and temperature on nutrient leaching suggesting that time, temperature, and possibly moisture had a “synergistic” effect on leaching. At 18°C and a 0.25 LF, moisture content of the substrate was likely consistently higher during the experiment due to less evaporation, exhibited by the lower amount of water applied to maintain the constant LF (Ku and Hershey, 1992). As is shown in Lunt et al. (1964), both moisture and nitrification have an effect on nutrient release from MAP and increased nitrification results in an increase of overall nutrient release. However, there was variability in release according to the nutrient. Regarding the leaching of N, Mg, and K, accelerated dissolution related to nitrification of ammonium at temperatures at or above 22°C may have been the cause for significantly higher leaching versus invariable leaching at 18°C (Rothbaum and Rohde, 1976). Conversely, there was significantly more leaching of P at lower temperatures, which may have been related to increased substrate moisture content. However, this requires further investigation. Based on these results, it could be confidently inferred that nutrient release from MAP is significantly lower at temperatures at or below 18°C.

In general, nutrient release and longevity of polymer-coated fertilizers like CRF2 is characterized by nitrogen release (Shaviv, 2001). Our results show no differences in N release between the temperatures tested. One could therefore come to the conclusion that CRF2 nutrient release does not differ between 18°C-26°C over a period of eight weeks. However, most notably, P and K leaching were significantly affected by temperature over time (Table 4.1). In regard to P and Ca, a distinctly higher rate leaching each week at 18°C most likely occurred due to differences in substrate moisture content. As was previously mentio1ned, substrate at 18°C was maintained at a 0.25 LF with a lower amount of water applied, indicating that less evaporation occurred between irrigation events. Du et al. (2006) demonstrated that a substrate environment with higher moisture content results in significantly greater release of P than any other nutrient from polymer-coated CRF. This result was exhibited in this experiment by both consistently higher P leaching each week (Figure 4.4) and greater total P leaching at 18°C (Table 4.2). While total Ca leached was not significantly different across temperatures (Table 4.2), leaching and thus release of Ca may have been affected by a similar mechanism as P based on similar trends in leaching over time (Figure 4.6). Much like N, K followed a comparably erratic pattern of leaching over time at all temperatures (Figure 4.5), and though significantly affected by week and temperature (Table 4.1), still resulted in the same total leaching of the nutrient (Table 4.2). Exact reasoning for the significant differences in K leaching overtime is unclear. When more closely examining the trend of K leaching over time, a trend in higher leaching with increased temperature after week six did emerge (Figure 4.5). Yet, this cannot be said with complete confidence since leaching was not examined for a longer period of time than eight weeks.

4.5. Conclusion

While leaching of various nutrients from the fertilizers tested was often affected by temperature, there are several proposed mechanisms by which this may have occurred. For AGT, nutrients were either rapidly solubilized and leached with the application of irrigation water (P, K, Ca, and S) or were solubilized due to the effects of temperature and the acidification of the substrate from the conversion of urea to ammonium (Mn, and Mg). Leaching of nutrients from MAP generally increased at or above temperatures of

22°C (N, K, and Mg) likely as a result of accelerated dissolution and microbial reactions related to nitrification. CRF2 leaching was generally similar over the small range of temperatures tested, and total leaching of most nutrients did not differ with temperature. P leaching from all treatments was highest at lower temperatures possibly due to effects of higher substrate moisture content. This trend in P leaching from the fertilizers tested requires further investigation. Additionally, further investigation of the effect of a constant LF on nutrient leaching at a wider variability of temperatures and over a longer period of time would provide additional insight as to its relation of these various mechanisms to release for different fertilizers, this study provides valuable information on short-term nutrient availability for greenhouse crops grown at temperatures averaging up to 26°C at a 0.25-0.30 LF. In general, when using controlled or slow-release fertilizers, the recommendation should be to not allow for mean temperatures to be at or below 18°C as nutrient release and availability may significantly decrease or not match plant nutrient demand.

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Treatment	Effect	*Macronutrient*					
		N	**P**	**K**	**Ca**	**Mg**	**S**
Control	Temperature (T)	***	NS	**	***	***	***
	Week (W)	**	NS	NS	***	NS	NS
	Irrigation volume	*	NS	NS	*	NS	NS
	T×W	NS	NS	NS	NS	NS	NS
AGT	Temperature (T)	***	***	**	NS	***	NS
	Week (W)	NS	***	***	***	***	***
	Irrigation volume	NS	**	NS	*	***	***
	T×W	NS	NS	NS	NS	***	NS
MAP	Temperature (T)	***	***	***	***	***	***
	Week (W)	***	***	***	***	***	NS
	Irrigation volume	***	**	***	NS	***	*
	T×W	**	**	***	NS	***	NS
CRF2	Temperature (T)	NS	***	*	***	NS	NS
	Week (W)	***	***	***	**	***	**
	Irrigation volume	NS	NS	*	NS	***	NS
	T×W	NS	NS	NS	NS	NS	NS

NS, *, **, or *** non-significant or significant at $p \leq 0.05$, 0.01, or 0.001 respectively

Table 4.1. Effect of temperature (T), week (W), irrigation volume, and the interaction between temperature and week (T×W) on macronutrient leaching over time. Leaching was tested at constant temperatures of 18° C, 22° C, or 26°C over an eight-week period.

Treatment	Temp (°C)	*Macronutrient (mg)*					
		N	**P**	**K**	**Ca**	**Mg**	**S**
Control	18	2.08	0.27	1.50	0.04b	1.53	3.88
Control	22	5.31	0.35	3.37	0.08ba	2.77	13.90
Control	26	5.45	1.39	6.65	0.11a	4.60	20.74
LSD		3.78	2.39	5.30	0.06	3.46	17.11
Significance		NS	NS	NS	*	NS	NS
AGT	18	54.72b	50.65a	102.90	9.51	10.87b	81.29
AGT	22	134.27a	31.28b	124.26	9.34	12.55b	82.59
AGT	26	117.17a	30.09b	136.14	5.21	15.05a	78.62
LSD		46.80	9.80	32.70	8.13	1.99	12.69
Significance		*	*	NS	NS	*	NS
MAP	18	4.95b	68.86a	23.14b	0.37	4.88b	4.06b
MAP	22	28.03a	62.86a	52.90a	0.58	9.09a	18.09a
MAP	26	32.99a	43.34b	48.30a	0.44	9.77a	16.85a
LSD		15.57	14.01	12.95	0.26	2.15	4.27
Significance		*	*	*	NS	*	**
CRF2	18	68.82	11.17a	23.62	4.59	8.85	24.48
CRF2	22	74.11	4.23b	28.29	1.77	9.18	20.85
CRF2	26	73.68	4.35b	31.19	1.52	9.10	20.19
LSD		57.79	5.70	15.91	3.55	5.57	13.85
Significance		NS	*	NS	NS	NS	NS
HSD		49.00	15.22	23.54	5.22	4.63	14.08
Significance		***	***	***	***	***	***

NS, *, **, or *** non-significant or significant at $p \leq 0.05$, 0.01, or 0.001 respectively

Table 4.2. Total macronutrients leached (mg). Leaching was tested over an eight-week period at constant temperatures of 18° C, 22° C, or 26° C. Values represent a mean of three replications. Means with the same letter are not significantly different and represent differences only between temperatures for one fertilizer. HSD = Tukey's honest significant difference between all treatment means.

Treatment	Temp (°C)	*Micronutrient (mg)*				
		Fe	**Mn**	**Zn**	**B**	**Cu**
Control	18	0.04	0.01	0.02	0.00b	0.01
Control	22	0.04	0.01	0.02	0.03a	0.02
Control	26	0.03	0.01	0.03	0.03a	0.02
LSD		0.04	0.02	0.03	0.02	0.02
Significance		NS	NS	NS	*	NS
AGT	18	0.04	0.05b	0.03	0.00b	0.01b
AGT	22	0.04	0.11a	0.04	0.03a	0.02a
AGT	26	0.03	0.13a	0.04	0.03a	0.02a
LSD		0.03	0.04a	0.02	0.01	0.00
Significance		NS	*	NS	**	**
MAP	18	0.03	0.02b	0.03	0.01b	0.01
MAP	22	0.05	0.04a	0.04	0.04a	0.02
MAP	26	0.04	0.03ba	0.04	0.04a	0.02
LSD		0.04	0.01	0.02	0.01	0.01
Significance		NS	*	NS	**	NS
CRF2	18	0.60	0.04	0.12	0.03	0.01
CRF2	22	0.55	0.05	0.07	0.06	0.03
CRF2	26	0.38	0.06	0.07	0.06	0.03
LSD		0.31	0.03	0.05	0.04	0.03
Significance		NS	NS	NS	NS	NS
HSD		0.19	0.03	0.04	0.03	0.02
Significance		***	***	***	**	**

NS, *, **, or *** non-significant or significant at $p \leq 0.05$, 0.01, or 0.001 respectively

Table 4.3. Total micronutrients leached (mg). Leaching was tested over an eight-week period at constant temperatures of 18° C, 22° C, or 26° C. Values represent a mean of three replications. Means with the same letter are not significantly different and represent differences only between temperatures for one fertilizer. HSD = Tukey's honest significant difference between all treatment means.

Treatment	Effect	*Micronutient*				
		Fe	**Mn**	**Zn**	**B**	**Cu**
Control	Temperature (T)	**	NS	NS	***	NS
	Week (W)	***	***	NS	NS	NS
	Irrigation volume	*	*	NS	NS	NS
	T×W	NS	NS	NS	NS	NS
AGT	Temperature (T)	*	***	***	***	***
	Week (W)	***	***	NS	***	***
	Irrigation volume	**	***	**	***	***
	T×W	***	**	*	**	*
MAP	Temperature (T)	NS	***	**	***	**
	Week (W)	*	***	NS	***	NS
	Irrigation volume	NS	***	***	***	NS
	T×W	NS	**	NS	NS	NS
CRF2	Temperature (T)	***	*	***	***	***
	Week (W)	***	***	**	***	NS
	Irrigation volume	NS	***	NS	NS	NS
	T×W	NS	**	NS	NS	NS

NS, *, **, or *** non-significant or significant at $p \leq 0.05$, 0.01, or 0.001 respectively

Table 4.4. Effect of temperature (T), week (W), irrigation volume, and the interaction between temperature and week (T×W) on micronutrient leaching over time. Leaching was tested at constant temperatures of 18° C, 22° C, or 26°C over an eight-week period.

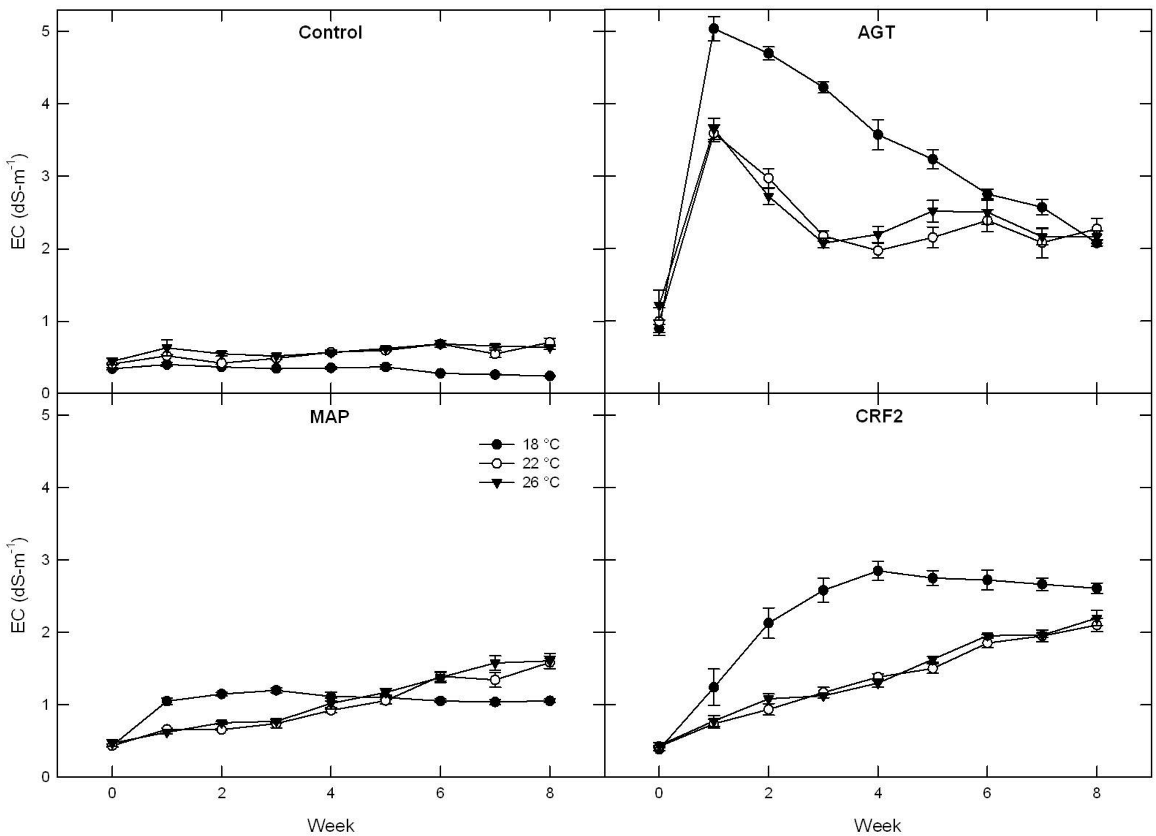

Figure 4.1. EC (dS·m^{-1}) of leachate samples. Error bars represent the standard error of the mean.EC was tested at constant temperatures of 18° C, 22° C, and 26° C over a period of eight weeks. Values are a mean of six replications.

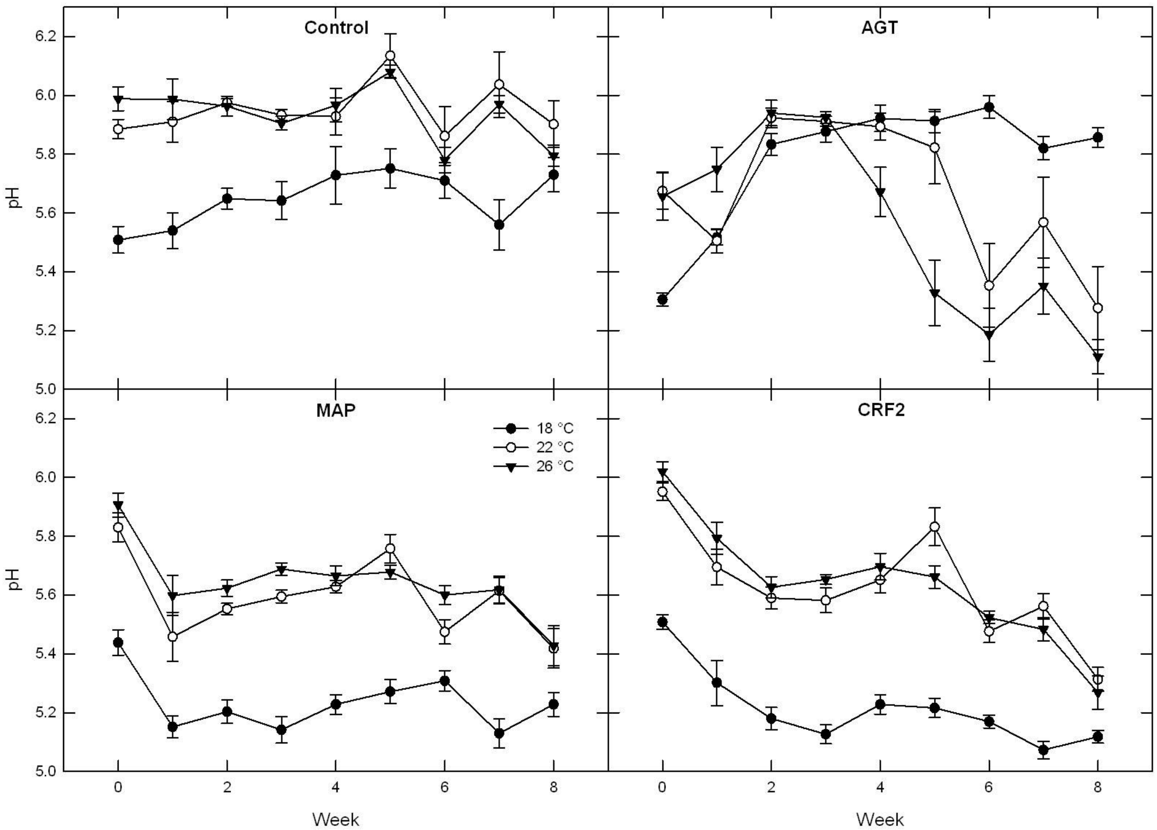

Figure 4.2. pH of leachate samples. Error bars represent the standard error of the mean.EC was tested at constant temperatures of 18° C, 22° C, and 26° C over a period of eight weeks. Values are a mean of six replications.

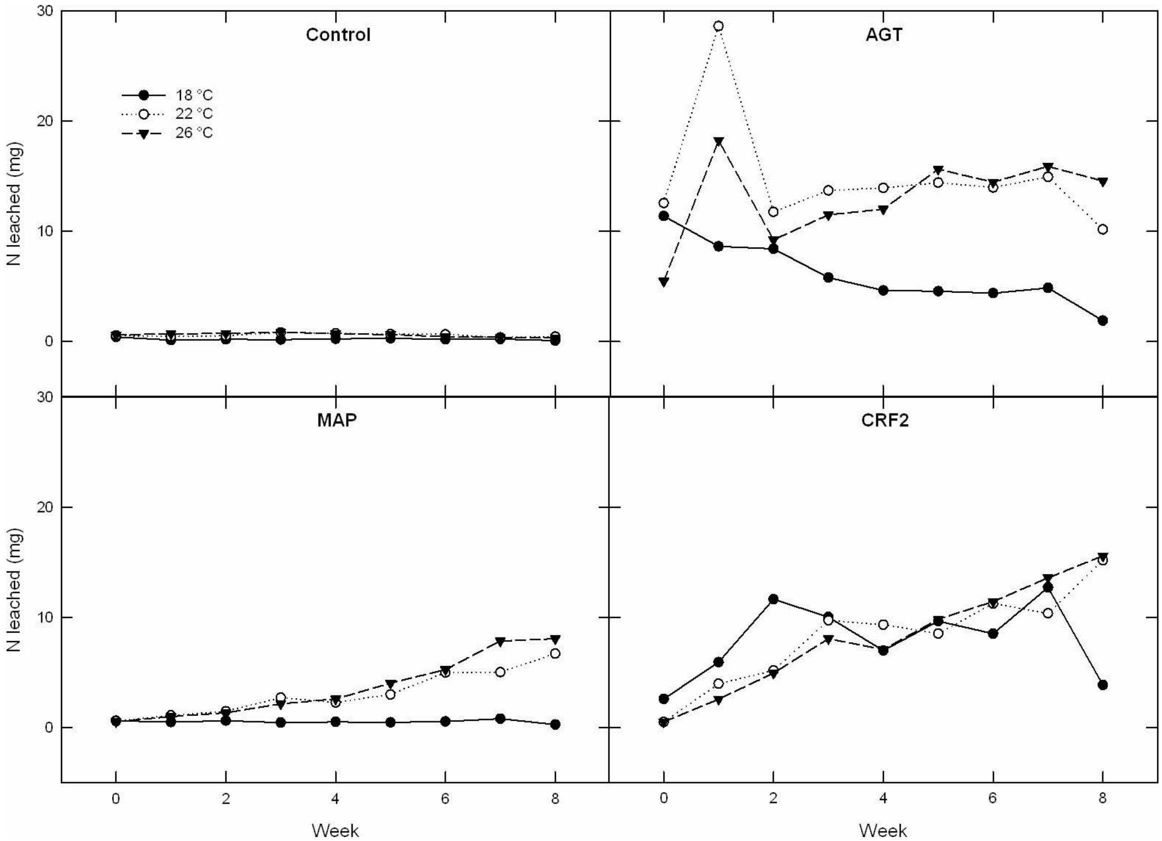

Figure 4.3. N leached (mg) per week. Leaching was measured at constant temperatures of 18°C, 22°C, and 26°C over a period of eight weeks. Values are a mean of three replications.

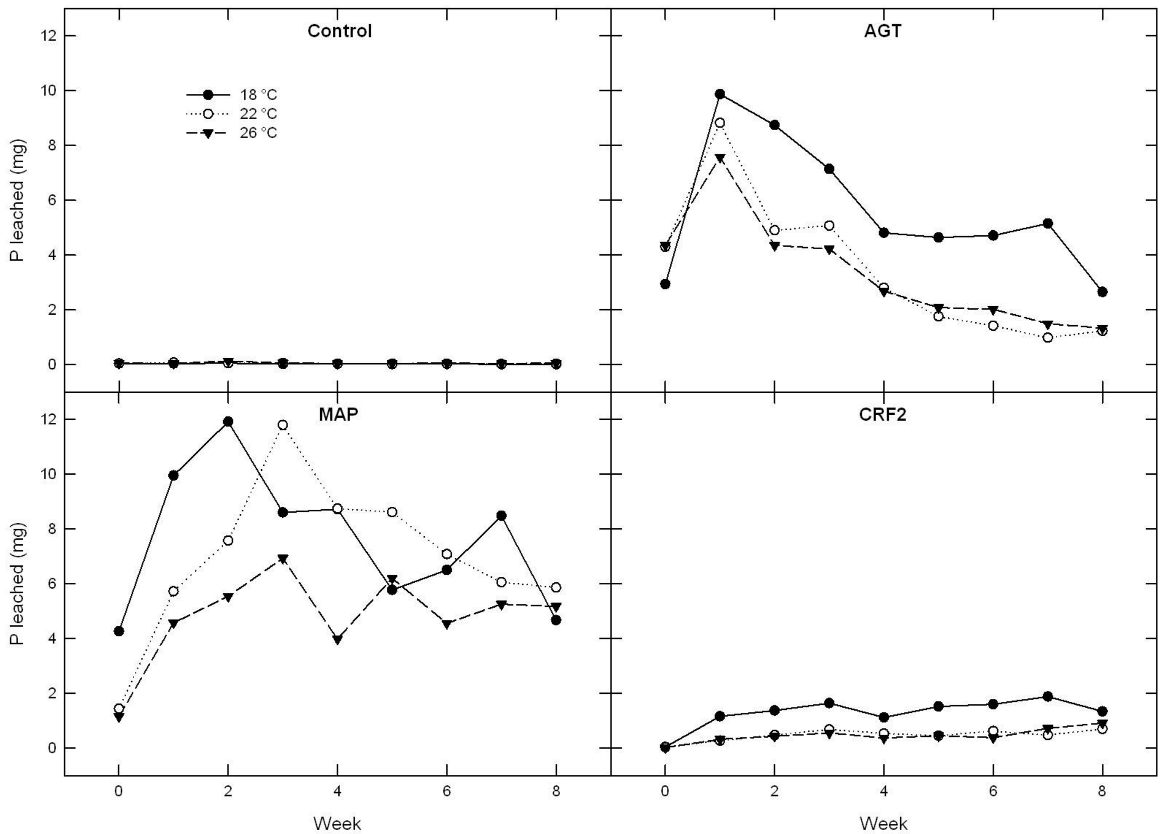

Figure 4.4. P leached (mg) per week. Leaching was measured at constant temperatures of 18°C, 22°C, and 26°C over a period of eight weeks. Values are a mean of three replications.

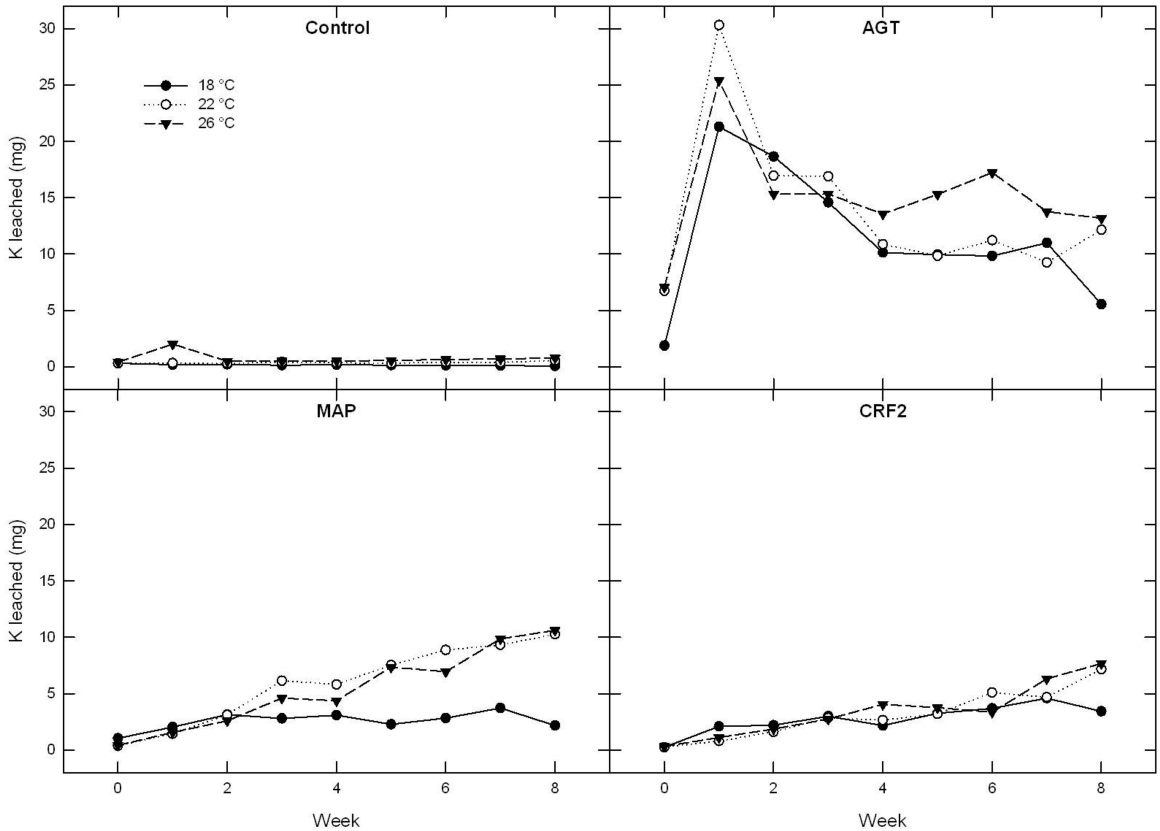

Figure 4.5. K leached (mg) per week. Leaching was measured at constant temperatures of 18°C, 22°C, and 26°C over a period of eight weeks. Values are a mean of three replications.

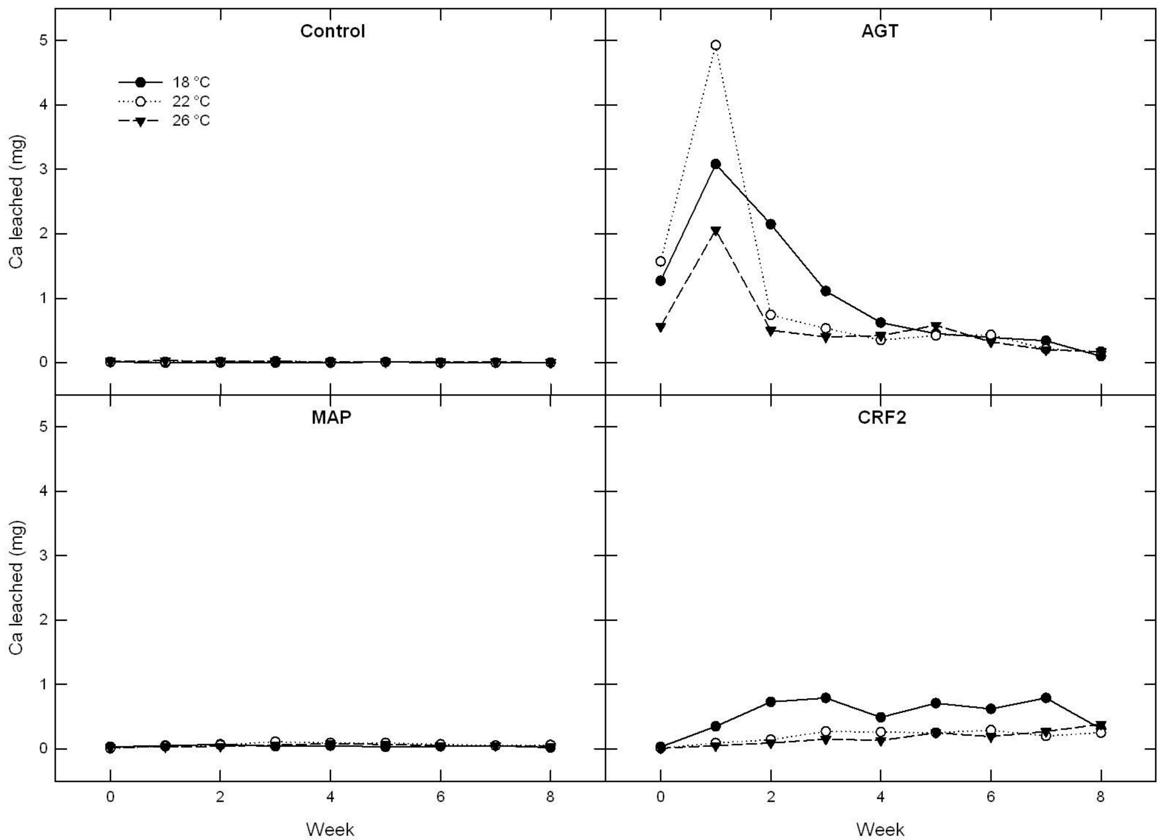

Figure 4.6. Ca leached (mg) per week. Leaching was measured at constant temperatures of 18°C, 22°C, and 26°C over a period of eight weeks. Values are a mean of three replications.

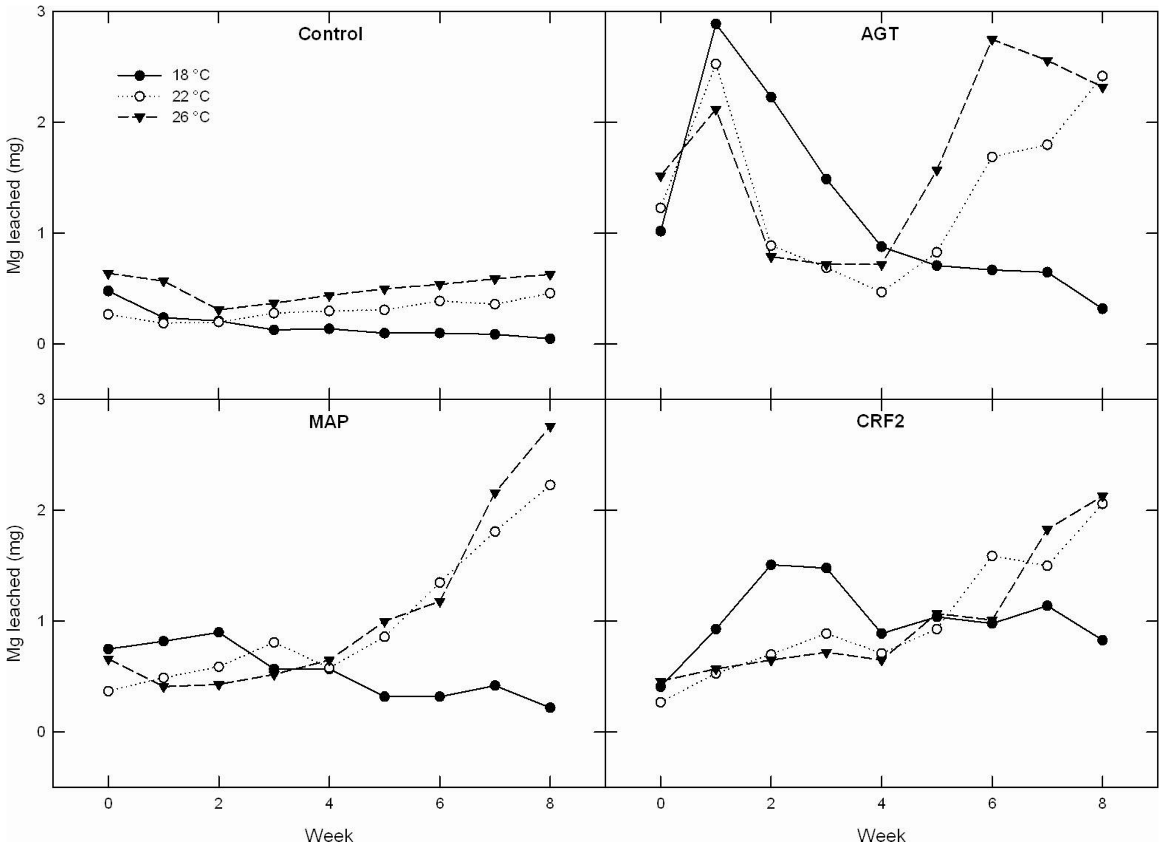

Figure 4.7. Mg leached (mg) per week. Leaching was measured at constant temperatures of 18°C, 22°C, and 26°C over a period of eight weeks. Values are a mean of three replications.

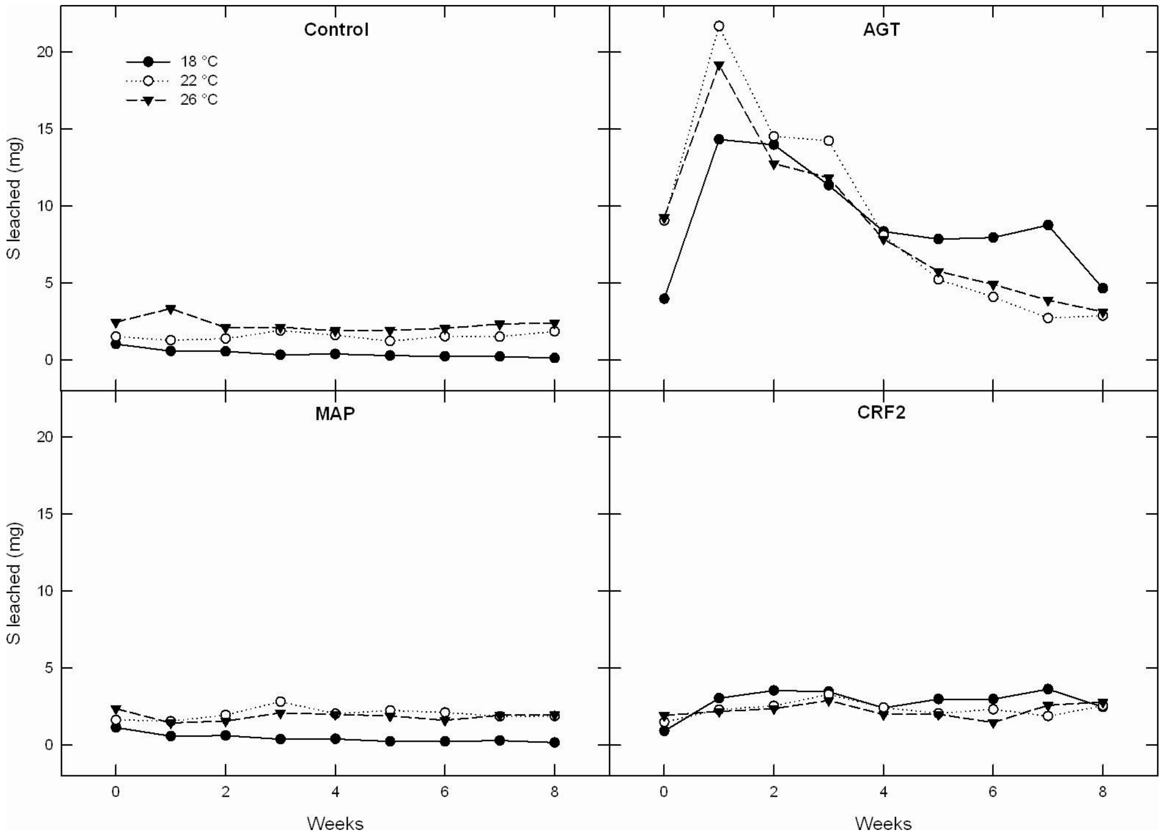

Figure 4.8. S leached (mg) per week. Leaching was measured at constant temperatures of 18°C, 22°C, and 26°C over a period of eight weeks. Values are a mean of three replications.

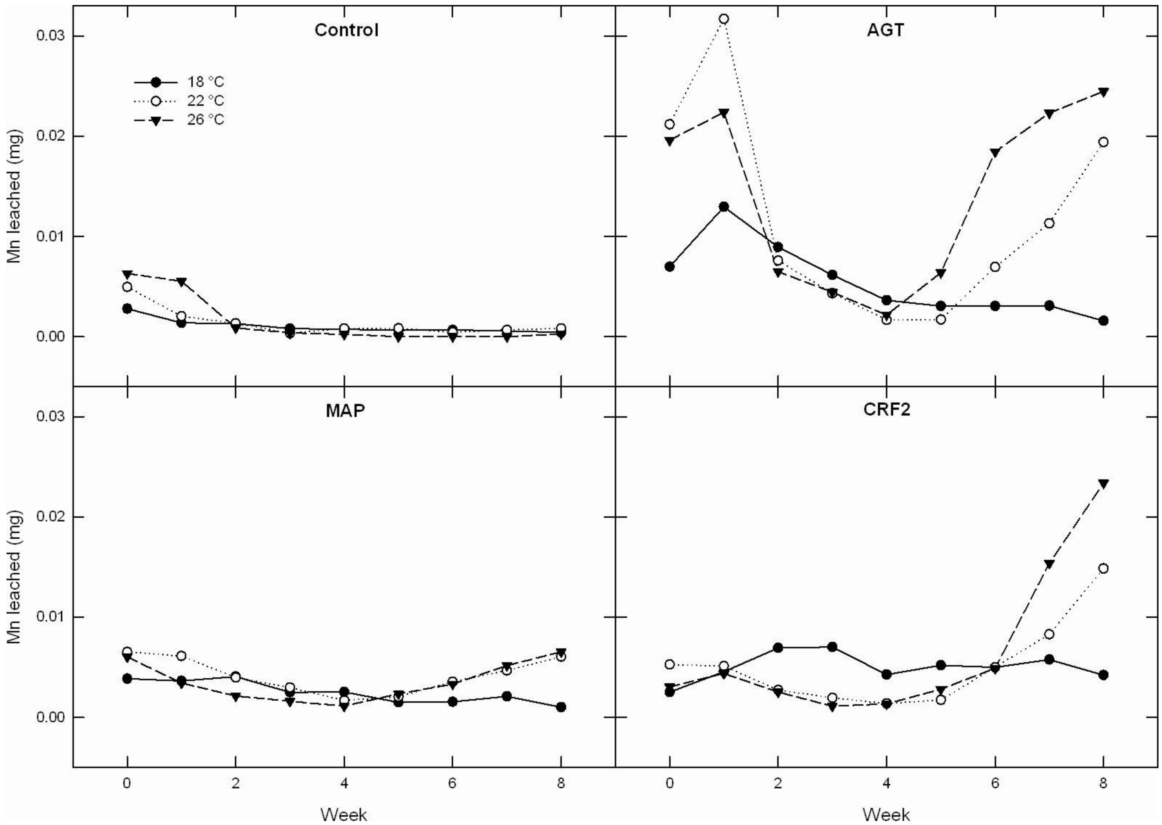

Figure 4.9. Mn leached (mg) per week. Leaching was measured at constant temperatures of 18°C, 22°C, and 26°C over a period of eight weeks. Values are a mean of three replications.

CHAPTER 5: GENERAL CONCLUSIONS

When determining a New Guinea Impatiens (NGI) fertility program, controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) can be used to produce plants of high quality. It is possible to apply WSF at low fertigation rates (75-150 $mg \cdot L^{-1}$ N) and have no reduction in growth due to substrate high electrical conductivity. If larger plants are desired, soybean-based fertilizer (SBF) can be fertigated at higher rates than WSF (>150 $mg \cdot L^{-1}$ N) and result in no suppression of growth. However, when SBF is used, potassium deficiency of NGI plants may occur. Similarly, advanced granular technology turf fertilizer (AGT) in its current formulation is probably not suitable for quality NGI production and may cause several nutrient deficiencies and reduced plant quality. Development of a quality index (QI) to discern differences in quality of plants treated with different fertilizers at varying rates can function as a non-conventional method to choose an optimum fertilization rate and incorporate consumer perceptions into the decision making process.

If highly efficient methods of irrigation are used during NGI production, CRF may result in greater leaching of nutrients – especially in regard to nitrogen. However, release patterns from polymer coated fertilizers vary, and for bedding plants a 3-4 month longevity may not be ideal. Choosing the proper CRF product for the crop is essential if nutrient leaching is to be reduced and plant quality maintained. Though not determined by this thesis, CRF may have more notable advantages for less efficient operations that continually use overhead irrigation. Due to the challenges growers face when growing NGI, WSF may be the best fertilization method as long as leaching is minimized and water is delivered in a way that minimizes waste. As a reiteration, SBF (as a second water-soluble fertilization method) can be used on salt sensitive crops such as NGI, but may require supplemental potassium.

When using slow or controlled release fertilizer products in a greenhouse setting, there may be less availability of nutrients at lower temperatures, depending on the product. CRF products will likely provide the maximum amount of control over a wider availability of temperatures by still providing sufficient nutrients, possibly in smaller quantities at lower temperatures. Slow-release products are less predictable in their release patterns, and those tested in this thesis resulted in availability of nutrients that may not appropriately match nutrient demand of bedding plant crops. This is especially the case at lower temperatures where availability of some nutrients such are significantly lower due to lack of microbial activity and/or a reduction in product dissolution rates.

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Appendix A: FERTILIZERS USED IN THIS RESEARCH

Nutrient	SBF	WSF	CRF	CRF2	AGT	MAP
Total Nitrogen	10.00%	20.00%	15.00%	15%	15%	7.00%
Ammoniacal	3.70%	7.97%	8.00%	8.40%	1.80%	7.00%
Nitrate	1.90%	12.03%	7.00%	6.60%	0%	0%
Urea	3.65%	0%	0%	0%	13.20%	0%
Other	0.75%	0%	0%	0%	0%	0%
Available Phosphate	4.00%	10.00%	9.00%	9.00%	9.00%	40.00%
Soluble Potash	3.00%	20.00%	12.00%	12.00%	12.00%	6.00%
Calcium	0.01%	0%	1.90%	1.90%	0.40%	0%
Magnesium	0.05%	0.15%	1.40%	1.30%	1.00%	15.00%
Sulfur	1.00%	0%	4.00%	6.00%	0.11%	0%
Boron	0.002%	0.02%	0.02%	0.02%	0%	0%
Copper	0.001%	0.01%	0.05%	0.05%	0%	0%
Iron	0.01%	0.10%	0.45%	0.46%	0.18%	0%
Manganese	0.005%	0.056%	0.06%	0.06%	0%	0%
Molybdenum	0.0003%	0.01%	0.02%	0.02%	0%	0%
Zinc	0.004%	0.0162%	0.05%	0.05%	0%	0%

Table A.1. Guaranteed manufacturer analyses of the six fertilizers tested. WSF, SBF, CRF, CRF2, AGT, and MAP represent: 1) Peters Peat-Lite 20-4.4-16.6 water-soluble fertilizer, (Scotts Co., Marysville, OH), 2) Daniels 10-1.8-2.5 soybean-based fertilizer (DP Foods, Sherman, TX), 3) Osmocote Plus 15-4-10, 3-4 month controlled-release fertilizer (Scotts Co., Marysville, OH), 4) Osmocote Plus 15-4-10, 5-6 month controlled-release fertilizer (Scotts Co., Marysville, OH), 5) Contec-DG 15-4-10, 5-month slow-release turf fertilizer (The Andersons Co., Maumee, OH), and 6) MagAmp K 7-17.7-5, six-month slow release fertilizer (MAP) (Sumitomo Corp., Tokyo, Japan), respectively.

Appendix B: CONSUMER PREFERENCE SURVEY

Instructions:

The following survey involves a research experiment in which different methods of production in the greenhouse were used. Please do not identify yourself - your responses will be kept confidential and anonymous. Completion of the form following this page assumes your agreement to participate in a voluntary matter, and that you are 18 years of age or older (if not, do not participate). Five minutes or less of your time is sufficient to complete the survey. You will be asked to give nine groups of plants a rating of 1 to 5 in four quality characteristics (where 1 is poor/not acceptable and 5 is excellent). You may refuse to answer questions that you do not wish to answer, and you may refuse to participate or withdraw at any time without penalty or repercussion. All responses will be collected and stored securely, only accessible by the principal investigator. Data will be used for statistical analysis to differentiate the different plant treatments. You may contact the principal investigator at any time. Feel free to remove and retain these instructions for future reference. Thank you very much for your participation.

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Figure B.1. Consumer preference survey letter and instructions.

Please take time to evaluate the nine different groups of plants, as a whole, according to the categories below. Rate each grouping (1-9) of plants as a whole with the following five designations:
1= poor/not acceptable, 2 = fair, 3 = good, 4 = very good, 5 = excellent. Circle your rating.

GROUP #	QUALITY CHARACTERISTIC	RATING				
1	Foliage and Plant Vigor	**1**	**2**	**3**	**4**	**5**
	Flower Number	**1**	**2**	**3**	**4**	**5**
	Uniformity	**1**	**2**	**3**	**4**	**5**
	Overall Rating	**1**	**2**	**3**	**4**	**5**
2	Foliage and Plant Vigor	**1**	**2**	**3**	**4**	**5**
	Flower Number	**1**	**2**	**3**	**4**	**5**
	Uniformity	**1**	**2**	**3**	**4**	**5**
	Overall Rating	**1**	**2**	**3**	**4**	**5**
3	Foliage and Plant Vigor	**1**	**2**	**3**	**4**	**5**
	Flower Number	**1**	**2**	**3**	**4**	**5**
	Uniformity	**1**	**2**	**3**	**4**	**5**
	Overall Rating	**1**	**2**	**3**	**4**	**5**
4	Foliage and Plant Vigor	**1**	**2**	**3**	**4**	**5**
	Flower Number	**1**	**2**	**3**	**4**	**5**
	Uniformity	**1**	**2**	**3**	**4**	**5**
	Overall Rating	**1**	**2**	**3**	**4**	**5**
5	Foliage and Plant Vigor	**1**	**2**	**3**	**4**	**5**
	Flower Number	**1**	**2**	**3**	**4**	**5**
	Uniformity	**1**	**2**	**3**	**4**	**5**
	Overall Rating	**1**	**2**	**3**	**4**	**5**

Figure B.2. Consumer preference survey. Plants were organized by treatment and then treatments were completely randomized on a greenhouse bench and assigned a group number (#).