EFFECT OF FERTILIZER SOURCE AND SOILLESS MEDIA CONSTITUENTS ON FE, MN, AND ZN LEACHING FROM GREENHOUSE AND CONTAINERIZED NURSERY PRODUCTION

By

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With increasing concern for the environment, sound crop management techniques are vital to reducing potential contamination of surface and ground water sources provided to growers through research. This study was conducted to contribute new knowledge pertinent to improving irrigation and fertilization practices to reduce discharge from greenhouse and containerized nursery operations which are potential contamination sources for surface and underground water supplies. This two year study examined micronutrient leaching from both greenhouse and container nursery production as influenced by micronutrient source. It also investigated the affect of various media substrates on micronutrient retention within the media.

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Chapter 1

INTRODUCTION

Increasing concern for environmentally sound crop production via reduction of contaminated run-off from containerized plant production has, and will continue to bring new legislation. New regulations and standards are being implemented by government agencies at all levels (Conover and Poole, 1992). Use of intensive fertilization and irrigation techniques is common in containerized crop production and leads to potential contamination of surface and ground water supplies. Research leading to environmentally sound crop management is vital to providing growers with necessary information to adjust production schemes to allow growers to become proactive instead of reactive towards run-off contamination issues (Johnson, 1991). Reducing contamination of surface and ground water is a regional concern since pollutants can be carried in rivers or aquifers a great distance. Thus, many residents could potentially use contaminated water for drinking and other uses.

Many nursery and greenhouse operations are located near surface and underground water sources and utilize the water from, and release contaminated run-off back into these sources. Containerized crop production is limited in medium volume used. This limitation provides a limited storehouse for required plant nutrients and a low water holding capacity of the medium (Sanderson, 1987). To maintain plant vigor and quality, growers rely heavily on fertilization, pesticides, and more frequent irrigations that can contribute to the entry of pollutants into surface and underground water sources. By increasing the nutrient and water efficiency of containerized crop production, the quality of water released from production nurseries and greenhouse operations can be improved by the reduction of pollutants released through run-off. In addition, the cost of fertilizer and water may be reduced for the grower. Through water efficient irrigation techniques and sound cultural practices, plant quality and environmental protection may reach an advantageous equilibrium.

Water standards for aesthetic contaminates such as Fe, Mn, and Zn are determined at secondary maximum contamination levels (SMCL). Inorganic SMCLs for Fe, Mn and Zn are observed at 0.3 $mg \cdot L^{-1}$, 0.05 $mg \cdot L^{-1}$, and 5.0 $mg \cdot L^{-1}$, respectively (Bradshaw, 1989). Although SMCLs are not enforceable, concentrations in excess of these SMCLs can exhibit unpleasant taste, odor, and appearance to drinking water as well as staining of porcelain fixtures and laundry. Intensive research has been conducted examining leaching fraction, fertilizer concentration, fertilizer type, and/or irrigation method influence on NO_3-N leachate levels in a peat-based medium for container-grown plants (Conover and Poole, 1992; Dole et al., 1992; Dole et al., 1994; Hershey and Paul, 1982; Karam and Niemiera, 1994; Ku and Hershey, 1991; Morvant, 1995; Rathier and Frink, 1989; Yeager et al., 1993; Yelanich and Biernbaum, 1990, 1993, and 1994). There has been little research examining the leaching potential of inorganic, divalent cations such as

Fe, Mn, and Zn in container-grown plants. This thesis will evaluate Fe, Mn, and Zn concentrations in leachate from greenhouse and container nursery production, as influenced by fertilizer source and irrigation method.

Fertilizer

Two fertilizer types used in greenhouse and container nursery production are: Controlled-release fertilizer (CRF), and soluble (liquid feed) fertilizer (SF). Controlled release fertilizer is known to decrease N in run-off and increase N retention by the crop compared to SF (Cox, 1985). Soluble fertilizer is considered inefficient when surface irrigation is used due to the high leaching of nutrients (Holcomb, 1980). Moreover, production of plants with SF can produce unacceptable levels of nitrates in leachate (Conover and Poole, 1992). An advantage of CRF over SF is the reduction of nutrient loss via leaching, resulting in higher efficiency of nutrient recovery and reduced fertilizer leaching (Holcomb, 1980; Maynard and Lorenz, 1979). Hershey and Paul (1982) found that N loss ranged from 12-23% for CRF, while N loss for SF was at 12-48%. In addition, Rathier and Frink (1989) concluded that CRF could be more efficient in reducing N leachate concentrations if applied in split applications.

Irrigation

Many irrigation techniques are available for growers, most common are overhead (hand) and microtube irrigation. Microtube irrigation systems, also referred to as trickle or drip irrigation, are used in greenhouse, outdoor container, or field crop production. Rathier and Frink (1989) noted that trickle irrigation used less water and released run-off with a lower N concentration than overhead sprinkler irrigation, while N loss to leaching was also decreased. For greenhouse production, microtube irrigation allowed more water to be retained in the media and produced plants with greater dry mass than capillary mats, ebb-and-flow, or hand-watering (Dole et al., 1994).

Sprinkler, mist systems, and manual (hand) watering are common types of overhead irrigation systems. Dole et al. (1994) noted that hand-watering resulted in a higher quality plant only at a higher fertilizer rate than other irrigation systems. A 10-15% leaching fraction (LF) is recommended for overhead watering, however, Yelanich and Biernbaum (1990) noted that some growers have a LF greater than 40%, increasing potential contamination of water sources.

Media

Components of container plant growing media have different chemical and physical properties that differ from field soils or soil-based media. Research has focused on assessing physical properties of various soilless media and their impact on plant growth (Bilderback et al., 1982; Fonteno et al., 1981). Root media must serve four functions to attain good plant growth: 1) reservoir for plant nutrients, 2) hold water so that it is available to the plant, 3) gas exchange between plant roots and the atmosphere, and 4) anchorage or support for the plant.

Peat moss is a major component in commercial mixes. Although cost is high, peat provides excellent water holding capacity, holding up to 60% of its volume in water (Nelson, 1991). Peat moss is acidic with a pH of 3.0-4.0 and requires addition of limestone to make the pH suitable for optimal plant growth. Pine bark is inexpensive compared to other material like peat moss and is a suitable component in growing media. A period of composting for bark is necessary before use in media to bring it to a stage of slow and steady decomposition.

Sand is used in most growing media for adding coarse texture needed to induce proper media drainage and aeration (Nelson, 1991). In addition, the high bulk density of sand makes it suitable for anchoring plants in locations where winds are prevalent. Perlite is a good substitute for sand for providing adequate drainage and aeration in the root media. Perlite is a siliceous volcanic rock that is heated to high temperatures (982°C) during the manufacturing process. Its biggest advantage over sand is its light weight. However, perlite is chemically inert and has a negligible CEC.

Studies have evaluated the chemical properties of soilless media and their effect on plant growth (Williams et al., 1988), and P leaching from soilless container media (Yeager and Barrett, 1984). Considerable amounts of P may be leached from soilless media due to the porosity of the media, daily irrigation and the composition of soilless mixes using both organic and inorganic media components such as pine bark, peat, and sand (Yeager and Barrett, 1984). Marconi and Nelson (1984) attribute greater P leaching from 1 peat:1 vermiculite (by volume) than from 1 sand:1 soil:1 peat (by volume) to lower P sorption in 1 peat:1 vermiculite. Pill et al. (1995) found that kenaf stem cores soaked in N can serve effectively as a bulking component of soilless media with the capacity to release N over an extended period. Moreover, they found NO_3 concentrations in leachate to be greater from a peat-vermiculite soilless mix compared to a peat-kenaf mix.

Broschat and Donselman (1985) examined extractable (ammonium acetate NH_4OAc, pH 7.0) Fe, Mg, Mn, Zn, and Cu in a peat-based medium amended with six commercial micronutrient fertilizers. While they found iron diethylenetriaminepentaacetic acid (FeDTPA) to be the best source of Fe, FeDTPA is soluble and all detectable Fe had leached from the medium within 40 weeks. Amounts of all five elements from the various fertilizer sources decreased in the media during the first month and then remained consistent for the remaining 18-month experimental period. In addition, extractable Fe, Mn, and Zn in the medium were reduced by addition of superphosphate present in Micromax Plus (Scotts Co., Marysville, Ohio) presumably due to the formation of insoluble phosphates at pH=7.0 during the extraction. Micronutrients like Fe, Mn, and Zn are so named due to low plant requirement. This does not mean Fe, Mn, and Zn cannot be readily leached from container-grown plants and become a pollutant in potable water sources.

Many soil testing methods have been modified for evaluating soilless mixes containing peat, bark, sand, perlite, and vermiculite. Methods for detection of pH, EC and elemental variables have been established for many soilless mixes (Bachman and Halbrooks, 1994; Berghage et al., 1987; Karla and Maynard, 1994; Markus et al., 1981; Warncke, 1986 and 1990). Berghage et al. (1987) modified the deionized (DI) water saturation medium extraction method by using 0.005 M DTPA (diethylenetriaminepentaacetic acid). The use of this method enhanced micronutrient cation test levels while maintaining macronutrient, pH, and soluble salt test results when compared to the DI water extraction procedure. By using DTPA extractants at a medium to extractant ratio of 1:4 (v/v), Markus et al. (1981) increased the amount of Zn, Mn, Fe, and Cu extracted from a peat-vermiculite media. Furthermore, Bachman and Halbrooks (1994) have shown DTPA to be an effective extraction agent for the micronutrients from peat-based soilless media.

Micronutrients

Seventeen essential nutrient elements and numerous nonessential elements comprise the solid material of the plant which are available in and taken up from the growing media. Six of these are Fe, Mn, Zn, Cu, B, and Mo which are referred to as micronutrients due to small amounts being utilized by plants. Common forms of these nutrients are sulfur-based salts, impregnated clays, and chelates for metals that are difficult to hold in media solution even at high pH.

In general, micronutrients are immobile with deficiency symptoms occurring in young leaves of the plants. Iron deficiency is one of the most common problems of many crops with interveinal chlorosis of young leaves. Manganese exhibits similar deficiency symptoms to Fe; however, Mn affects middle leaves of plants more than Fe due to its partial mobility within the plant. Zinc deficiency is noted by malformation of young, developing plant leaves. The pH influences the availability of micronutrients in mineral soils and soilless media (Nelson 1991). Iron, Mn, and Zn availability is highest at lower pH while soilless medium tend to have slightly acidic to basic pH.

Objectives of Research

The research presented has three objectives:

1) to determine the effect of fertilizer source and irrigation method on plant growth and Fe, Mn, and Zn leaching.

2) to determine the effect of media components or a combination of those media components amended with various micronutrient fertilizers on Fe, Mn, and Zn leachate concentration.

3) to determine Fe, Mn, and Zn leachate concentrations from media components or a combination of those media components amended with various micronutrient fertilizers as affected by Ca and Mg.

The information gained from this research will enable growers to produce high quality, salable plants in selected soilless media so that the amount of heavy metals (Fe, Mn, and Zn) released to the environment through run-off is minimized.

Literature Cited

Bachman, G.R. and M.C. Halbrooks. 1994. Multiple applications of FeDTPA or DTPA on micronutrient extraction and potential availability from peat-based medium. Commun. Soil Sci. Plant Anal. 25:3101-3113.

Berghage, D.M., D.M. Krauskopf, D.D. Warncke, and I. Widders. 1987. Micronutrient testing of plant growth media: Extractant identification and evaluation. Commun. Soil Sci. Plant Anal. 18:1089-1109.

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peat moss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:1081-1084.

Bradshaw, M.H. 1989. Understanding your water test report- Microbial, chemical, and nuisance contaminants. Kansas State University County Extension. MF-912. In: World wide web @ http://ingis:acn.purdue.edu:9999 /Wetnet/government / DIAGNOSE/standards.html.

Broschat, T.K. and H.M. Donselman. 1985. Extractable Mg, Fe, Mn, Zn, and Cu from a peat-based container medium amended with various micronutrient fertilizers. J. Amer. Soc. Hort. Sci. 110:196-200.

Conover, C.A. and R.T. Poole. 1992. Effect of fertilizer and irrigation on leachate levels of NH_4, NO_3, and P in container production of *Nephrolepsis exalta* 'Fluffy Ruffle'. J. Environ. Hort. 10:238-241.

Cox, D.A. 1985. Nitrogen recovery by seed geranium as influenced by nitrogen source. HortScience 20:923-925.

Dole, J.M., J.C. Cole, and R.M. Smith. 1992. Effect of controlled-release and constant liquid fertilization on leachate and plant quality. HortScience 27:582. (abstr.).

Dole, J.M., J.C. Cole, and S.L. von Broembsen. 1994. Growth of poinsettias, nutrient leaching, and water-use efficiency respond to irrigation methods. HortScience 29:858-864.

Fonteno, W.C., D.K. Cassel, and R.A. Larson. 1981. Physical properties of three container media and their effect on poinsettia growth. J. Amer. Soc. Hort. Sci. 106:736-741.

Hershey, D.R. and J.L. Paul. 1982. Leaching-losses of nitrogen from pot chrysanthemums with controlled-release or liquid fertilization. Scientia Hort. 17:145-152.

Holcomb, E.J. 1980. How to increase fertilizer efficiency through slow-release formulations. Amer. Nurseryman 152(7):9,38,40,42.

Johnson, J.R. 1991. Nutrient runoff from nurseries- Is it a problem? Proc. Intl. Plant Prop. Soc. 41:428-431.

Karam, N.S. and A.X. Niemiera. 1994. Cyclic sprinkler irrigation and pre-irrigation substrate water content affect water and N leaching from containers. J. Environ. Hort. 12:198-202.

Karla, Y.P. and D.G. Maynard. 1994. A comparison of extractants for the determination of cation exchange capacity and extractable cations by a mechanical vacuum extractor. Commun. Soil Sci. Plant Anal. 25:1505-1515.

Ku, C.S.M. and D.R. Hershey. 1991. Leachate electrical conductivity and growth of potted poinsettia with leaching fractions of 0 to 0.4. J. Amer. Soc. Hort. Sci. 116:802-806.

Marconi, D.J. and P.V. Nelson. 1984. Leaching of applied phosphorus in container media. Scientia Hort. 22:275-285.

Markus, D.K., J.E. Steckel, and J.R. Trout. 1981. Micronutrient testing in artificial mix substrates. Acta Hort. 126:219-235.

Maynard, D.N. and O.A. Lorenz. 1979. Controlled-release fertilizers for horticultural crops. In: J. Janick (ed.). Horticultural Reviews, Vol. 1. AVI Publishing, Westport, Conn.

Morvant, J.K. 1995. Effects of irrigation method on plant growth, water and nutrient efficiency, and run-off. M.S. Thesis, Oklahoma State Univ., Stillwater.

Nelson, P.V. 1991. Greenhouse operations and management. 4th ed. Prentice Hall, Englewood Cliffs, N.J.

Pill, W.G., S. Bing, H. D. Tilmon, and R. W. Taylor. 1995. Leaching loss and plant uptake of nitrogen in soilless media containing ground kenaf (*Hibiscus cannabinus* L.) stem core. J. Hort. Sci. 70:833-840.

Rathier, T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and Alberta spruce under different irrigation and N fertilization regimes. J. Environ. Hort. 7:32-35.

Sanderson, K.C. 1987. Selecting the right fertilizers for container-grown woody ornamentals. Amer. Nurseryman 165(1):160-177.

Warncke, D.D. 1986. Analyzing greenhouse growth media by the saturation extraction method. HortScience 21:223-225.

Warncke, D.D. 1990. Testing artificial growth media and interpreting the results, p.337-357. In: R.L. Westerman (ed.). Soil testing and plant analysis. Soil Sci. Soc. of Amer. Inc., Madison, Wis.

Williams, B.J., J.C. Peterson, and J.D. Utzinger. 1988. Liming reactions in sphagnum peat-based growing media. J. Amer. Soc. Hort. Sci. 113:210-214.

Yeager, T.H. and J.E. Barrett. 1984. Phosphorus leaching from ^{32}P-superphosphate-amended soilless container media. HortScience 19:216-217.

Yeager, T.H., R. Wright, D. Fare, C. Gilliam, J. Johnson, T. Bilderback and R. Zondag. 1993. Six state survey of container nursery nitrate nitrogen runoff. J. Environ. Hort. 11:206-208.

Yelanich, M.V. and J.A. Biernbaum. 1990. Effect of fertilizer concentration and method of application on media nutrient concentration, nitrogen runoff and growth of *Euphorbia pulcherrima* 'V-14 Glory'. Acta Hort. 272:185-189.

Yelanich, M.V. and J.A. Biernbaum. 1993. Root-medium nutrient concentration and growth of poinsettia at three fertilizer concentrations and four leaching fractions. J. Amer. Hort. Sci. 188:771-776.

Yelanich, M.V. and J.A. Biernbaum. 1994. Fertilizer concentration and leaching affect nitrate-nitrogen leaching from potted poinsettia. HortScience 29:874-875.

Chapter 2

FERTILIZER SOURCE AFFECTS FE, MN, AND ZN LEACHING, NUTRIENT DISTRIBUTION, AND GERANIUM GROWTH

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Abstract. **When Fe, Mn, and Zn were applied as a granular incorporated fertilizer (GIF) or water soluble fertilizer (WSF), minimal differences were observed in plant growth parameters measured. More Mn was leached from growing medium when applied as GIF than with WSF. Secondary maximum contamination level (0.05 mg·L^{-1}) for Mn was exceeded in the leachate during the experimental period with both fertilizer sources. Upper and middle regions of the growing medium had a higher concentration of Fe, Mn, and Zn than the lower region when micronutrients were surface applied. Element amounts were evenly distributed among media regions for GIF treatments that were incorporated into the medium prior to the experiment. At the conclusion of the study, Fe medium retention percentage was greater with WSF than with GIF. In contrast, GIF had a greater percentage of Zn retained in the medium than WSF.**

Introduction

Improving the quality of water released from container production nurseries and greenhouse operations is an increasing concern in many areas of the United States. Because of availability, water from ground and surface sources is widely used for drinking and other household needs (Hornby, 1986). Pollution is a threat to our ground and surface waters and must be considered as management decisions are made about production practices.

Container plant production differs from field production in that little or no mineral soil is used in the growing medium. In addition, container crops have a limited amount of nutrients and water available to the plant due to the small volume of growing medium in the container (Morvant, 1995). Therefore, more frequent irrigation and fertilization is needed to provide adequate plant nutrition for containerized plants compared to field-grown plants with no root restriction. Intense irrigation and fertilization leads to possible contamination of ground and surface water sources since excess water flows out of the production area and potentially into potable water sources.

Nitrate-N and PO_4-P environmental contamination has been of utmost concern to growers and consumers. Several studies have examined greenhouse and container nursery production methods to reduce runoff of these two contaminants by implementing better management practices (Broschat, 1995; Conover and Poole 1992; Dole et al., 1994; Hershey and Paul, 1982; Marconi and Nelson, 1984; Morvant et al., 1997; Rathier and Frink, 1989; Yeager and Barrett, 1984; Yelanich and Biernbaum, 1994). Nitrate concentrations greater than 10 mg·L^{-1} in drinking water are considered unsafe for human consumption (U.S. Environmental Protection Agency, 1982), and PO_4-P is much more readily leached from container media composed of pine bark, spaghnum peat, perlite, and vermiculite than from mineral soils (Marconi and Nelson, 1984; Yeager and Barrett, 1984). Phosphorous adsorption isotherms on seven media components and component mixtures were conducted by Marconi and Nelson (1984). Resulting graphs conferred greater leaching loss of P in soilless mixes and components due to a lower P adsorption capacity.

Hershey and Paul (1982) measured N leaching losses in potted chrysanthemums (*Dendranthema* × *morifolium* Ramat. 'Bright Golden Anne') fertilized with controlled release fertilizer (CRF) and water soluble fertilizer (WSF). They noted that N lost through leaching was greater at higher rates of CRF and WSF. Furthermore, N loss occurred during the first half of the crop cycle when using a CRF while N leaching losses occurred throughout the experiment with WSF. The percentage of applied N lost by leaching varied from 12 to 23% with CRF at rates of 1.68-3.36 g N/pot, while N losses with WSF varied from 12 to 48% with 1.2-3.6 g N/pot. Yelanich and Biernbaum (1990) estimated that N runoff from top watering poinsettia (*Euphorbia pulcherrima* Willd. 'V-14 Glory') with 400 mg·L^{-1} N and 50% leaching fraction (LF) was 40 times greater than N runoff from top watering with 100 mg·L^{-1} N and 12% LF. Rathier and Frink (1989) examined total NO_3-N output from containerized nursery plants fertilized with various N CRF and WSF and found less nitrate was leached by trickle than by overhead irrigation. In addition, slow release N sources lost less nitrate in the runoff water compared to soluble N forms; however, slow release sources still lost sufficient nitrate to pollute ground water unless annual fertilizer needs were managed by split applications. Several studies have examined other management practices to reduce runoff volume such as irrigation method, irrigation water volume applied, and leaching fraction (LF) (Conover and Poole, 1992; Dole et al., 1994; Ku and Hershey, 1991).

We are not aware of any studies evaluating Fe, Mn, and Zn leaching from greenhouse or nursery container production. Broschat and Donselman (1985), however, examined extractable (ammonium acetate NH_4OAc, pH 7.0) Fe, Mg, Mn, Zn, and Cu in a peat-based medium amended with six commercial micronutrient fertilizers. While they found iron diethylenetriaminepentaacetic acid (FeDTPA) to be the best source of Fe, FeDTPA is soluble and all detectable Fe had leached from the medium within 40 weeks. Amounts of all five elements from the various fertilizer sources decreased in the medium during the first month and then remained consistent for the remaining 18-month experimental period. In addition, extractable Fe, Mn, and Zn amounts in the medium were reduced by addition of superphosphate present in Micromax Plus (Scotts Co., Marysville, Ohio) due to the formation of insoluble phosphates (Broschat and Donselman, 1985).

Like PO_4-P, micronutrients may leach more readily from container production using a soilless growing medium as compared to the mineral soils of field production. Marconi and Nelson (1984) conducted P adsorption isotherms on seven media components and component mixtures and noted a greater leaching loss of P in soilless mixes and components due to a lower P adsorption capacity. Furthermore, a separate experiment resulted in 33% of P applied being leached from a 1 peat moss:1 vermiculite mix (by volume) compared to less than 5% P leached from a 1 sand:1 mineral soil:1 peat moss mixture (by volume) under similar watering schemes (Marconi and Nelson, 1984). Soilless medium components may alter the adsorption capacity (CEC) of the medium for micronutrients, affect the number of exchange sites, or displace micronutrient cations from exchange sites. Thus, soilless media may increase the movement of micronutrients through the medium profile and out the bottom of the pot.

Iron, Mn, and Zn are inorganic cations which are major components in commercial granular incorporated fertilizer (GIF) and WSF. These ions can be leached during production and are considered secondary contaminants in drinking water (U.S. EPA, 1982). The Environmental Protection Agency (EPA) has set secondary maximum contamination levels (SMCLs) for Fe, Mn, and Zn and recommend that levels of these elements should not exceed 0.3 $mg \cdot L^{-1}$ for Fe, 0.05 $mg \cdot L^{-1}$ for Mn, and 5.0 $mg \cdot L^{-1}$ for Zn in drinking water (Bradshaw 1989). As secondary contaminants, these drinking water recommendations are not enforceable by law, but unsightly discoloration of porcelain fixtures and clothing could occur at ion concentrations in excess of their regulatory level. In addition, micronutrient ions may have a detrimental effect on aquatic organisms, such as mussels, many species of which are threatened or endangered in the United States (Stolzenburg, 1992).

The purpose of this study was to determine 1) the effect of Fe, Mn, and Zn applied as a GIF or WSF on plant growth and Fe, Mn, and Zn leaching, 2) Fe, Mn, and Zn distribution throughout the medium, and 3) Fe, Mn and Zn retention in the medium.

Materials and Methods

Commercial micronutrient source (Expt. 1). Commercially grown geranium (*Pelargonium hortorum* L. 'Orbit Red') seedling plugs (Jolly Farmer, East Lempster, N.H.) were planted, three per pot, in 15 cm diameter by 11 cm deep (1.9 L) pots containing 1.5 L of a 3 peat moss:1 perlite (by vol.) medium amended with 11.6 g dolomite/pot on 8 Feb. 1996. The medium had 88% total porosity (liquid and air), 38% air space, 50% total water holding capacity, 55% available water, 45% unavailable water, and a bulk density of 0.08 $g \cdot mL^{-1}$ based on medium dried at 80°C for 12 h. Plants were grown in a corrugated polycarbonate covered greenhouse (Oklahoma State University Research Greenhouse, Stillwater, Okla.) with an average air temperature of 29/20°C day/night, and maximum photosynthetic photon flux (PPF) of 1504 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Pots were spaced 38 cm by 38 cm on containerized benches with 16 pots per bench, and fertilized with 200 $mg \cdot L^{-1}$ N as 20N-4.4P-16.6K formulated with calcium nitrate, diammonium phosphate, and potassium nitrate. Each bench (16 pots) was one replication.

Manufacturer's recommended rates of GIF (Micromax, Scotts Co.) and WSF (Soluble Trace Element Mix, STEM, Scotts Co.) were applied to the appropriate treatments. The GIF was incorporated at 1.1 g Micromax/pot based on the recommended rate of 0.9 $kg{\cdot}m^{-3}$. Water soluble fertilizer was applied at the recommended rate of 599 $mg{\cdot}L^{-1}$ water. A third treatment containing no micronutrient fertilizer (NOM) was included to establish the potential Fe, Mn, and Zn leachate contribution of the unamended medium. The WSF was applied in three applications (118 mL/pot), with the first application occurring one day prior to the first irrigation and subsequent applications after irrigation 6 and 12 during the 18 irrigation period. Each application contained 1/3 of the recommended rate of WSF. No leaching occurred during application of the WSF.

Plants were irrigated with microtubes consisting of a 2.5 mm diameter main line, 1.9 mm internal diameter leader tubes, and lead-massed emitters (Chapin Watermatics, Watertown, N.Y.). All plants in each replication (bench) were watered when one previously selected test plant per replication was at or below a target mass as determined by daily weighing. This target mass corresponded to 50% or less available water in the container. To determine the target irrigation mass prior to the study, 18 geranium seedlings were planted in six pots as described above, watered to container capacity and plant, pot, and media mass recorded. Plants were allowed to dry to the permanent wilting point and plant, pot, and media mass recorded. Target irrigation masses were calculated as follows: [(container capacity mass - wilting point mass) x .50] + wilting point mass = the total mass at 50% available water. The target mass was obtained by averaging the six container masses. When the test plant of a replication weighed at or less than the target mass, all plants in the replication were irrigated for 45 s with a flow rate of 17.0 $L{\cdot}min^{-1}$.

Every fifth irrigation consisted of clear water (no fertilizer) to leach soluble salts. A 0.3 to 0.5 LF was used at each irrigation. Irrigation time was increased to 60 s beginning 14 Mar. 1996 to maintain LF value. Leaching fraction was determined by dividing the total amount of leachate for each treatment by the total amount of water applied to that treatment during the experimental period. Standard disease and insect control procedures were followed (White, 1993).

The following data were recorded at each irrigation: date, mass of test plant, amount of water applied/bench, and amount of leachate/bench. The volume of water applied per bench was determined using a flow meter (Electronics Digital Meter, Great Plains Industries, Wichita Kans.). The volume of leachate per bench was obtained by collecting the leachate and measuring with a 1.0 L graduated cylinder. Leachate samples were collected at each irrigation and stored at 7°C until analyzed for pH (pH/mV/Temp Bench Meter, Cole-Parmer Instruments, Chicago, Ill.), electrical conductivity (EC) (Solu-bridge, Beckman Instruments Inc., Cedar Grove, N.J.), and Fe, Mn, and Zn concentration using atomic absorption spectroscopy (Model 2380; Perkin-Elmer Corp., Norwalk, Conn.) (Isaac and Johnson, 1975) after each irrigation at room temperature.

Initial pH and EC of the medium were determined using a 1:2 (v/v) medium to distilled water (dH_2O) extraction procedure with a 30 min equilibrium time. The unamended medium had a pH of 3.6 and a EC < 0.1 $dS \cdot m^{-1}$. Final medium pH readings were 5.1 for NOM, 5.0 for GIF, and 5.0 for WSF treatments, while final EC readings were 1.0, 1.2, and 1.0 $dS \cdot m^{-1}$, respectively. Final elemental concentration was determined for medium samples dried at 50°C for 24 h, weighed, and stored at room temperature until analysis. Micronutrients were extracted following the modified saturated media extraction procedure described by Berghage et al. (1987), except 100 cm^3 of medium was used, gravity filtration using Whatman 41 ashless filter paper was performed, and the dilution factor (volume extractant and dH_20: grams extracted medium) varied for each sample to allow reporting on a concentration basis (μg/g). Electrical conductivity of the medium slurry, pH of medium filtrate and Fe, Mn, and Zn concentration of the medium were determined as previously described.

At harvest, three medium samples per replication were collected as a vertical core of medium from the top to the bottom of the root ball (growing medium and plant roots), combined, and analyzed for pH, EC, Fe, Mn, and Zn as described above. Another three medium samples per replication were divided into representative upper, middle, and lower regions, combined by region, and treated as described above for each replication. One root ball from each replication was left intact, air dried, and weighed to determine a representative mass of medium remaining in the pot at the conclusion of the study. Elemental concentration of each region was determined. Nutrient concentration of vertical core samples were determined then multiplied by final media mass per pot to obtain Fe, Mn, and Zn amounts retained by the medium at the conclusion of the study.

Initial geranium transplants were divided into shoots and roots with medium and elemental concentrations were determined for shoots and roots. Samples were dried at 50°C for seven days, weighed, ground to pass through a 917 μm mesh screen, and stored in air tight jars until analyzed for Ca, K, Mg, Fe, Mn, and Zn content by atomic absorption spectroscopy (Isaac and Johnson, 1975). Ground plant samples were also analyzed for ammonia-based N by the macro-Kjeldahl method (Horowitz, 1980), and P colorimetrically (hydroquinone method) (Olsen and Sommers, 1982). Initial shoot Fe, Mn, and Zn concentrations were 409, 179, and 77 $\mu g \cdot g^{-1}$ dry mass, respectively.

Each replication was harvested between 21 Mar. and 19 Apr. 1996, after 18 irrigations had been applied. The following data were recorded at harvest: plant height, plant diameter (average of diameter at widest point and the diameter perpendicular to the widest point), and quality rating (1-5, with 5 being the best salable quality). Geraniums from each treatment were divided into shoots and roots, dried at 50°C for seven days, and weighed. Plants were combined to obtain one homogeneous sample of shoots and one homogeneous sample of roots per replication. Shoot and root samples were ground to pass through a 917 μm mesh screen, and stored in air tight jars until analysis. Ground plant samples were analyzed for Ca, K, Mg, P, Fe, Mn, Zn, and ammonia-based N as described above.

Since commercial micronutrient formulations were applied at manufacturer's recommended rates in the commercial fertilizer source experiment, unequal amounts of each micronutrient were applied per pot. Thus, the total amount of Fe, Mn, and Zn applied to each treatment differed and statistical results were based on a percentage of Fe, Mn, and Zn retained in the media based on the total Fe, Mn, and Zn applied to the individual treatments.

Balanced micronutrient source (Expt. 2). Experiment 1 was repeated with the following exceptions. The geranium plugs were planted on 6 Sept. 1996 and harvested on 1 Nov. 1996. Initial shoot Fe, Mn, and Zn concentrations were 286, 67, and 19 μg/g dry mass, respectively. The growing medium had a total porosity (liquid and air) of 43%, 21% air space, 22% total water holding capacity by volume, 49% available water, 51% unavailable water, and a bulk density of 0.09 $g \cdot mL^{-1}$ medium based on oven-dried medium at 80°C for 12 h. Average air temperatures of 31/19°C day/night and a maximum PPF of 523 $\mu mol \cdot m^{-2} \cdot s^{-1}$ were recorded. A 50 GIF/50 WSF treatment was included which utilized 50% GIF and 50% WSF to supply equal micronutrient amounts during appropriate GIF and WSF application period(s). No micronutrient fertilizer control treatment was included. The WSF and 50% WSF treatments were synthesized so that micronutrient elemental concentrations were equal to those applied by the GIF. Nutrient sources for the WSF were B: H_3BO_3; Cu: $CuSO_4 \cdot 5H_2O$; Fe: $FeC_6H_5O_7$; Mn: $MnSO_4 \cdot H_2O$; Mo: $(NH_4)_6Mo_7O_{24}$; and Zn: $ZnSO_4 \cdot 7H_2O$. Initial unamended medium pH was 3.0 and EC was 0.2 $dS \cdot m^{-1}$. Final medium pH and EC readings were 4.5 and 1.0 $dS \cdot m^{-1}$ for GIF, 5.0 and 0.9 $dS \cdot m^{-1}$ for WSF treatments, and 5.0 and 1.0 $dS \cdot m^{-1}$ for 50 GIF/50 WSF, respectively. Leachate samples were collected as described in the previous experiment, pH was lowered below 2.0 using 1.0 M nitric acid (HNO_3), and leachate samples were stored at room temperature until micronutrient analysis.

Statistics. A randomized complete block design was used for both experiments. Each fertilizer treatment was replicated 4 times with 16 subsamples using benches as replications and pots as subsamples. Data were analyzed by the general linear model procedures with means separation by protected LSD or a paired t-test when appropriate (SAS Institute, Cary, N.C.). Regression models for leachate volume and amount of Fe, Mn, and Zn leached were fit using Tablecurve (Jandel Scientific, Corte Madera, Calif.).

Results

Commercial micronutrient source (Expt. 1). Plants receiving micronutrient fertilizer, regardless of source, were taller and had larger diameters, larger root and shoot dry mass (DM), and better quality ratings than plants grown without micronutrient fertilizer (Table 2.1). Plants receiving WSF were larger than those receiving GIF in all growth parameters measured. However, plant quality did not differ between the two micronutrient fertilizer treatments.

A greater percentage of Fe was leached from WSF than from GIF (Table 2.2, Fig. 2.1). In contrast, a greater percentage of Mn was leached from GIF than from WSF. There was no difference in the percentage of Zn leached by the two fertilizers. The NOM treatment had 0.17, 0.06, and 0.06 $mg \cdot L^{-1}$ Fe, Mn, and Zn leached, respectively, during the experiment and was excluded in the statistical analysis. No significant difference occurred in LF between treatments (Table 2.2).

Initial EC for GIF was higher than leachate EC with NOM fertilizer or WSF. At the conclusion of the experiment, no difference in EC of GIF and WSF was apparent, but the NOM treatment had a lower leachate EC than either fertilizer treatment (Table 2.3).

Commercial GIF produced leachate with the lowest pH initially, but leachate pH of GIF and WSF were not significantly different at the conclusion of the study. In contrast, NOM and WSF treatments had the highest initial pH with the NOM treatment exhibiting a higher final leachate pH compared with media amended with fertilizer.

No significant difference due to fertilizer treatment was found for medium pH or medium EC. However, the main effect of region within the pot was significant for medium pH ($P \leq 0.001$). Mean medium pH across all fertilizer treatments for upper, middle, and lower root zones were 5.2, 4.9, and 4.1, respectively. Upper and middle medium regions had a significantly higher medium pH compared to the lower region. Medium region was not significant with regards to medium EC.

A significant treatment by region interaction occurred for the percentage of Mn retained in the medium at the conclusion of the study (Table 2.4). The percentage of Mn in the middle and lower regions of GIF-amended medium was significantly greater than percentages retained for those medium regions amended with WSF. The Mn percentage decreased from the top to the bottom of the medium profile with WSF. In contrast, GIF-amended medium had the highest percentage of Mn in the middle region of the medium compared to the upper and lower medium regions. The main effect of region was significant for Zn. The percentage of Zn was smallest in the lower medium region (16.5%) compared to the upper (36.7%) and middle (35.3%) medium regions. A greater percentage of Fe was retained in medium root ball with WSF (61.2%) than with GIF

(11.7%). In contrast, a greater percentage of Zn was retained in the medium root ball with GIF (38.0%) than WSF (14.5%).

There was no significant difference in Ca, Mg, Fe, or Zn concentration in shoots or in N, P, K, Mg, Fe, and Zn concentration in roots between micronutrient fertilizer sources (Table 2.5). Higher Mn concentrations occurred in shoots and roots from medium with GIF than in shoots and roots from medium treated with WSF. Plants treated with GIF tended to have a greater Fe and Zn concentration in shoots and roots than plants receiving WSF. Greater concentrations of N, P, and K occurred in GIF-treated shoots than in WSF-treated shoots (Table 2.5). Roots receiving GIF had a higher Ca concentration than roots from WSF treatments.

Balanced micronutrient source (Expt. 2). A significantly ($P \leq 0.05$) greater shoot DM was produced by plants receiving WSF (12.5 g) and 50 GIF/50 WSF (12.2 g) fertilizer treatments than plants receiving GIF (10.5 g). In all other growth parameters measured, no difference occurred between the three micronutrient fertilizer treatments (data not shown).

Iron and Mn amounts leached from the GIF-amended medium were greater compared to media amended with WSF or 50 GIF/50 WSF (Fig. 2.2, 2.3). A greater amount of Zn was leached from GIF (10.6 mg) than from WSF (6.3 mg) or 50 GIF/50 WSF (5.2 mg) treatments (Fig. 2.4). Amount leached, regardless of element, was similar for WSF and 50 GIF/50 WSF sources. Initial leachate EC and pH readings and LF for all fertilizer treatments were not significantly different (data not shown).

No significant difference due to fertilizer treatment was determined for medium pH or EC. Medium pH of the middle region was significantly higher than medium pH of the upper and lower medium regions (Table 2.6). Electrical conductivity significantly decreased from the upper to middle to lower medium regions (Table 2.6).

A significant fertilizer by region interaction occurred for the amount of Fe and Zn extracted from the media (Table 2.7). There was no difference among regions for GIF-amended medium in amount Fe extracted. In contrast, the amount of Fe extracted in the WSF and 50 GIF/50 WSF treatments was highest in the upper region and lowest in the lower region within the same fertilizer treatment. The amount of Zn extracted was significantly greater in the upper and middle regions compared to the lower medium region within WSF and 50 GIF/50 WSF treatments. The total amount of Fe, Mn, and Zn retained in the container media at the conclusion of the experiment was not significantly different between the fertilizer treatments (data not shown).

Greater K concentrations occurred in shoots grown with GIF (2.11%) compared to shoots receiving WSF (1.84%). The shoot K concentrations (1.97%) of plants receiving 50 GIF/50 WSF did not differ from either of the other fertilizer treatments. No other differences in shoot or root elemental concentrations we tested between the three fertilizer treatments were significant (data not shown).

Discussion

As expected, plants receiving micronutrient fertilizer, regardless of source, grew better than plants receiving no micronutrient fertilizer (Table 2.1). These results confirm the need for micronutrient application during plant production in soilless media to assure optimum plant growth and development. Greater heights and diameters of plants receiving water soluble micronutrient fertilizers may be attributed to their availability for plant uptake early in the production cycle compared to GIF. Granular incorporated fertilizers require time to dissolve in the medium before plant uptake can occur. Young plants also have limited root systems which may have restricted root contact with the GIF at the beginning of the experiment.

Sixty days were needed to achieve 18 irrigations for the commercial fertilizer source experiment; whereas, the balanced micronutrient source experiment needed only 45 days to obtain an equal number of irrigations for all treatments. Differences in experimental duration is associated with higher day/night temperatures for the second experiment. Difference in media characteristics, such as water holding capacity and total porosity also contributed to the 15 day duration difference. The water holding capacity and total porosity values of the medium in the commercial fertilizer source experiment (Expt. 1) was twice the water holding capacity and total porosity values of the medium used in the balanced fertilizer source experiment (Expt. 2). Although a 15 day difference in experimental duration occurred, plant growth in the GIF treatment was similar between the two studies.

Greater quantities of Fe, Mn, and Zn were leached from GIF than from WSF treatments (Table 2.2, Fig. 2.1) in the commercial micronutrient study; however, larger quantities of Fe, Mn, and Zn were applied to each container in GIF than in WSF due to formulation differences. These results support the findings of Hershey and Paul (1982) in which more nutrient was leached as the amount of nutrient applied increased. Although they tested within fertilizer sources, comparable results should occur regardless of fertilizer source. Moreover, Hershey and Paul (1982) reported that with a CRF, the amount of N leached was decreased by half compared to that leached when using a liquid fertilizer at the same N application rate. Since reduced amounts of Fe, Mn, and Zn in leachate was produced from WSF with minimal differences occurring in plant growth between GIF and WSF treatments, growers can improve management practices by utilizing surface applications of WSF in their production schemes to minimize run-off and potential contamination of off-site areas. However, cost of fertilizer and labor must be considered when deciding on a micronutrient fertilizer source.

The amount of Fe, Mn, and Zn leached from GIF compared to WSF or 50 GIF/50 WSF treatments was greater at the same leachate volume for the balanced micronutrient study (Fig. 2.2, 2.3, 2.4). However, Rathier and Frink (1989) found that a slow release N source lost less nitrate in runoff water than a WSF. Conover and Poole (1992) reported the effect of fertilizer type on NO_3-N and P leachate content (mg/pot) to be inconsistent. However, NH_4-N content in the leachate was consistently lower from the CRF than from the liquid fertilizer. Yeager et al. (1993) also indicated that nursery operations can expect lower amounts of NO_3-N in production bed runoff using CRF rather than a combination of CRF and soluble fertilizers. Micronutrients may not follow the same leaching properties of N, and the influence of fertilizer type on macronutrient leaching may be inversely related to micronutrient leaching and runoff. Discrepancies in results from this micronutrient study and other macronutrient studies may be attributed to greater amounts of macronutrients than micronutrients being applied to the production area. Furthermore, sources of macronutrient and micronutrient fertilizers may be different.

Iron, Mn, and Zn ions applied as WSF or a 50 GIF/50 WSF combination were better retained in the medium than with GIF. Linear regression equations for leaching of each element were similar regardless of fertilizer treatment (Fig. 2.1, 2.2, 2.3, 2.4). Therefore, similarities in leaching properties were element specific, rather than dependent on micronutrient fertilizer source.

Target LF value (0.3-0.5) was achieved in all treatments for both studies. This LF range is typical for commercial growing conditions, making our results characteristic of a typical production situation. Ideally, the nutrient release pattern of a GIF should coincide with the nutrient uptake of the crop (Barron, 1977). However, the amount of Fe leached from WSF-amended media suggests that application rate was greater than nutrient uptake of the crop. In comparison, the high percentage of Mn leached indicates that the rate of Mn released from the GIF treatment was much greater than the rate of uptake by the plant in the commercial fertilizer source study

The total concentration of Fe and Zn leached throughout both studies were below U.S. EPA guidelines for SMCLs (Bradshaw, 1989). While Fe and Zn leaching were lower than their respective SMCLs, these elements could accumulate over time in soils and water sources. In contrast, the cumulative concentration ($mg \cdot L^{-1}$) of Mn leached exceeded the SMCL guideline of 0.05 $mg \cdot L^{-1}$ in both studies, regardless of fertilizer source. Manganese appears to pose a contamination threat since it was released in amounts greater than its SMCL guidelines. Although SMCLs are not enforceable by law, if leachate discharge is accumulated in soil and water supplies, potential Fe, Mn, and Zn contamination may lead to problems in using ground and surface water sources for drinking water, wash water, and other purposes. These concerns are supported by Yeager et al. (1993) who noted that NO_3 concentrations exceeded the drinking water standard of 10 $mg \cdot L^{-1}$ in samples collected. While Fe, Mn, and Zn pose little or no threat to human health, results from this study suggest that aquatic organisms, such as mussels, may be affected negatively if micronutrient-contaminated discharge continues to enter surface water sources.

Medium pH for the commercial micronutrient experiment was lowest in the lower medium region (4.1), while the upper (5.2) and middle (4.9) regions had a significantly greater pH. These results agree with findings from Morvant et al. (1997). However, Molitor (1990) reported similar medium pH throughout the root zone when utilizing trickle irrigation. Moreover, Molitor suggests that the medium pH was less stratified with trickle irrigation due to a more uniform distribution of ammonia throughout the root zone preventing an increased amount of nitrifying bacteria in any one location of the root zone. In the balanced micronutrient experiment, medium EC was significantly higher in the upper and middle regions compared to the lower region of the medium (Table 2.6). As with previous experiments (Argo and Biernbaum, 1994, 1995; Molitor, 1990; Morvant et al., 1997), root medium EC was highest in the upper region of the root zone.

In the commercial micronutrient experiment, Mn percentage decreased from the top to the bottom of the medium profile with WSF (Table 2.4, 2.7). Water soluble fertilizer and 50 GIF/50 WSF had more of each element in the upper and middle regions than in the lower medium region. These results agree with Argo and Biernbaum (1994, 1995), Molitor (1990), and Morvant et al. (1997) who reported the highest medium N concentration in the upper region compared to the middle and lower media regions. Since WSF fertilizer treatments were applied as a surface application, these results support the assumption that most nutrients applied as a surface application will be retained in the upper portion of the growing medium. Greater concentration of Fe, Mn, and Zn in the upper region of growing medium when applied as a WSF could be attributed to the formation of insoluble phosphates as the medium pH increased from the initial 3.6 to 5.1, thus limiting the mobility of these elements through the medium profile. Broschat and Donselman (1985) reported reduced extractability of Fe, Mn, and Zn from growing medium when superphosphate was added presumably due to the formation of insoluble phosphates. In contrast, GIF was incorporated throughout the medium and little difference occurred between regions in the amount of each element present.

In summary, results from this experiment indicate that micronutrient fertilizers are desirable for optimum geranium growth and quality. A granular incorporated micronutrient source increased the amount of Mn leached from production compared to WSF or a 50 GIF/50 WSF combination of fertilizer sources, exceeding its SMCL. The concentration of Mn can be elevated by accumulation of Mn in soil after leachate discharge; posing a greater concern to potable water contamination. At regular irrigation intervals, Fe and Zn pose less threat to ground water aquifers, though the potential of Fe and Zn accumulation over time still exists. Upper and middle regions of the growing medium had a higher nutrient content than the lower region when micronutrients were surface applied. Element amounts were distributed evenly among all regions for GIF treatments that were incorporated into the medium prior to the experiment. At the conclusion of the study, Fe medium retention was greater with WSF than with GIF while GIF had a greater percentage of Zn retained in the medium than WSF.

Literature Cited

Argo, W.R. and J.A. Biernbaum. 1994. Irrigation requirements, root-medium pH, and nutrient concentrations of Easter lilies grown in five peat-based media with and without an evaporation barrier. J. Amer. Soc. Hort. Sci. 119:1151-1156.

Argo, W.R. and J.A. Biernbaum. 1995. The effect of irrigation method, water soluble fertilization, preplant nutrient charge, and surface evaporation on early vegetative and root growth of poinsettia. J. Amer. Soc. Hort. Sci. 120:163-169.

Barron, H.M. 1977. Controlled release fertilizer and its use in hot climates. South Flor. Nurseryman 89(46):16-17, 35-38.

Berghage D.M., D.M. Krauskopf, D.D. Warncke, and I. Widders. 1987. Micronutrient testing of plant growth media: Extractant identification and evaluation. Commun. Soil Sci. Plant Anal. 18:1089-1109.

Bradshaw, M.H. 1989. Understanding your water test report- Microbial, chemical, and nuisance contaminants. Kansas State University County Extension. MF-912. In: World wide web @ http://ingis:acn.purdue.edu:9999 /Wetnet/government /DIAGNOSE/standards.html.

Broschat, T. K. 1995. Nitrate, phosphate, and potassium leaching from container-grown plants fertilized by several methods. HortScience 30:74-77.

Broschat, T.K. and H.M. Donselman. 1985. Extractable Mg, Fe, Mn, Zn, and Cu from a peat-based container medium amended with various micronutrient fertilizers. J. Amer. Soc. Hort. Sci. 110:196-200.

Conover, C.A and R.T. Poole. 1992. Effect of fertilizer and irrigation on leachate levels of NH_4, NO_3, and P in container production of *Nephrolepsis exalta* 'Fluffy Ruffle'. J. Environ. Hort. 10:238-241.

Dole, J.M., J.C. Cole, and S.L. von Broembsen. 1994. Growth of poinsettias, nutrient leaching, and water-use efficiency respond to irrigation methods. HortScience 29:858-864.

Hershey, D.R. and J.L. Paul. 1982. Leaching-losses of nitrogen from pot chrysanthemums with controlled-release or liquid fertilization. Scientia Hort. 17:145-152.

Hornby, A.G. 1986. Ground water: The hidden resource. Proc. Water Quality and Agriculture's Role for the Future. Okla. Coop. Ext. Serv., Circ. E-891:71-74.

Horowitz, W. 1980. Official methods of analysis of the Association of Analytical Chemists, 13th ed. Assoc. of Official Anal. Chem., Washington D.C., p.15. section 2.058.

Isaac, R.A. and W.C. Johnson, Jr. 1975. Collaborative study of wet and dry techniques for the elemental analysis of plant tissue by atomic absorption spectrophotometry. Assoc. Offic. Anal. Chem. 58:436.

Ku, C.S.M. and D.R. Hershey. 1991. Leachate electrical conductivity and growth of potted poinsettia with leaching fractions of 0 to 0.4. J. Amer. Soc. Hort. Sci. 116:802-806.

Marconi, D.J. and P.V. Nelson. 1984. Leaching of applied phosphorus in container media. Scientia Hort. 22:275-285.

Molitor, H.D. 1990. The European perspective with emphasis on subirrigation and recirculation of water and nutrients. Acta Hort. 272:165-173.

Morvant, J.K. 1995. Effects of irrigation method on plant growth, water and nutrient efficiency, and run-off. M.S. Thesis, Oklahoma State Univ., Stillwater.

Morvant, J.K., J.M. Dole, and E. Allen. 1997. Irrigation systems alter distribution of roots, soluble salts, nitrogen, and pH in the root medium. HortTechnology 7:156-159.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus, p. 404-430. In: A.L Page, R.H. Miller and P.R. Keeney (eds.). Methods of Soil Analysis. Part 2. Chemical and Microbial Properties. Amer. Soc. Agron. and Soil Sci. Amer., Madison, Wis.

Rathier T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and Alberta spruce under different irrigation and N fertilization regimes. J. Environ. Hort. 7:32-35.

Stolzenburg, W. 1992. The mussels' message. Nature Conservancy 42(6):17-23.

U.S. Environmental Protection Agency. 1982. Manual of individual drinking water systems. U.S. Environmental Protection Agency, Office of Drinking Water, Washington D.C. EPA-570/9-82-004.

White, J.W. 1993. Geraniums IV. The Grower's Manual. 4th ed. Ball Publishing, Geneva, Ill.

Yeager, T.H. and J.E. Barrett. 1984. Phosphorus leaching from ^{32}P-superphosphate-amended soilless container media. HortScience 19:216-217.

Yeager, T.H., R. Wright, D. Fare, C. Gilliam, J. Johnson, T. Bilderback, and R. Zondag. 1993. Six state survey of container nursery nitrate nitrogen runoff. J. Environ. Hort. 11:206-208.

Yelanich, M.V. and J.A. Biernbaum. 1990. Effect of fertilizer concentration and method of application on media nutrient concentration, nitrogen runoff and growth of *Euphorbia pulcherrima* 'V-14 Glory'. Acta Hort. 272:185-189.

Yelanich, M.V. and J.A. Biernbaum. 1994. Fertilizer concentration and leaching affect nitrate-nitrogen leaching from potted poinsettia. HortScience 29:874-875.

Table 2.1. Plant height, diameter, shoot and root dry mass, and quality rating of *Pelargonium hortorum* 'Orbit Red' grown with no micronutrient (NOM), commercial granular incorporated (GIF), or water soluble (WSF) micronutrient fertilizer. Means are an average of data from four replications of 16 subsamples each, except for root dry mass where 9 subsamples were used; Expt. 1.

Fertilizer	Plant height (cm)	Plant diameter (cm)	Shoot dry mass (g)	Root dry mass (g)	Plant quality[z]
NOM	12.6	21.8	7.9	0.8	2.0
GIF	15.1	28.5	11.4	1.2	4.5
WSF	18.4	31.1	17.2	1.8	4.5
Significance ($LSD_{0.05}$):					
Fertilizer	1.7	2.1	1.6	0.2	0.3

[z] On a scale from 1 to 5 (1=poorest and 5=best).

Table 2.2. Leaching fraction, total (mg) and percent Fe, Mn, and Zn leached from media with no micronutrient (NOM), granular incorporated (GIF), or water soluble (WSF) micronutrient fertilizer during 18 irrigations. Means are an average of four replications with 16 plants each; Expt. 1.

Fertilizer	Leaching fraction	Fe mg	Fe %[z]	Mn mg	Mn %[z]	Zn mg	Zn %[z]
NOM	0.46	--	--	--	--	--	--
GIF	0.43	9.3	0.4	79.1	18.0	11.6	6.6
WSF	0.37	8.9	3.4	8.0	2.9	3.3	2.2
Significance:							
Fertilizer	NS	--	*	--	*	--	NS

[z] Percentage of Fe, Mn, and Zn applied that was leached.
[NS,*] Not significant or significant at $P \leq 0.05$.

Table 2.3. Initial and final EC and pH of leachate from no micronutrient (NOM), granular incorporated (GIF), and water soluble (WSF) fertilizer treatments. Means are an average of four replications each; Expt. 1.

	EC ($dS \cdot m^{-1}$)		pH	
Fertilizer	Initial	Final	Initial	Final
NOM	1.7	1.8	5.7	6.3
GIF	1.9	2.2	5.1	5.6
WSF	1.7	2.3	5.7	5.8
Significance ($LSD_{0.05}$):				
Fertilizer	0.1	0.3	0.2	0.4

Table 2.4. Percent of Mn retained in the media based on the total Mn applied. Media were divided equally into upper, middle, and lower media regions after 18 irrigations that were treated with a granular incorporated (GIF), or a water soluble (WSF) fertilizer. Means are an average of four replications of three subsamples each; Expt. 1.

		Percent (%)
Fertilizer	Region	Mn
GIF	Upper	24.8
	Middle	32.3
	Lower	23.9
WSF	Upper	21.4
	Middle	10.9
	Lower	3.2
Significance ($LSD_{0.05}$):		
Region for same fertilizer		6.3
Region for different fertilizer		12.6

Table 2.5. Shoot and root elemental concentration of *Pelargonium hortorum* 'Orbit Red' grown with a commercial granular incorporated (GIF), or a water soluble (WSF) micronutrient fertilizer. Means are an average of four replications with 16 subsamples for shoots and 9 subsamples for roots; Expt.1.

	Dry weight (%)					Dry weight (μg/g)		
Fertilizer	N	P	K	Ca	Mg	Fe	Mn	Zn
					Shoot			
GIF	2.97	0.29	2.56	0.98	0.37	88	353	79
WSF	2.18	0.22	2.09	1.08	0.40	54	131	40
Significance:								
Fertilizer	0.73[z]	0.06	0.19	NS	NS	NS	91	NS
					Root			
GIF	1.57	0.36	2.10	0.49	0.18	193	269	86
WSF	1.34	0.26	1.67	0.38	0.17	68	119	35
Significance:								
Fertilizer	NS	NS	NS	0.05	NS	NS	52	NS

[z] Not significant (NS) or LSD at the 5% level.

Table 2.6. Effect of region on pH and EC of media treated with a granular incorporated (GIF), water soluble (WSF), or a 50 GIF/50 WSF micronutrient fertilizer treatment with micronutrient concentrations applied equally to all treatments. Means are an average of four replications of three subsamples each; Expt. 2.

Region	pH	EC
Upper	4.8	1.7
Middle	5.5	1.1
Lower	4.5	0.8
Significance ($LSD_{0.05}$):		
Region	0.2	0.1

Table 2.7. Amount of Fe, Mn, and Zn in the upper, middle, and lower media regions after 18 irrigations treated with a granular incorporated (GIF), water soluble (WSF), or a 50 GIF/50 WSF micronutrient fertilizer treatment with micronutrient concentrations applied equally to all treatments. Means are an average of four replications of three subsamples each; Expt. 2.

		Dry weight (µg/g)		
Fertilizer	Region	Fe	Mn	Zn
GIF	Upper	189	86	33
	Middle	187	67	45
	Lower	199	47	32
WSF	Upper	350	62	38
	Middle	191	84	32
	Lower	72	60	14
50 GIF/50 WSF	Upper	377	79	42
	Middle	224	93	47
	Lower	112	57	24
Significance:				
Region for same fertilizer		86[z]	NS	10
Region for different fertilizer		85	NS	10

[z] Not significant (NS) or LSD at the %5 level.

Figure 2.1. Amount of Fe, Mn, and Zn leached from granular incorporated (GIF) and water soluble fertilizers (WSF) as a function of L leachate. Fe-GIF ($y= 2.3E\text{-}02 + 1.5E\text{-}05x\ln x$, $r^2= 0.96$); Fe-WSF ($y= 0.7 + 1.8E\text{-}05x\ln x$, $r^2= 0.95$); Zn-GIF ($y= 3.5 + 1.5E\text{-}05x\ln x$, $r^2= 0.72$); Zn-WSF ($y= 0.3 + 7.4E\text{-}06x\ln x$, $r^2= 0.72$); Mn-GIF ($y^{0.5}= 2.1 + 2.9E\text{-}02x^{0.5}$, $r^2= 0.98$); Mn-WSF ($y^{0.5}= 0.3 + 1.2E\text{-}02x^{0.5}$, $r^2= 0.70$), $P\leq 0.05$; Expt. 1.

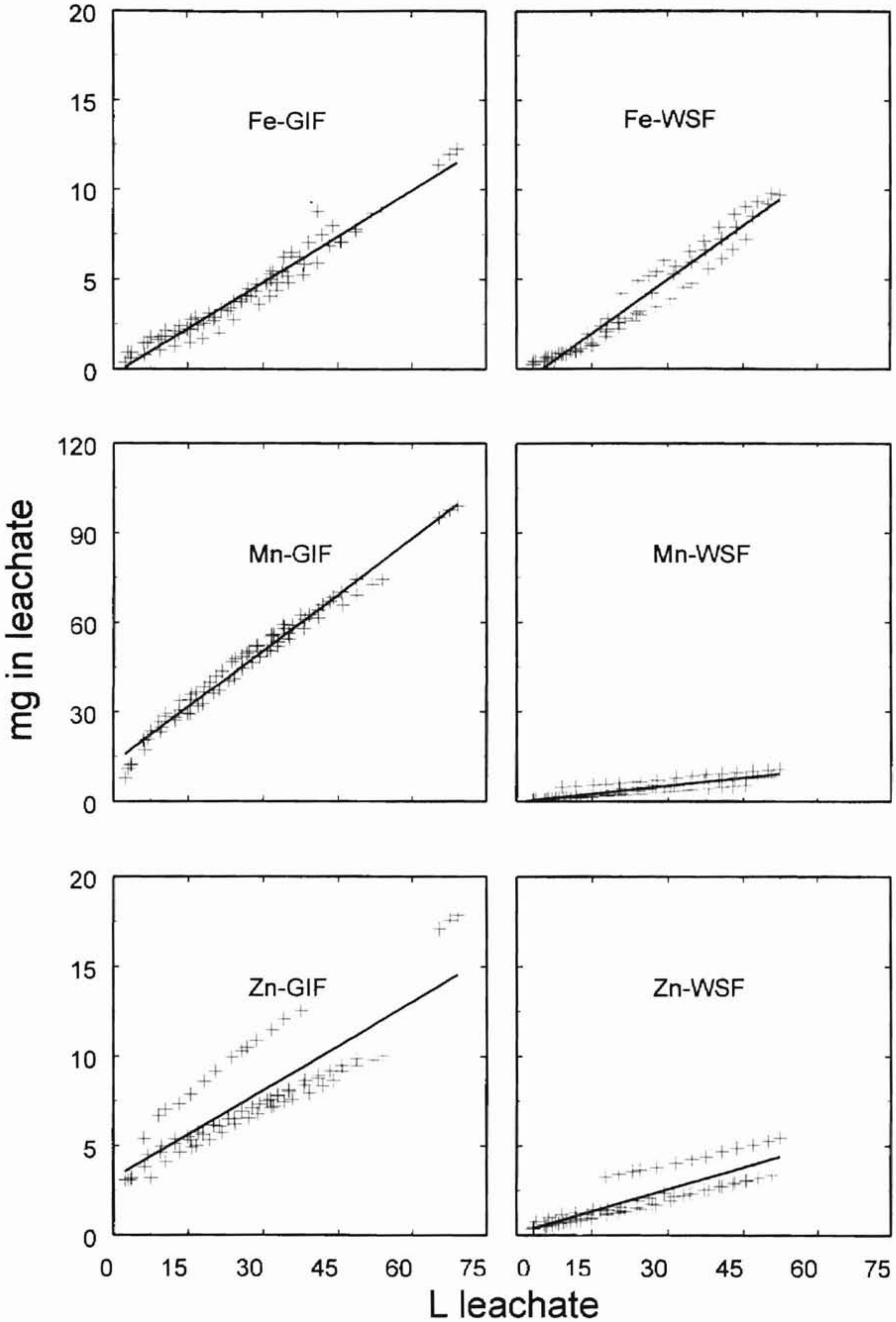
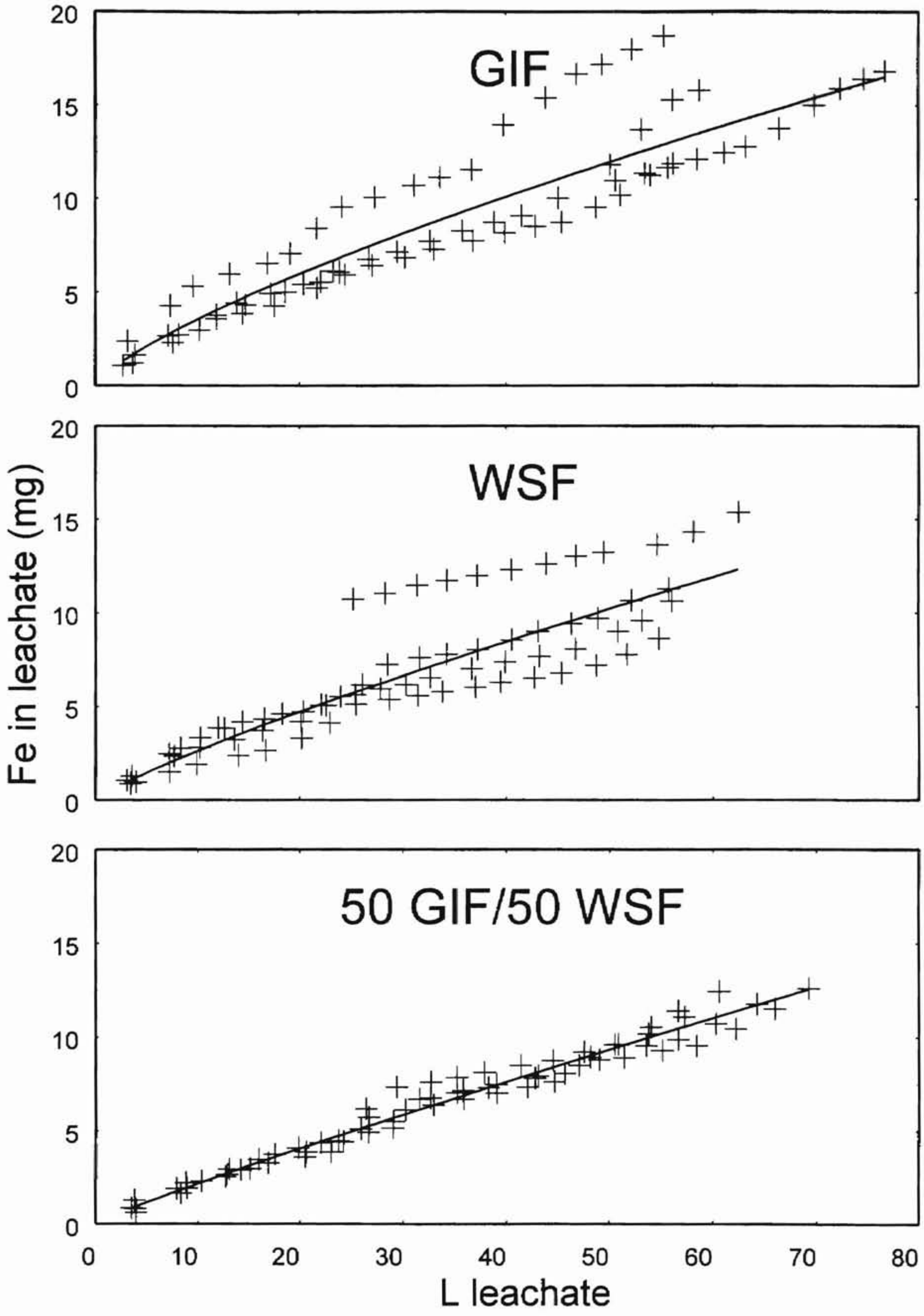
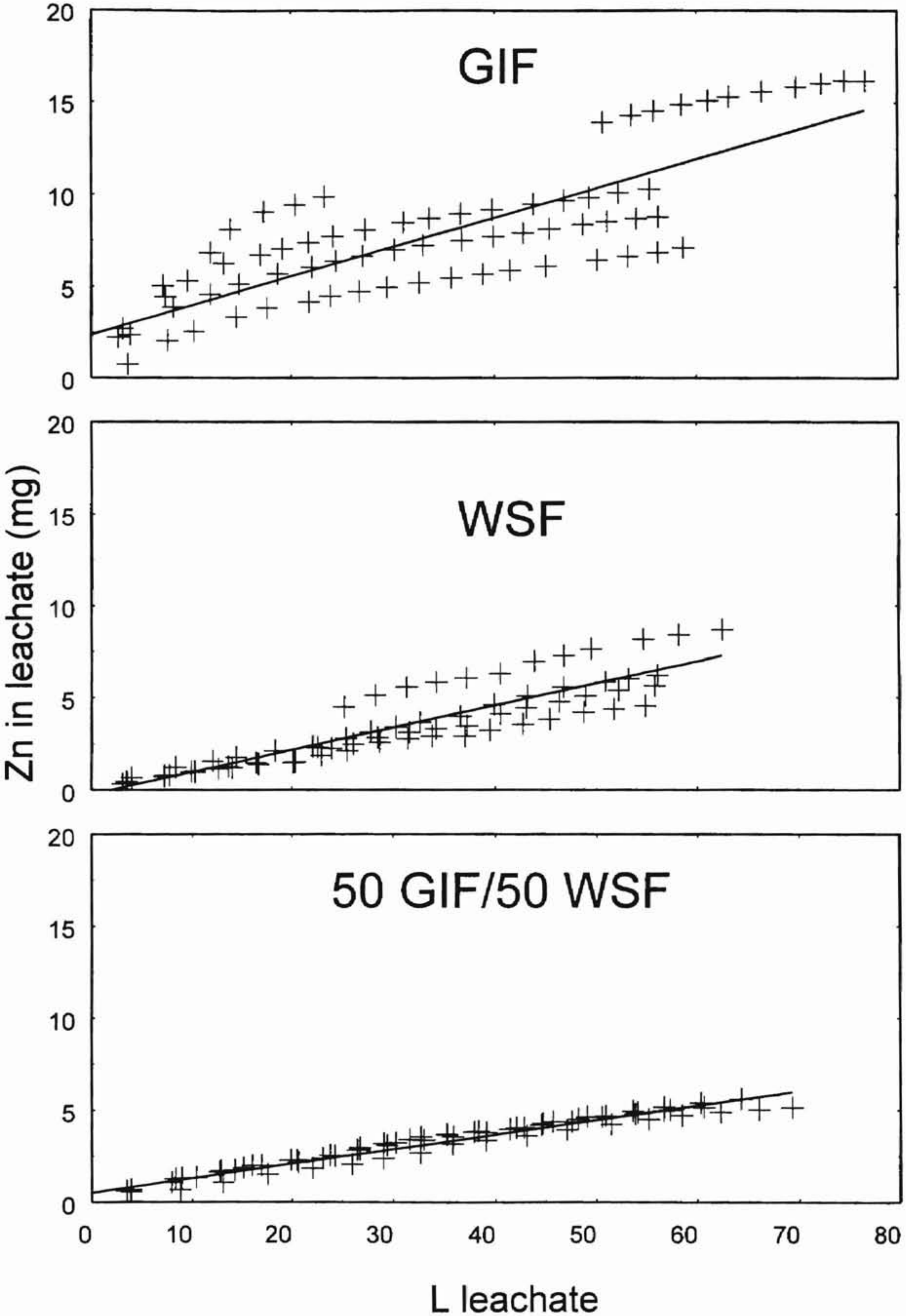

Fe-GIF
Fe-WSF
Mn-GIF
Mn-WSF
Zn-GIF
Zn-WSF
mg in leachate
L leachate
0
15
30
45
60
75
5
10
20
90
120

Figure 2.2. Amount of Fe leached from a granular incorporated (GIF), water soluble (WSF) and a 50 GIF/50 WSF micronutrient fertilizer as a function of L leachate. Fe-GIF ($y= 3.4E\text{-}03x^{0.76}$, $r^2= 0.80$); Fe-WSF ($y= 0.2 + 1.8E\text{-}03x^{0.80}$, $r^2= 0.74$); Fe-50/50 ($y= 6.5E\text{-}04x^{0.88}$, $r^2= 0.97$), $P\leq 0.05$; Expt. 2.



GIF
WSF
50 GIF/50 WSF
Fe in leachate (mg)
L leachate
0
5
10
15
20
0
10
20
30
40
50
60
70
80

Figure 2.4. Amount of Zn leached from a granular incorporated (GIF), water soluble (WSF) and a 50 GIF/50 WSF micronutrient fertilizer as a function of L leachate. Zn-GIF ($y= 2.1 + 1.8E\text{-}03x/\ln x$, $r^2= 0.67$); Zn-WSF ($y= 0.5 + 1.4E\text{-}03x/\ln x$, $r^2= 0.80$); Zn-50/50 ($y= 0.8 + 2.2E\text{-}03x^{0.5}\ln x$, $r^2= 0.97$), $P\leq 0.05$; Expt. 2.



GIF
WSF
50 GIF/50 WSF
Zn in leachate (mg)
L leachate
0
5
10
15
20
0
10
20
30
40
50
60
70
80

Chapter 3

FERTILIZER SOURCE AFFECTS MICRONUTRIENT LEACHING FROM CONTAINER PLANT PRODUCTION UNDER SPRINKLER AND DRIP IRRIGATION.

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Additional index words. Micronutrient, microtube irrigation, soilless media

Abstract. **When Fe, Mn, and Zn were applied as a granular incorporated (GIF) or a water soluble (WSF) fertilizer to largeleaf Korean boxwoods (*Buxus microphylla* Var. *koreana* Nakai.) under sprinkler or drip irrigation, minimal differences in plant growth occurred regardless of fertilizer source. Medium pH and EC values were greater in the upper regions of the medium compared to the lower medium regions under drip irrigation, while little difference in medium pH and EC occurred throughout the medium profile under sprinkler irrigation for both fertilizers. Greater Fe and Zn concentrations occurred in the upper and middle regions of the growing medium than in the lower medium region when micronutrients were surface applied while Fe, Mn, and Zn amounts were distributed evenly among all**

regions for GIF treatments. Leachate pH increased from the initial to the final sampling date while leachate EC decreased under sprinkler irrigation. Leachate Fe, Mn, and Zn concentrations for GIF treatments were highest during the first two weeks of the experiment; whereas, leachate from WSF treatments were released over the course of the experimental period, especially during WSF application dates. Cumulative Fe, Mn, and Zn leachate concentration for both GIF and WSF sources exceeded secondary maximum contamination level (SMCL) guidelines.

Introduction

Increased environmental consciousness of the public and concern for safe drinking water necessitates evaluation of plant nursery production practices and their impact on water resources. The nursery industry releases large volumes of runoff that may contaminate surface and ground water sources. Runoff from production sites may contain NO_3-N, P, and other ions commonly applied as fertilizers.

Yeager et al. (1993) sampled nursery bed runoff, containment reservoirs or ponds, wells, and surface water discharged from nurseries in six states. The authors found that runoff from container beds averaged 8 to 20 $mg \cdot L^{-1}$ NO_3-N depending on fertilizer method and that NO_3-N levels from some runoff collection ponds, property borders, and wells exceeded Environmental Protection Agency (EPA) drinking water standards (10 $mg \cdot L^{-1}$ NO_3-N). Data from this report supports environmental concerns and the need for implementation of better management practices by nursery operators.

Container plant production is limited by container size which restricts root volume, and limits the water and fertilizer reservoir available to the plant. Moreover, plants are grown in an artificial medium that contains little, if any, soil. Nursery producers must rely heavily on fertilizers and pesticides for producing high quality crops. Runoff from production sites via rain and irrigation can concentrate these chemicals in collection areas and/or allow them to enter surface and ground water sources (Wilkerson, 1990).

Much of the container nursery stock is fertilized with soluble fertilizers delivered through sprinkler irrigation systems. Cultural practices that might reduce water contamination include use of drip or trickle irrigation and controlled release fertilizers (CRF). Drip irrigation reduces water inputs and runoff without effect on plant growth by applying water and chemicals directly into containers. Rathier and Frink (1989) reported much less nitrate leached by drip or trickle irrigation than by sprinkler irrigation. In addition, Weatherspoon and Harrell (1980) reported that three times as much water was necessary with sprinkler irrigation than with drip irrigation for container bed production.

Controlled release fertilizers release their nutrients slowly over time and are considered more efficient for container culture than soluble fertilizers (Sanderson, 1987). Rathier and Frink (1989) noted that controlled release N sources lost less nitrate to runoff than water soluble N formulations; however, sufficient nitrate was lost by CRF to contaminate water resources unless it was applied as split applications throughout the crop cycle. Broschat (1995) concluded that NO_3-N, P and K leaching is significantly reduced by using CRF compared to water soluble fertilizer (WSF) formulations. In addition, Conover and Poole (1992) found lower concentrations of NH_4-N in the leachate from plants grown in containers using a CRF as opposed to a WSF.

To our knowledge, there are no similar studies evaluating CRF and WSF effects on micronutrient leaching from container-grown plants. Ions such as Fe, Mn, and Zn can be leached during production and are considered secondary contaminants in drinking water (U.S. EPA, 1982). The EPA uses secondary maximum contamination levels (SMCLs) in regulating and has recommended that concentrations should not exceed 0.3 $mg \cdot L^{-1}$ for Fe, 0.05 $mg \cdot L^{-1}$ for Mn, and 5.0 $mg \cdot L^{-1}$ for Zn in drinking water (Bradshaw, 1989). The purpose of this study was to determine the effect of a granular incorporated fertilizer (GIF) and a WSF on plant growth, plant quality, and on Fe, Mn, and Zn leaching from container plant production using sprinkler or drip irrigation.

Materials and Methods

Sprinkler irrigation (Expt. 1). Rooted cuttings (Greenleaf Nursery, Park Hill, Okla.) of largeleaf Korean boxwood (*Buxus microphylla* Var. *koreana* Nakai.) were grown in 3.8 liter containers containing 3 pine bark:1 peat:1 sand (by volume) amended with 2.4 $kg \cdot m^{-3}$ each of gypsum and dolomite, and 1.8 $kg \cdot m^{-3}$ N using 17N-3P-10K (Osmocote 17-7-12, Scotts Co. Marysville, Ohio). Planting medium had 63% porosity (liquid and air), 25% air space, 36% water holding capacity, and a bulk density of 0.33 $g \cdot mL^{-1}$. Initial pH and electrical conductivity (EC) of the medium were determined using a 1:2 (v/v) medium to distilled water (dH_2O) extraction with a 30 min equilibrium time. The medium had a pH of 5.5 and a EC of 0.4 $dS \cdot m^{-1}$.

Two plants per pot were planted on 19 April 1997 and grown on container plant production beds designed for water runoff research (Cole et al., 1993) for 13 weeks at the Nursery Research Station in Stillwater, Okla. Containers were placed 30.5 cm by 30.5 cm on the beds. Plants were grown with an average air temperature of 39/18°C day/night, and a maximum photosynthetic photon flux (PPF) of 1535 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Nursery medium for the GIF treatment was amended with 0.9 $kg \cdot m^{-3}$ Micromax (Scotts Co.) prior to planting. The WSF treatment was synthesized so that micronutrient concentrations were equal to those applied via the GIF. The WSF treatment was prepared using the following nutrient sources: B: H_3BO_3; Cu: $CuSO_4 \cdot 5H_2O$; Fe: $FeC_6H_5O_7$; Mn: $MnSO_4 \cdot H_2O$; Mo: $(NH_4)_6Mo_7O_{24}$; and Zn: $ZnSO_4 \cdot 7H_2O$. Nutrients were applied in two separate solutions: 1) sulfate-based Cu, Fe, Mn, and Zn, and 2) B and Mo on the same day. The B, Mo fertilizer solution was brought to a pH of 7.0 using 1 M NaOH. The WSF was applied by fertigation on 23 April, 28 May, and 24 June 1997. Each WSF application contained 1/3 of the GIF rate.

Plants were irrigated with 1.3 cm of water per day, which is an industry standard. The sprinkler irrigation was supplied by Rainbird 15Q sprinklers (Cole et al., 1993). Beds were calibrated periodically to insure uniform distribution of 1.3 cm of water daily.

Visual quality ratings were recorded for each container on a monthly basis (1-5, with 5 being best salable quality). Leachate volume and micronutrient concentration were determined per replication weekly and were collected in 20.3 cm diameter by 8.9 cm deep (2879 cm^3) saucers (American Plant Products, Oklahoma City, Okla.). During the week of WSF application, leachate volume and micronutrient concentration were determined the day prior to, the day of , and the day following WSF application. Leachate samples were representative of Fe, Mn, and Zn concentration leached through the container during the irrigation period. Plastic collars five cm in diameter were fabricated from saucers described above and secured in place with silicon around each 3.8 liter container to prevent water from overhead sprinklers from diluting leachate samples. Leachate samples were stored at 7°C until analyzed for Fe, Mn, and Zn concentration using atomic absorption spectroscopy (Model 2380; Perkin-Elmer Corp., Norwalk, Conn.) (Isaac and Johnson, 1975). Leachate pH (pH/mV/Temp Bench meter, Cole-Parmer Instruments, Chicago, Ill.), and EC (Solu-bridge, Beckman Instruments Inc., Cedar Grove, N.J.), were determined at each fertilizer application date and the last leachate collection date.

Plants were harvested on 20 July 1997 and plant height, diameter (average of diameter at widest point and the diameter perpendicular to that point), and quality rating (1-5, with 5 being best salable quality) were recorded. Plants were divided into shoots and roots and dried at 52°C for seven days. Shoot and root dry masses were determined and samples were ground to pass through a 917 μm screen and stored in air tight jars until analyzed for Fe, Mn, and Zn concentration by atomic absorption spectroscopy (Isaac and Johnson, 1975).

Six medium samples per treatment were divided into equal upper, middle, and lower regions. Medium samples were air-dried, weighed, and extracted following the modified saturated media extraction method described by Berghage et al. (1987) except 100 cm^3 of medium was extracted using vacuum filtration with Whatman 41 ashless filter paper, and a dilution factor (volume of extractant and dH_2O: grams extracted medium) determined for each sample to allow reporting on a dry weight basis (µg/g). Electrical conductivity of the medium slurry, pH and Fe, Mn, and Zn concentrations of the medium filtrate were determined as previously described.

Drip irrigation (Expt. 2). This experiment was performed as previously described with the following exceptions. Plants were drip irrigated using a 2.5 mm diameter central line, 122 cm long, 1.9 mm internal diameter flexible leader tubes, and circular drip emitters (Dramm, Manitowoc, Wis.) placed on the media surface of each 3.8 liter container. The WSF treatment applications were made as surface applications to the appropriate containers in the same volume of water that would be applied in a normal irrigation.

Statistics. For both experiments, each fertilizer treatment had twelve replications with four pots per replication. Means were determined for all variables and data were analyzed using 95% confidence intervals (SAS Institute, Cary, N.C.).

Results

Sprinkler irrigation (Expt. 1). All growth parameters measured were similar regardless of fertilizer source (data not shown). Medium pH and EC of regions were similar, with an overall mean of 4.4 and 1.3, respectively. Minimal differences in Fe, Mn, and Zn concentrations between medium regions were found for media amended with GIF (Fig. 3.1). In contrast, highest concentrations of Fe, and Zn were located in the upper medium regions compared to the middle and lower media regions for WSF amended medium (Fig. 3.1). However, the inverse of this trend was observed in Mn distribution through the medium.

Final leachate pH (6.3) was higher than the initial pH (6.0), while leachate EC significantly decreased from the initial (1.4) to the final (0.5) sampling date, with no differences occurring between fertilizers. Minimal differences in Fe, Mn, and Zn leachate concentration occurred over the 13 week experimental period between GIF and WSF treatments (Fig. 3.2). However, leachate samples collected on WSF application dates produced significantly greater amounts of leachate ion concentration compared to GIF leachate. Leachate concentrations of Fe, Mn, and Zn were highest during the first 2 weeks of the experiment and then decreased for the remainder of the experiment.

Drip irrigation (Expt. 2). Plant diameter was significantly larger for plants grown with WSF (15.1 cm) compared to plants grown with GIF (14.3 cm). Results were similar between fertilizer sources for all other growth measurements. No significant difference due to fertilizer source occurred for medium pH or EC. Across the regions, medium pH of the upper (4.6) and middle (4.5) regions were significantly greater than the pH of the lower region (4.3). Electrical conductivity decreased from the upper (1.3 $dS \cdot m^{-1}$) to middle (0.9 $dS \cdot m^{-1}$) and lower (0.9 $dS \cdot m^{-1}$) regions. Amount of Fe, Mn, and Zn extracted from GIF-amended medium was similar among regions (Fig. 3.3). Iron and Zn concentration of the upper region of medium amended with WSF was greater than that extracted from the middle and lower medium regions. Amount of Mn extracted was significantly lower in the upper than in the middle and lower regions (Fig. 3.3).

Minimal differences occurred between initial and final leachate pH regardless of fertilizer source. Leachate EC, however, significantly decreased from the initial (1.0) to the final (0.4) collection date, with no difference between treatments. Except on WSF application dates, minimal differences between GIF and WSF treatments in Fe, Mn, and Zn concentration in leachate occurred over the 13 week experimental period. Leachate samples from the WSF treatment collected on WSF application dates contained significantly greater amounts of all three micronutrients compared to GIF leachate (Fig. 3.4). Leachate concentrations of Fe, Mn, and Zn were highest during the first 2 weeks of the experiment and then decreased during the remainder of the experiment.

Discussion

With exception of plant diameter, growth parameters and quality ratings were not affected by fertilizer source (data not shown). While plants grown with WSF under drip irrigation (Expt. 2) produced a larger plant diameter than plants grown with GIF (15.1 cm, 14.3 cm, respectively), both fertilizer sources were adequate for production of marketable plants. The larger diameter of plants receiving WSF may be attributed to the readily available nutrients for plant uptake early in the production cycle compared to GIF. Time is required for GIF to dissolve in the medium before plant uptake of nutrients can occur. Limited root systems of young plants may have also restricted root contact with the GIF at the beginning of the experiment. However, minimal difference in plant diameter was observed between the fertilizer treatments with sprinkler irrigation (Expt. 1). Delivery of WSF by fertigation may not be as efficient in delivering micronutrients to the entire medium ball as surface applications of WSF by hand due to excess water and nutrients falling between pots and the wetting of foliage which will reduce the amount of nutrients reaching the medium; therefore, differences in plant growth were not as apparent when using sprinkler compared to drip irrigation between the fertilizer treatments. Although the different irrigation regimes of the two experiments cannot be directly compared, both systems produced adequate commercial plant quality.

Medium pH and EC for the drip irrigation experiment were greater in the upper medium region compared to lower region of the medium for both fertilizer sources. These results agree with Morvant et al. (1997), who found medium pH to be greater in the upper region of the medium compared to the lower medium region. However, Molitor (1990) reported similar medium pH throughout the root zone when utilizing trickle irrigation. Higher EC in the upper region compared to the lower region of the root zone agrees with previous experiments (Argo and Biernbaum, 1994; Molitor, 1990; Morvant et al., 1997).

Except for Mn, nutrient distribution throughout the growing medium was consistent for both experiments. The upper medium region had more Fe and Zn than the middle and lower medium region (Fig. 3.1, 3.3). These results agree with Argo and Biernbaum (1994), Molitor (1990), and Morvant et al. (1997), who reported the highest medium N concentrations in the upper region compared to the middle and lower media regions. In contrast, Mn concentration was higher in the lower medium region than the upper and middle regions. Because WSF treatments were applied by surface application and fertigation, most nutrients applied might be retained in the upper portion of the growing medium as observed with Fe, and Zn. Moreover, greater Fe and Zn concentration in the upper region of growing medium may be attributed to the formation of insoluble Fe and Zn phosphates within the medium, thus limiting the mobility of these elements through the medium profile (Broschat and Donselman, 1985). Manganese may not be involved in phosphate precipitation under medium conditions and readily move through the medium profile, thus increasing Mn concentration in the middle and lower medium regions compared to the upper medium region. Granular incorporated fertilizer was distributed throughout the medium and minimal difference occurred between regions. Phosphate precipitation of Fe and Zn may have occurred within GIF-amended medium, but the initial incorporation of micronutrients throughout the medium reduced significant nutrient distribution differences.

Leachate concentrations for Fe, Mn, and Zn in both experiments were similar, regardless of fertilizer source over the 13 week experimental period except on WSF application dates (Fig. 3.2, 3.4). Water soluble fertilizer treatments produced significantly higher leachate concentrations for all three nutrients compared to GIF leachate samples collected on WSF application dates. Our results agree with those of other studies (Rathier and Frink, 1989; Conover and Poole, 1992; and Yeager et al., 1993) that concluded that use of CRF over WSF or a combination of fertilizer sources will produce lower NO_3-N, NH_4-N, and P content (mg/pot) in leachate from production sites. Granular incorporated fertilizer leachate concentrations for Fe, Mn, and Zn were high for the first few weeks of the experiment and then decreased and stabilized for the duration of the experiment. Hershey and Paul (1982) reported similar results in the amount of N leached using a CRF versus a WSF.

Cumulative Fe, Mn, and Zn concentrations for both fertilizer sources under sprinkler and drip irrigation exceeded their respective SMCL guidelines and all elements tested appear to pose a contamination threat to the environment. Although these guidelines are not enforceable by law, contaminants in leachate discharge may accumulate in soil and water supplies and potentially lead to human and animal health problems. Fertilizer source effect on Fe, Mn, and Zn leachate concentrations were inconsistent. Micronutrient concentration was higher for GIF compared to WSF leachate on some dates, while on other sampling dates the opposite response occurred. Data variability may indicate environmental effects due to plant evapotranspiration or rainfall.

Similar inconsistencies were reported by Conover and Poole (1992). Moreover, Yeager and Cashion (1993) indicated that leachate NO_3-N concentrations varied considerably over a production period and sampling at any given time could yield misleading results of overall NO_3-N or P input into the environment.

In summary, minimal differences in plant growth occurred between plants grown with a GIF or a WSF source. Medium pH and EC values were greater in the upper regions of the medium compared to the lower regions under drip irrigation, while little difference in medium pH and EC occurred under sprinkler irrigation for both fertilizers. Upper and middle regions of the growing medium had a higher Fe and Zn concentration than the lower medium region when micronutrients were applied to the medium surface. Element amounts were distributed evenly among all regions for GIF treatments where incorporation of the fertilizer source into the medium occurred prior to the experiment. Leachate pH increased from the initial to the final testing date while leachate EC decreased under sprinkler irrigation. Leachate Fe, Mn, and Zn concentrations for GIF treatments were highest during the first two weeks of the experiment; whereas, leachate from WSF treatments were released over the course of the experimental period, especially during WSF application dates. While WSF source increased cumulative Fe, Mn, and Zn leachate concentrations compared to GIF, both fertilizer sources exceeded SMCL guidelines for each element. The concentration of these elements can increase by accumulation in soil after leachate discharge; posing a greater concern to potable water contamination. These results identify that human health and safety are not threatened by micronutrient contamination to water resources immediately. Accumulation of these elements over time, however, may render them a potential threat. Lachate discharge from plant production areas has caused detrimental effects on aquatic organisms such as mussels (Stolzenburg, 1992).

Literature Cited

Argo, W.R. and J.A. Biernbaum. 1994. Irrigation requirements, root-medium pH, and nutrient concentrations of Easter lilies grown in five peat-based media with and without evaporation barrier. J. Amer. Soc. Hort. Sci. 199:1151-1156.

Berghage D.M., D.M. Krauskopf, D.D. Warncke, and I. Widders. 1987. Micronutrient testing of plant growth media: Extractant identification and evaluation. Commun. Soil Sci. Plant Anal. 18:1089-1109.

Bradshaw, M.H. 1989. Understanding your water test report- Microbial, chemical, and nuisance contaminants. Kansas State University County Extension. MF-912. In: World wide web @ http://ingis:acn.purdue.edu:9999 /Wetnet/government / DIAGNOSE/standards.html.

Broschat, T.K. 1995. Nitrate, phosphate, and potassium leaching from container-grown plants fertilized by several methods. HortScience 30:74-77.

Broschat, T.K. and H.M. Donselman. 1985. Extractable Mg, Fe, Mn, Zn, and Cu from a peat-based container medium amended with various micronutrient fertilizers. J. Amer. Soc. Hort. Sci. 110:196-200.

Cole, J.C., V.L. Stamback, and C. Gray. 1993. Design for a simulated nursery for water runoff research. HortScience 28:952-953.

Conover C.A. and R.T. Poole. 1992. Effect of fertilizer and irrigation on leachate levels of NH_4, NO_3, and P in container production of *Nephrolepsis exalta* 'Fluffy Ruffle'. J. Environ. Hort. 10:238-241.

Hershey, D.R. and J.L. Paul. 1982. Leaching-losses of nitrogen from pot chrysanthemums with controlled-release or liquid fertilization. Scientia Hort. 17:145-152.

Isaac, R.A. and Johnson, W.C., Jr. 1975. Collaborative study of wet and dry techniques for the elemental analysis of plant tissue by atomic absorption spectrophotometry. Assoc. Offic. Anal. Chem. 58:436.

Morvant, J.K., J.M Dole, and E. Allen. 1997. Irrigation systems alter distribution of roots, soluble salts, nitrogen, and pH in the root medium. HortTechnology 7:156-159.

Molitor, H.D. 1990. The European perspective with emphasis on subirrigation and recirculation of water and nutrients. Acta Hort. 272:165-173.

Rathier T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and Alberta spruce under different irrigation and N fertilization regimes. J. Environ. Hort. 7:32-35.

Sanderson, K.C. 1987. Selecting the right fertilizers for container-grown woody ornamentals. Amer. Nurseryman 165(1):160-177.

Stolzenburg, W. 1992. The mussels' message. Nature Conservancy 42(6):17-23.

U.S. Environmental Protection Agency. 1982. Manual of individual drinking water systems. U.S. Environmental Protection Agency, Office of Drinking Water, Washington D.C. EPA-570/9-82-004.

Weatherspoon, D.M. and C.C. Harrell. 1980. Evaluation of drip irrigation for container production of woody landscape plants. HortScience 15:488-489.

Wilkerson, D.C. 1990. Developing a management plan for irrigation runoff. GrowerTalks 53(12):62-68.

Yeager, T. and G. Cashion. 1993. Controlled-release fertilizers affect nitrate nitrogen runoff from container plants. HortTechnology 3:174-177.

Yeager, T., R. Wright, D. Fare, C. Gilliam, J. Johnson, T. Bilderback and R. Zondag. 1993. Six state survey of container nursery nitrate nitrogen runoff. J. Environ. Hort. 11:206-208.

Figure 3.1. Amount of Fe, Mn, and Zn extracted from the upper, middle, and lower media regions treated with a granular incorporated (GIF) or a water soluble (WSF) fertilizer with micronutrient concentrations applied equally to both treatments under sprinkler irrigation. Means are an average of six replications. Horizontal bars indicate 95% confidence intervals; Expt. 1.

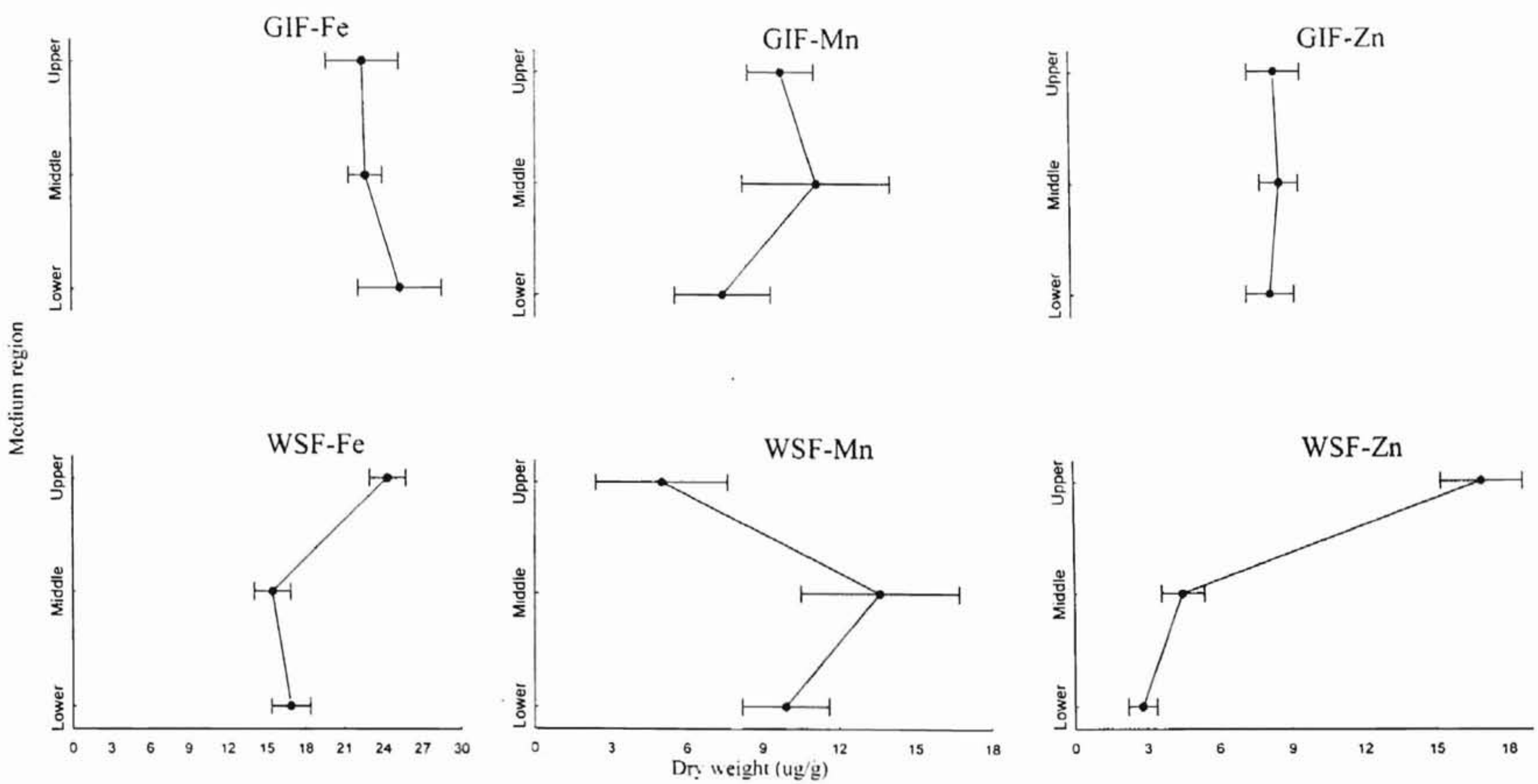
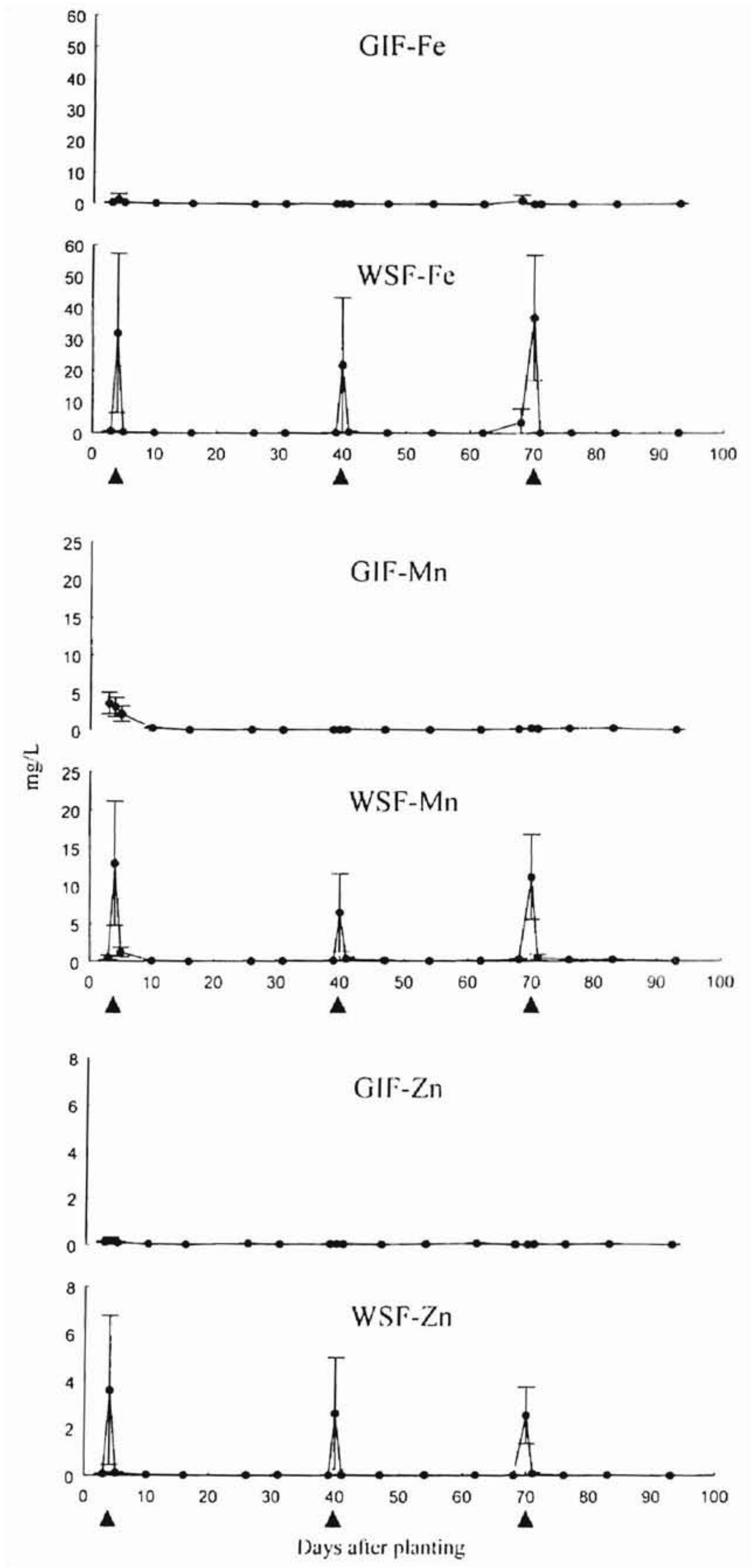
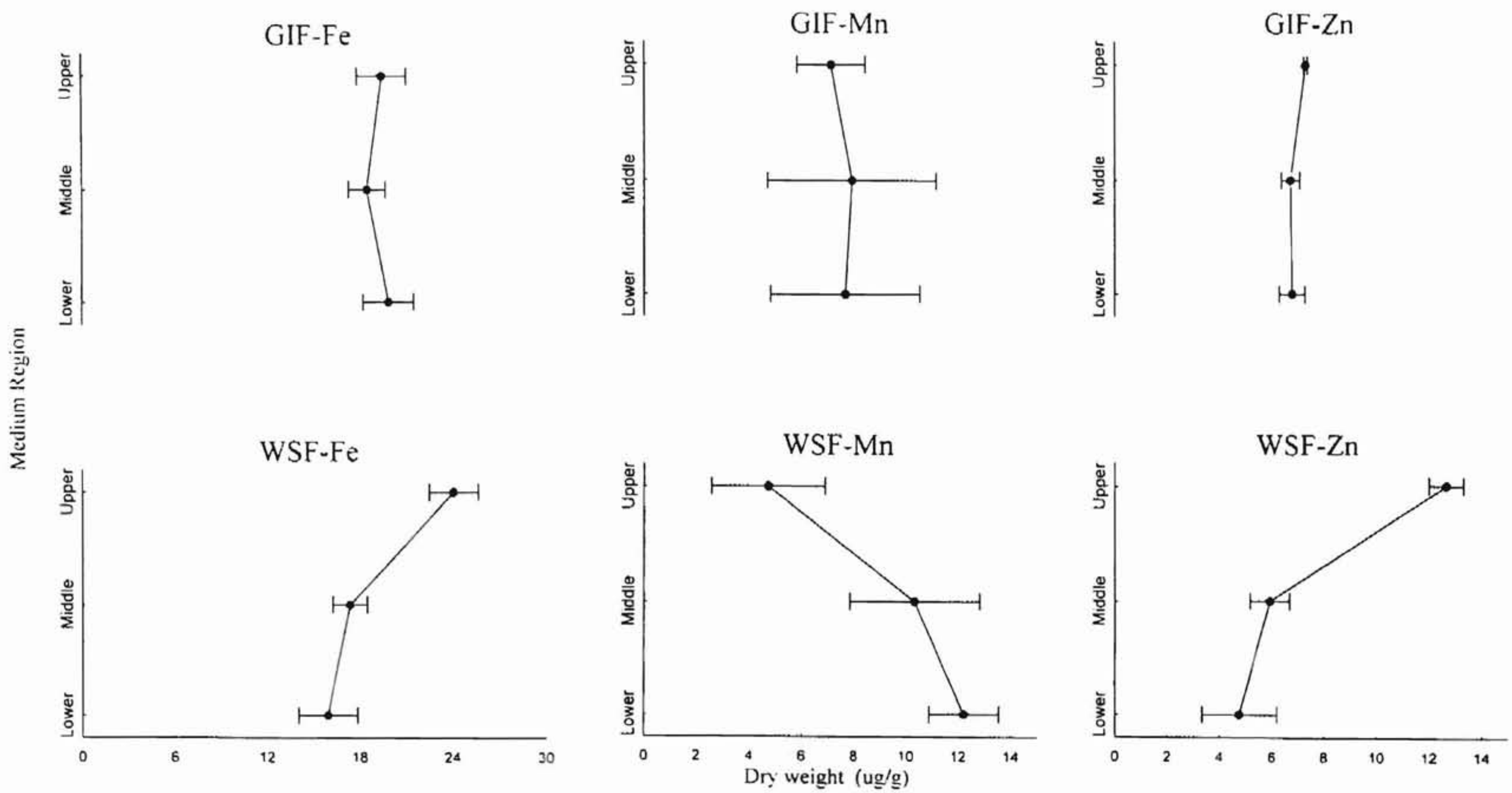

GIF-Fe
GIF-Mn
GIF-Zn
WSF-Fe
WSF-Mn
WSF-Zn
Upper
Middle
Lower
Medium region
0 3 6 9 12 15 18 21 24 27 30
0 3 6 9 12 15 18
Dry weight (ug/g)

Figure 3.2. Leachate concentration of Fe, Mn, Zn from *Buxus microphylla* Var. *koreana* grown with a granular incorporated (GIF) and water soluble (WSF) fertilizer in a 3:1:1 (by vol.) pine bark:peat:sand container medium under sprinkler irrigation at various days after planting. Triangles indicate the three applications of WSF. Means are an average of 12 replications of two subsamples. Vertical bars indicate 95% confidence intervals; Expt. 1.



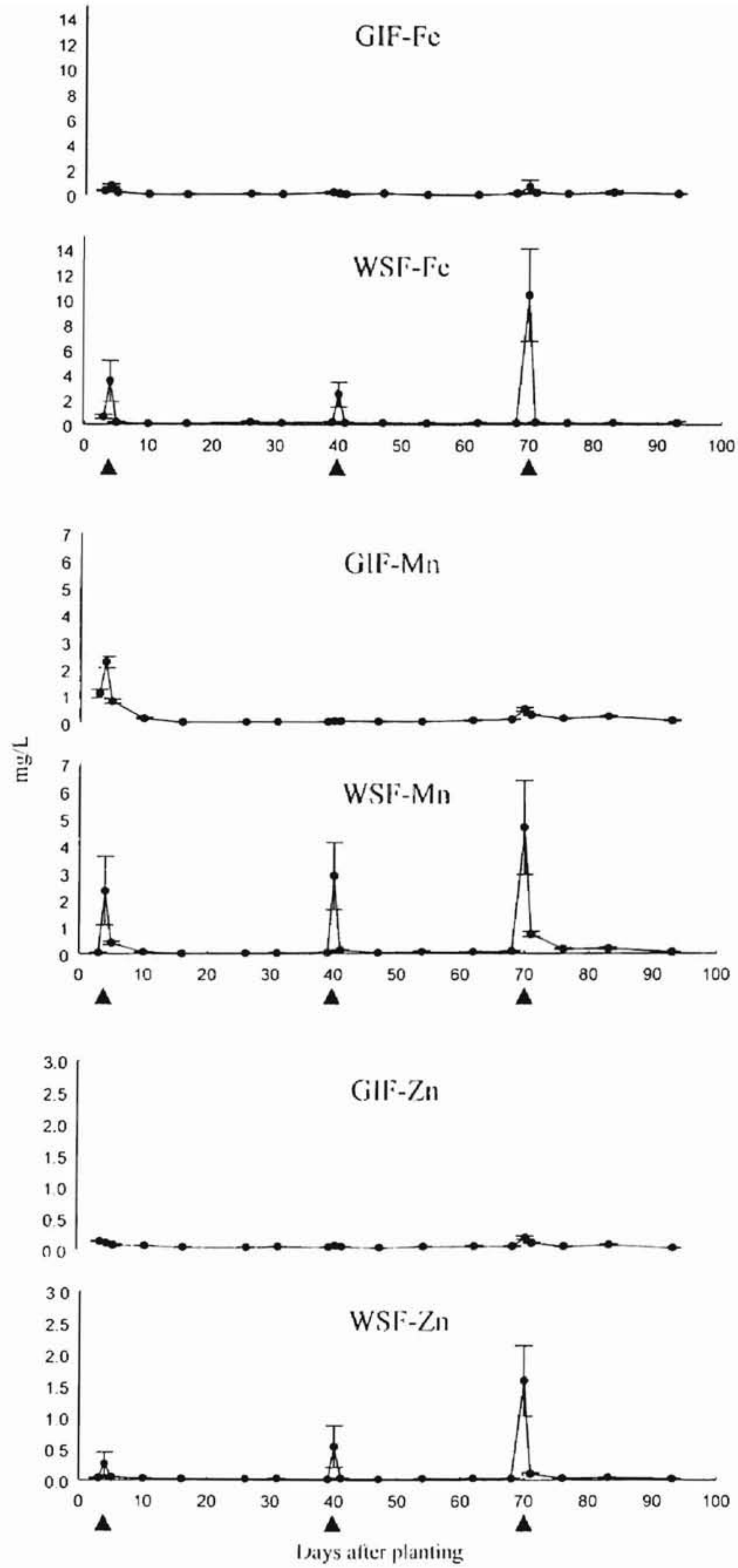
GIF-Fe
WSF-Fe
GIF-Mn
WSF-Mn
GIF-Zn
WSF-Zn
mg/L
Days after planting

Figure 3.3. Amount of Fe, Mn, and Zn extracted from the upper, middle, and lower media regions treated with a granular incorporated (GIF) or a water soluble (WSF) fertilizer source with micronutrient concentrations applied equally to both treatments under drip irrigation. Means are an average of six replications. Horizontal bars indicate 95% confidence intervals; Expt. 2.



GIF-Fe
GIF-Mn
GIF-Zn
WSF-Fe
WSF-Mn
WSF-Zn
Medium Region
Upper
Middle
Lower
0 6 12 18 24 30
0 2 4 6 8 10 12 14
Dry weight (ug/g)

Figure 3.4. Leachate concentration of Fe, Mn, Zn from *Buxus microphylla* Var. *koreana* grown with a granular incorporated (GIF) and water soluble (WSF) fertilizer in a 3:1:1 (by vol.) pine bark:peat:sand container medium under drip irrigation at various days after planting. Triangles indicate the three applications of WSF. Means are an average of 12 replications of two subsamples. Vertical bars indicate 95% confidence intervals; Expt. 2.


GIF-Fe
WSF-Fe
GIF-Mn
WSF-Mn
GIF-Zn
WSF-Zn
mg/L
Days after planting
0
10
20
30
40
50
60
70
80
90
100

Chapter 4

MICRONUTRIENT FERTILIZER, AND CA AND MG APPLICATION INFLUENCES FE, MN, AND ZN LEACHING FROM SOILLESS MEDIA.

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Abstract. **Sphagnum peat moss (PT), perlite (PR), pine bark (PB), sand (SN), and two media formulated (by volume) from these constituents (3 PT:1 PR, and 3 PB:1 PT:1 SN) were investigated to determine the effect of individual media constituents and mixes on Fe, Mn, and Zn leaching influenced by a granular incorporated (GIF) or a water soluble (WSF) fertilizer source, and Ca or Mg surface application. Intrinsic properties of individual media had a greater effect on Fe, Mn, and Zn retention in the media than the influence of fertilizer source, Ca, or Mg application. Medium EC increased linearly with increasing Ca and Mg application rate for all six media. Perlite and SN had greater amounts of Fe, Mn, and Zn in leachate compared to other media with similar trends observed between WSF and**

GIF sources. Medium components like PR and SN provide properties to soilless media needed for optimum plant production such as media aeration and stability. However, they should be used in combination with other media components that permit ion retention in the media.

Introduction

Components of container plant growing media have different chemical and physical properties that differ from field soils or soil-based media. Much research has focused on assessing physical properties of various soilless media and their impact on plant growth (Bilderback et al., 1982; Fonteno et al., 1981). Mathematical models for moisture characteristics of horticultural media have also been described by Milks et al. (1989). Various media components, macronutrient and micronutrient fertilizer sources, water sources and application methods, liming materials, and plant roots form complex chemical systems in the growing medium.

Studies have evaluated the chemical properties of soilless media and their effect on plant growth (Williams et al., 1988), and P leaching from soilless container media (Yeager and Barrett, 1984). Considerable amounts of P may be leached from soilless media due to the porosity of the media, daily irrigation and the composition of soilless mixes using both organic and inorganic media components such as pine bark, peat, and sand (Yeager and Barrett, 1984). Marconi and Nelson (1984) attribute greater P leaching from 1 peat:1 vermiculite (by volume) than from 1 sand:1 soil:1 peat (by volume) to lower P sorption in 1 peat:1 vermiculite. Pill et al. (1995) found that kenaf stem cores soaked in N can serve effectively as a bulking component of soilless media with the capacity to release N over an extended period. Moreover, they found NO_3 concentrations in leachate to be greater from a peat-vermiculite soilless mix compared to a peat-kenaf mix. Other research has shown that water-soluble P readily moves through a soilless medium profile if the pH is below 6.0 while media with a pH above 6.0 restricts P movement (Spinks and Pritchett, 1956). Based on medium pH, Spinks and Pritchett (1956) recommend different P application methods to be utilized for the reduction of P in leachate.

Broschat and Donselman (1985), examined extractable (ammonium acetate NH_4OAc, pH 7.0) Fe, Mg, Mn, Zn, and Cu in a peat-based medium amended with six commercial micronutrient fertilizers. While they found iron diethylenetriaminepentaacetic acid (FeDTPA) to be the best source of Fe, FeDTPA is soluble and all supplemental Fe had leached from the medium within 40 weeks. Amounts of all five elements from the various fertilizer sources decreased in the media during the first month and then remained consistent for the remaining 18-month experimental period. Moreover, they reported extractable Fe, Mn, and Zn amounts in the medium were reduced by addition of superphosphate present in Micromax Plus (Scotts Co., Marysville, Ohio) possibly due to the formation of insoluble phosphates.

A series of experiments were conducted to investigate the effect of Ca and Mg on micronutrient leaching from four media constituents and two mixes. Objectives of this study were to: 1) examine the effect of media constituents and mixes on Fe, Mn, and Zn leaching influenced by a granular incorporated (GIF) or a water soluble (WSF) fertilizer source; and 2) determine whether Ca and Mg influence the leaching of Fe, Mn, and Zn from media constituents and mixes using GIF or WSF micronutrient sources.

Materials and Methods

General procedures. A plantless system was designed to evaluate peat moss (PT), perlite (PR), sand (SN), and pine bark (PB) individually and in two mixes: 3 PT:1 PR, and 3 PB:1 PT:1 SN (by volume). Chemical and physical characteristics of the six air-dried, unamended media were determined (Table 4.1). Cation exchange capacity (CEC) of each of the six media was determined at the Research and Extension Analytical Laboratory, Wooster, Ohio. Initial Fe, Mn, and Zn concentration of the media components and mixes were determined negligible using the modified saturated media extraction procedure described by Berghage et al. (1987), except 100 cm^3 of medium was used and gravity filtration using Whatman 41 ashless filter paper was performed. Fifteen cm diameter by 11 cm deep (1.9 L) pots were filled with media. Volume of media for each pot was determined by weight using bulk density. Micromax (Scotts, Co., Marysville, Ohio) (GIF) was incorporated into each medium at its recommended rate of 0.9 $kg{\cdot}m^{-3}$. Commercial soluble trace element mix (STEM, Scotts, Co.) (WSF) was applied to the medium surface (100 mL/pot) at its recommended rate of 599 $mg{\cdot}L^{-1}$. Distilled water (dH_2O, pH= 5.6) was added to the surface of the medium in each pot in an open (draining) system until saturation. Drained dH_2O was reapplied to media constituents and mixes that were hydrophobic several times to assure uniform saturation of the media. Each medium was allowed to equilibrate for 48 h at 20°C after saturating and before purging the system with 500 mL/pot dH_2O. Leachate from each media treatment was collected in 20.3 cm diameter by 8.9 cm deep (2.9 L) plastic saucers (American Plant Products, Oklahoma City, Okla.). Leachate volumes were determined and samples filtered using Whatman No. 41 ashless filter paper. Filtrate of samples was analyzed for pH (pH/mV/Temp Bench meter, Cole-Parmer Instruments, Chicago, Ill.), electrical conductivity (EC) (Solu-bridge, Beckman Instruments Inc., Cedar Grove, N.J.), and Fe, Mn, and Zn concentration of the leachate using atomic absorption spectroscopy (Model 2380; Perkin-Elmer Corp., Norwalk, Conn.) (Isaac and Johnson, 1975).

Media with GIF (Expt. 1). Individual media constituents and mixes were amended with GIF at its recommended rate on 6 Aug. 1997. The GIF was incorporated into each medium prior to the experiment. Leachate samples were collected on 8 Aug. 1997.

Media with WSF (Expt. 2). Experiment 1 was repeated except no GIF was used and WSF was surface applied in 100 mL of dH_2O at its recommended rate to individual media constituents and mixes on 6 Aug. 1997. Leachate samples were collected on 8 Aug. 1997.

GIF with Ca (Expt. 3). Granular incorporated fertilizer was incorporated into each medium on 14 July 1997 as described in Expt. 1. Calcium was applied as a surface application 'chase' to each medium after allowing the saturated media to equilibrate for a 24 h period. Calcium solution was applied at 0, 100, 200, and 400 $mg \cdot L^{-1}$ in 100 mL solution to the appropriate treatments. Calcium solution that leached into the collection saucers initially was reapplied until absorbed by the media. The Ca source was $Ca(NO_3)_2 \cdot 4\,H_2O$ and rates were chosen based on guidelines for Ca concentration in soilless growth media for optimum plant production (Warncke and Krauskopf, 1983). Leachate samples were collected on 16 July 1997.

WSF with Ca (Expt. 4). Experiment 3 was repeated except no fertilizer was incorporated into each medium. Instead, WSF was surface applied to each medium on 29 July 1997 as described in Expt. 2. Leachate samples were collected on 31 July 1997.

GIF with Mg (Expt. 5). Media constituents and mixes were amended with GIF at its recommended rate on 17 July 1997. One hundred mL of Mg solution was surface applied 24 h after media saturation at 0, 35, 70, and 140 $mg \cdot L^{-1}$ to appropriate treatments. The Mg source was $Mg(NO_3)_2 \cdot 6\,H_2O$ and rates based on guidelines for Mg concentration in soilless growth media for optimum plant production (Warncke and Krauskopf, 1983). Leachate samples for all treatments were collected in saucers on 19 July 1997.

WSF with Mg (Expt. 6). Experiment 5 was repeated with the following changes. No GIF was used, and instead, WSF was surface applied to each media on 1 Aug. 1997 as described in Expt. 2. Leachate samples for all treatments were collected on 3 Aug. 1997.

Statistics. The design was completely randomized with six medium treatments (four components and two mixes) for Expt. 1 and 2. Each treatment was replicated four times with individual pots representing a single unit. Data were analyzed using general linear model procedures and mean separation by protected LSD (SAS Institute, Cary, N.C.). For Expt. 3, 4, 5, and 6, the experimental design was a factorial treatment combination with four Ca or Mg rates and six media arranged in a split block. Each treatment was replicated three times with individual pots representing a single unit. Data were analyzed using general linear model procedures with trend analysis for Ca or Mg rates and single-degree of freedom F-tests for significant interactions (SAS Institute, Cary, N.C.).

Results

Media with GIF (Expt. 1). Pine bark and SN had the greatest leachate pH while PT and 3 PT:1 PR had the lowest pH of the media. Peat, SN and 3 PT:1 PR had a greater EC than all other media (Table 4.2). More Fe was leached from PR than from any other media constituent or mix (Table 4.2). In contrast, leachate from SN had the most while PB and 3 PB:1 PT:1 SN had the least Mn concentration. Sand and PR had the most Zn in leachate and leachate from PB and from 3 PB:1 PT:1 SN had the least.

Media with WSF (Expt. 2). Leachate pH was significantly different for all media, as was EC except that EC for PT and 3 PT:1 PR were similar and higher than any other medium (Table 4.2). A significantly greater amount of Fe was present in the leachate from SN than from any other medium. Leachate from PR had the greatest Mn and Zn concentration compared to leachate from the other media (Table 4.2).

GIF with Ca (Expt. 3). No significant interactions between Ca rate and media occurred. Medium EC and Zn content in leachate increased linearly as Ca concentration increased. Sand had the greatest pH while PT had the lowest leachate pH of the media. In contrast, PT and 3 PT:1 PR had a greater EC than all other media (Table 4.3). Perlite produced a significantly greater Fe leachate content compared to all other media. More Mn and Zn were leached from SN than any other medium (Table 4.3).

WSF with Ca (Expt. 4). There was no significant interaction between Ca rate and media for pH of leachate; however, leachate from PR had the highest while PT and 3 PT:1 PR had the lowest pH. Medium EC increased linearly as Ca rate increased for all media except for PR which had a curvilinear response (Table 4.4). A curvilinear response occurred for Fe leachate content as Ca application rate increased for SN and 3 PB:1 PT:1 SN. Manganese content in the leachate increased linearly for PT, 3 PT:1 PR, and 3 PB:1 PT:1 SN media as Ca rate increased. In contrast, there was a quadratic response between Mn in leachate and Ca application rate for PB and PR media (Table 4.4). Perlite exhibited a quadratic relationship between Zn content of leachate and Ca application rate (Table 4.4).

GIF with Mg (Expt. 5). No significant Mg by media interactions occurred, nor did Mg rate influence any parameter measured. Sand had the highest pH while PT had the lowest pH of the media. Medium EC was greatest for PT and 3 PT:1 PR than any other medium (Table 4.5). Leachate Fe content was significantly greater with PR compared to other media (Table 4.5). The amount of Mn in leachate did not differ regardless of media. Zinc occurred in the highest concentrations in leachate from SN. Leachate from PR contained less Zn than leachate from SN but more Zn than leachate from any other medium tested (Table 5).

WSF with Mg (Expt. 6). No significant Mg by media interactions were found for medium pH, Mn, or Zn leachate content. There was a linear increase in the amount of Mn and Zn leached as Mg application rate increased (Table 4.6). Leachate pH was highest with the inorganic constituents PR and SN compared to organic constituents and mixes (Table 4.6). Moreover, PR had a significantly greater amount of Mn and Zn leached compared to other media being evaluated. Medium EC linearly increased as Mg application rate increased for all media (Table 4.7). A curvilinear response occurred for Fe leachate content as Mg application rate increased with SN (Table 4.7).

Discussion

Greater percentages of Fe, Mn, and Zn were leached from GIF in Expt.1 than from WSF in Expt. 2 (Table 4.2). In the media with GIF study (Expt. 1), larger quantities of Fe, Mn, and Zn were applied to each container than in Expt. 2 due to formulation and recommendation differences of the commercial GIF and WSF products. These results support the findings of Hershey and Paul (1982) in which more nutrient was leached as the amount of nutrient applied increased. Although they tested within fertilizer sources, comparable results should occur regardless of fertilizer source. Moreover, Hershey and Paul (1982) reported that with a CRF, the amount of N leached was decreased by half compared to that leached when using a liquid fertilizer at the same N application rate. With reduced amounts of Fe, Mn, and Zn in leachate produced from WSF with minimal differences occurring in plant growth between GIF and WSF treatments when both were applied in equal amounts (Chapter 2, 3), growers can improve management practices by utilizing surface applications of WSF in their production schemes to minimize run-off and potential contamination of off-site areas. However, economic costs for fertilizer and labor must be considered when deciding on a micronutrient fertilizer source.

Media CEC had the greatest influence on results from these experiments. Cation exchange capacity is a non-specific surface adsorption where fixed, negative electrical charges will attract and hold positive electrical charges (cations) like Fe, Mn, Zn and other positively charged fertilizer components . In all experiments, PR and SN exhibited high Fe, Mn, and Zn leachate content for both fertilizer sources. Both of these components are inorganic with a very low CEC. The higher CEC of PT, 3 PT:1 PR, and 3 PB:1 PT:1 SN compared to that of PR and SN should lead to better retention of exchangeable ions. Nelson (1991) stated that most composted organic material, clay, and PT have a high CEC while SN, PR, polystyrene and other noncomposted materials have an insignificant CEC. A medium CEC of 6-15 meq/100 cm^{-3} is desirable for greenhouse growing media and lower levels result in the medium not acting as a suitable reservoir for nutrients with frequent fertilization becoming necessary (Nelson, 1991). Moreover, physical and electrostatic adsorption within the media may also contribute to ion retention in organic components and mixes with an organic component.

Although components like SN and PR are added to container media for specific functions such as increased aeration and drainage, it is desirable to include a component like PT with a high CEC. This is evident in examining the characteristics of individual components and media mixes used in this study (Table 4.1). Peat alone has a high CEC of 23 meq/100 g while SN and PR have a CEC of 2 meq/100 g and 1 meq/100 g, respectively. When used in combination, CEC of 3 PT:1 PR and 3 PB:1 PT:1 SN increased to 17 and 5 meq/100 g, respectively.

Possible precipitation or chelation reactions within individual media components and mixes must also be considered. However, for precipitation to be a major factor in prevention of micronutrient leaching of the medium, Fe, Mn, and Zn leaching concentrations would have been consistent across all media which our results did not show. Furthermore, no phosphate was introduced into our system which would be the element most likely to form an insoluble precipitant with Fe, Mn, and Zn. In contrast, Broschat and Donselman (1985) noted extractable Fe, Mn, and Zn amounts in the peat-based medium were reduced by addition of superphosphate present in Micromax Plus (Scotts Co., Marysville, Ohio) compared to other fertilizer sources due to the formation of insoluble phosphates.

Chelation of Fe, Mn, and Zn may also occur within medium containing organic matter. However, in this study Fe, Mn, and Zn content in leachate increased when Ca or Mg concentration increased in our 'chase' application. This is most evident in Expt. 5 (Table 4.4) where a strong curvilinear relationship occurred for Fe content in the leachate regardless off media as Ca concentration increases. Thus, surface adsorption and not precipitation or chelation of Fe, Mn, and Zn was the major reaction occurring within the individual medium and mixes and adsorption of Fe, Mn, and Zn were directly related to the CEC of each individual component or mix.

Micronutrient fertilizer source and Ca or Mg application effect on micronutrient leaching were minimal except for EC. The increase in EC with increased Ca and Mg application rates would be expected since excess Ca and Mg not displacing other exchangeable ions would be leached from the media. The leaching fractions varied as a consequence of evaporation from the media surface during the equilibrium period and water holding capacity differences between the media, resulting in greater leachate dilution for PB which could have contributed to lower Fe, Mn, and Zn content in leachate from PB despite a lower CEC than with the other media.

Data obtained from these experiments represent media properties immediately after planting. Media pH was not buffered to make pH of all media consistent. The purpose of this experiment was to evaluate each component or mix at its inherent pH value. Media pH may have an impact on micronutrient retention in media in all experiments. Media pH effects the plant nutrient availability and therefore the ability of the nutrients to be leached, since nutrients must be found in the liquid fraction of the medium to be plant available. In general, micronutrients such as Fe, Mn, and Zn are more readily available to plants at a low pH and are unavailable at higher pH (Nelson, 1991). Results from this study show that micronutrient retention was poorest with media constituents possessing a slightly acidic to basic pH range. Inorganic media constituent such as PR and SN produced a higher pH than other organic media components or mixes consisting of organic and inorganic constituents. In contrast, Spinks and Pritchett (1956) reported that water-soluble P readily moved through a soilless medium if the pH was below 6.0, while P movement was restricted at higher medium pH. These findings suggest micronutrient leaching relates more to intrinsic properties of the media like CEC rather than pH.

In summary, intrinsic properties of individual media like CEC had a greater effect on Fe, Mn, and Zn retention in the media than the influence of Ca or Mg application. In general, leachate from PR and SN had greater amounts of Fe, Mn, and Zn compared to other media. Furthermore, similar trends regarding ion content were observed between WSF and GIF sources regardless of Ca or Mg application rates indicating that Ca or Mg did not replace the micronutrients previously added to the medium. Medium EC increased linearly with increasing Ca and Mg application rate for all six media. Medium components like PR and SN provide properties to soilless media needed for optimum plant production such as media aeration and stability. However, they should be used in combination with other media components that permit ion retention in the media.

Literature Cited

Berghage D.M., D.M. Krauskopf, D.D. Warncke, and I. Widders. 1987. Micronutrient testing of plant growth media: Extractant identification and evaluation. Commun. Soil Sci. Plant Anal. 18:1089-1109.

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peat moss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107: 1081-1084.

Broschat, T.K. and H.M. Donselman. 1985. Extractable Mg, Fe, Mn, Zn, and Cu from a peat-based container medium amended with various micronutrient fertilizers. J. Amer. Soc. Hort. Sci. 110:196-200.

Fonteno, W.C., D.K. Cassel, and R.A. Larson. 1981. Physical properties of three container media and their effect on poinsettia growth. J. Amer. Soc. Hort. Sci. 106:736-741.

Isaac, R.A. and W.C. Johnson, Jr. 1975. Collaborative study of wet and dry techniques for the elemental analysis of plant tissue by atomic absorption spectrophotometry. Assoc. Offic. Anal. Chem. 58:436.

Marconi, D.J. and P.V. Nelson. 1984. Leaching of applied phosphorus in container media. Sci. Hort. 22:275-285.

Milks, R.R., W.C. Fonteno, and R.A. Larson. 1989. Hydrology of horticultural substrates: I. Mathematical models for moisture characteristics of horticultural container media. J. Amer. Soc. Hort. Sci. 114:48-52.

Nelson, P.V. 1991. Greenhouse operation and management. 4th ed. Prentice Hall, Englewood Cliffs, N.J.

Pill, W.G., S. Bing, H.D. Tilmon, and R.W. Taylor. 1995. Leaching losses and plant uptake of nitrogen in soilless media containing ground kenef (*Hibiscus cannabinus* L.) stem core. J. Hort. Sci. 70:833-840.

Spinks, D.O. and W.L. Pritchett. 1956. The downward movement of phosphorus in potting soils as measured by P^{32}. Proc. Fla. State Hort. Soc. 69:385-388.

Warncke, D.D. and D.M. Krauskopf. 1983. Greenhouse growth media: Testing and nutrition guidelines. Michigan State University Ext. Bul. 736.

Williams, B.J., J.C. Peterson, and J.D. Utzinger. 1988. Liming reactions in sphagnum peat-based growing media. J. Amer. Soc. Hort. Sci. 113:210-214.

Yeager, T.H. and J.E. Barrett. 1984. Phosphorus leaching from ^{32}P-superphosphate-amended soilless container media. HortScience 19:216-217.

Table 4.1. Chemical and physical properties of selected media components and mixes.

Media	pH	EC	Total porosity (%)	Water holding capacity (%)	Air space (%)	Bulk density ($g \cdot cm^{-3}$)	Cation exchange capacity (meq/100
Peat (PT)	3.6	1.2	73	52	21	0.08	23
Perlite (PR)	7.2	0.1	68	35	33	0.11	1
Pine bark (PB)	5.2	0.2	52	27	25	0.17	2
Sand (SN)	8.9	0.8	30	26	4	1.80	2
3 PT:1 PR	4.0	0.2	91	69	22	0.09	17
3 PB:1 PT:1 SN	4.6	0.1	54	28	26	0.30	5

Table 4.2. Media effect on leachate pH, EC, and Fe, Mn, and Zn content as influenced by granular incorporated (GIF) and water soluble (WSF) fertilizer. Fertilizer sources were applied at manufacturer's recommended rates. Means are an average of four replication; Expt. 1 and 2.

Media	pH	EC	mg (%)[z]		
			Fe	Mn	Zn
			GIF (Expt. 1)		
Peat (PT)	2.8d	1.3a	17.0b (14)	11.7b (47)	4.9bc (49)
Perlite (PR)	3.7c	0.8b	48.0a (40)	12.0b (48)	5.9ab (59)
Pine bark (PB)	4.1a	0.5c	2.0c (2)	3.6c (14)	0.9d (9)
Sand (SN)	4.1ab	1.2a	11.1bc (9)	25.9a (100)	7.4a (74)
3 PT:1 PR	2.9d	1.3a	11.9bc (10)	11.0b (44)	4.2c (42)
3 PB:1 PT:1 SN	3.9b	0.7bc	3.9c (3)	4.1c (17)	1.5d (15)
LSD $_{(0.05)}$:	0.2	0.3	10.8	5.6	1.7
			WSF (Expt. 2)		
PT	3.3f	0.35a	0.07b (2)	0.14bc (3)	0.04b (1)
PR	6.0b	0.10d	0.02b (1)	0.86a (18)	0.33a (12)
PB	4.9c	0.15c	0.09b (2)	0.21b (4)	0.04b (1)
SN	6.9a	0.23b	0.50a (11)	0.04c (1)	0.03b (1)
3 PT:1 PR	3.4e	0.35a	0.05b (1)	0.09bc (2)	0.03b (1)
3 PB:1 PT:1 SN	4.5d	0.14c	0.09b (2)	0.08bc (2)	0.01b (1)
LSD $_{(0.05)}$:	0.09	0.04	0.09	0.14	0.08

[z] Percentage of element leached based on amount element applied to each treatment.

Table 4.3. Leachate pH, EC, and Fe, Mn, and Zn content of leachate from six media amended with a granular incorporated (GIF) fertilizer as influenced by Ca application at four concentrations 24 h after media saturation. Means are an average of 12 observations, except for PT and SN media where 10 observations were used; Expt. 3.

			mg		
Treatment	pH	EC	Fe	Mn	Zn
			Ca rate ($mg \cdot L^{-1}$) main effect		
0	3.6	0.9	10.0	9.5	2.3
100	3.9	0.9	6.5	8.2	2.0
200	3.9	1.1	9.0	7.5	2.5
400	3.9	1.1	8.1	9.7	3.1
Significance:					
Ca-Linear (L)	NS	*	NS	NS	*
Ca-Quadratic (Q)	NS	NS	NS	NS	NS
Ca-Cubic (C)	NS	NS	NS	NS	NS
			Media main effect		
Peat (PT)	2.8	1.4	5.0	9.0	2.9
Perlite (PR)	3.7	0.7	30.0	8.3	3.7
Pine bark (PB)	4.3	0.7	3.0	6.2	1.1
Sand (SN)	5.2	1.0	5.7	18.1	4.5
3 PT:1 PR	3.2	1.3	3.1	6.1	1.6
3 PB:1 PT:1 SN	4.0	1.0	3.7	6.3	1.2
Significance:					
Media ($LSD_{0.05}$)	0.2	0.2	5.8	1.8	0.9

Table 4.4. Leachate pH, EC, and Fe, Mn, and Zn leachate content of six media amended with water soluble (WSF)fertilizer as influenced by Ca application at four concentrations 24 h after media saturation. Means are an average of three replications; Expt. 4.

Ca				mg		
($mg \cdot L^{-1}$)	Media	pH	EC	Fe	Mn	Zn
0	Peat (PT)	3.4	0.3	0.05	0.07	0.02
	Perlite (PR)	6.0	0.1	0.02	1.22	0.39
	Pine bark (PB)	4.9	0.1	0.13	0.13	0.03
	Sand (SN)	5.0	0.2	0.46	0.07	0.03
	3 PT:1 PR	3.6	0.5	0.07	0.16	0.04
	3 PB:1 PT:1 SN	4.5	0.2	0.15	0.12	0.01
100	PT	3.3	0.4	0.08	0.15	0.04
	PR	6.1	0.2	0.02	1.62	0.54
	PB	5.0	0.2	0.12	0.17	0.03
	SN	7.2	0.3	0.19	0.02	0.03
	3 PT:1 PR	3.5	0.5	0.05	0.24	0.06
	3 PB:1 PT:1 SN	4.4	0.2	0.20	0.21	0.03
200	PT	3.3	0.4	0.07	0.24	0.08
	PR	6.3	0.2	0.02	1.77	0.68
	PB	5.0	0.2	0.14	0.19	0.03
	SN	6.9	0.3	0.93	0.04	0.03
	3 PT:1 PR	3.5	0.6	0.05	0.30	0.08
	3 PB:1 PT:1 SN	4.3	0.3	0.15	0.27	0.03
400	PT	3.2	0.6	0.07	0.31	0.08
	PR	6.3	0.4	0.04	1.31	0.43
	PB	4.6	0.3	0.13	0.38	0.05
	SN	7.3	0.5	0.10	0.05	0.03
	3 PT:1 PR	3.5	0.7	0.05	0.39	0.09
	3 PB:1 PT:1 SN	4.2	0.4	0.16	0.55	0.06
Significance:						
Ca-Linear (L)		NS	***	**	**	NS
Ca-Quadratic (Q)		NS	NS	**	NS	*
Ca-Cubic (C)		NS	NS	**	NS	NS
Media ($LSD_{0.05}$)		0.7	0.03	0.03	0.2	0.07
Ca-L*PT		NS	**	NS	**	NS
Ca-Q*PT		NS	NS	NS	NS	NS
Ca-C*PT		NS	NS	NS	NS	NS
Ca-L*PR		NS	**	NS	NS	NS
Ca-Q*PR		NS	*	NS	**	**

Ca-C*PR	NS	NS	NS	NS	NS
Ca-L*PB	NS	**	NS	NS	NS
Ca-Q*PB	NS	NS	NS	**	NS
Ca-C*PB	NS	NS	NS	NS	NS
Ca-L*SN	NS	**	**	NS	NS
Ca-Q*SN	NS	NS	**	NS	NS
Ca-C*SN	NS	NS	NS	NS	NS
Ca-L*3 PT:1 PR	NS	**	NS	*	NS
Ca-Q*3 PT:1 PR	NS	NS	NS	NS	NS
Ca-C*3 PT:1 PR	NS	NS	NS	NS	NS
Ca-L*3 PB:1 PT:1 SN	NS	**	NS	**	NS
Ca-Q*3 PB:1 PT:1 SN	NS	NS	NS	NS	NS
Ca-C*3 PB:1 PT:1 SN	NS	NS	*	NS	NS

Table 4.5. Leachate pH, EC, and Fe, Mn, and Zn content of leachate from six media amended with a granular incorporated (GIF) fertilizer as influenced by Mg application at four concentrations 24 h after media saturation. Means are an average of 12 observations; Expt. 5.

				mg	
Media	pH	EC	Fe	Mn	Zn
Peat (PT)	2.9	1.4	3.2	5.5	1.7
Perlite (PR)	3.9	0.8	29.1	10.7	4.0
Pine bark (PB)	4.2	0.7	2.1	5.1	0.9
Sand (SN)	4.6	1.1	7.1	40.5	5.9
3 PT:1 PR	3.2	1.3	3.3	6.2	1.8
3 PB:1 PT:1 SN	3.9	0.8	2.4	4.4	0.8
Significance:					
Mg-Linear (L)	NS	NS	NS	NS	NS
Mg-Quadratic (Q)	NS	NS	NS	NS	NS
Mg-Cubic (C)	NS	NS	NS	NS	NS
Media ($LSD_{0.05}$)	0.2	0.1	7.1	NS	0.9

Table 4.6. Leachate pH, Mn and Zn content of leachate from six media amended with water soluble (WSF) fertilizer as influenced by Mg application at four concentrations 24 h after media saturation. Means are an average of 12 observations; Expt. 6.

		mg	
Treatment	pH	Mn	Zn
		Mg rate ($mg \cdot L^{-1}$) main effect	
0	4.9	0.21	0.06
35	4.9	0.24	0.06
70	4.9	0.32	0.10
140	4.9	0.38	0.12
Significance:			
Mg-Linear(L)	NS	*	*
Mg-Quadratic(Q)	NS	NS	NS
Mg-Cubic(C)	NS	NS	NS
		Media main effect	
Peat (PT)	3.3	0.07	0.02
Perlite (PR)	6.1	1.05	0.34
Pine bark (PB)	4.9	0.26	0.04
Sand (SN)	7.1	0.02	0.02
3 PT:1 PR	3.6	0.17	0.03
3 PB:1 PT:1 SN	4.4	0.15	0.04
Significance:			
Media ($LSD_{0.05}$)	0.1	0.09	0.06

Table 4.7. Leachate EC, and Fe leachate content of six media amended with water soluble (WSF) fertilizer as influenced by Mg applied as a chase at four concentrations 24 h after media saturation. Means are an average of three replications; Expt. 6.

Mg ($mg \cdot L^{-1}$)	Media	EC	Fe (mg)
0	Peat (PT)	0.37	0.07
	Perlite (PR)	0.10	0.02
	Pine bark (PB)	0.15	0.11
	Sand (SN)	0.21	0.22
	3 PT:1 PR	0.55	0.05
	3 PB:1 PT:1 SN	0.16	0.12
35	PT	0.41	0.04
	PR	0.10	0.02
	PB	0.15	0.10
	SN	0.27	0.07
	3 PT:1 PR	0.59	0.05
	3 PB:1 PT:1 SN	0.16	0.10
70	PT	0.41	0.04
	PR	0.14	0.02
	PB	0.17	0.14
	SN	0.31	0.05
	3 PT:1 PR	0.61	0.05
	3 PB:1 PT:1 SN	0.21	0.11
140	PT	0.50	0.04
	PR	0.21	0.02
	PB	0.22	0.09
	SN	0.44	0.03
	3 PT:1 PR	0.65	0.04
	3 PB:1 PT:1 SN	0.28	0.08
Significance:			
Mg-Linear (L)		***	**
Mg-Quadratic (Q)		NS	NS
Mg-Cubic (C)		NS	*
Media ($LSD_{0.05}$)		0.03	0.02
Mg-L*PT		**	NS
Mg-Q*PT		NS	NS
Mg-C*PT		NS	NS
Mg-L*PR		**	NS
Mg-Q*PR		NS	NS

Mg-C*PR	NS	NS
Mg-L*PB	**	NS
Mg-Q*PB	NS	NS
Mg-C*PB	NS	*
Mg-L*SN	**	**
Mg-Q*SN	NS	**
Mg-C*SN	NS	**
Mg-L*3 PT:1 PR	**	NS
Mg-Q*3 PT:1 PR	NS	NS
Mg-C*3 PT:1 PR	NS	NS
Mg-L*3 PB:1 PT:1 SN	**	NS
Mg-Q*3 PB:1 PT:1 SN	NS	NS
Mg-C*3 PB:1 PT:1 SN	NS	NS

Chapter 5

SUMMARY

When Fe, Mn, and Zn were applied as a granular incorporated fertilizer (GIF) or a water soluble fertilizer (WSF), minimal differences occurred in any growth parameter measured for greenhouse and containerized nursery production utilizing sprinkler or microtube irrigation. Greater amounts Fe, Mn, and Zn were leached from the growing medium when utilizing a GIF source for greenhouse production. Leachate Fe, Mn, and Zn concentrations were highest at the beginning of experiments with GIF while leachate concentrations were highest for WSF at application for containerized nursery production. However, cumulative Fe, Mn, and Zn leached exceeded their respective secondary maximum contamination level (SMCL) of $0.3\ mg \cdot L^{-1}$, $0.05\ mg \cdot L^{-1}$, and $5.0 \cdot mg\ L^{-1}$ during the experimental period with both fertilizer sources. Although these guidelines are not enforceable by law, contaminants in leachate discharge may accumulate in soil and water supplies and potentially lead to human and animal health problems. Potential Fe, Mn, and Zn contamination may lead to problems in using ground and surface water sources for drinking water, wash water, and other purposes. At present, Fe, Mn, and Zn pose no or little threat to human health; however, aquatic organisms, such as mussels, may be affected negatively if micronutrient-contaminated discharge continues to enter surface water sources.

Medium analysis yielded Fe, Mn, and Zn at higher concentrations in the upper and middle medium regions than in the lower region when micronutrients were surface applied using a WSF while element concentrations were evenly distributed among media regions for GIF treatments that were incorporated into the medium prior to the experiment for greenhouse crop production. Similar trends were noted for containerized nursery production with the exception of Mn which had a higher concentration in the lower medium region compared to the upper and middle regions when applied as a WSF. Medium pH and EC were greater in the upper and middle regions of the medium compared to the lower region under drip irrigation, however, minimal differences were found when utilizing sprinkler irrigation.

Intrinsic properties of individual media had a greater effect on Fe, Mn, and Zn leaching from the growing media than the influence of fertilizer source, Ca, or Mg application. Medium components with low CEC, like PR and SN, had greater amounts of Fe, Mn, and Zn leached from the medium than other components or mixes. Although components like PR and SN provide properties to soilless media needed for optimum plant production, they should be utilized in combination with other media components that permit ion retention in the media.

SELECTED BIBLIOGRAPHY

Argo, W.R. and J.A. Biernbaum. 1994. Irrigation requirements, root-medium pH, and nutrient concentrations of Easter lilies grown in five peat-based media with and without an evaporation barrier. J. Amer. Soc. Hort. Sci. 119:1151-1156.

Argo, W.R. and J.A. Biernbaum. 1995. The effect of irrigation method, water soluble fertilization, preplant nutrient charge, and surface evaporation on early vegetative and root growth of poinsettia. J. Amer. Soc. Hort. Sci. 120:163-169.

Bachman, G.R. and M.C. Halbrooks. 1994. Multiple applications of FeDTPA or DTPA on micronutrient extraction and potential availability from peat-based medium. Commun. Soil Sci. Plant Anal. 25:3101-3113.

Barron, H.M. 1977. Controlled release fertilizer and its use in hot climates. South Flor. Nurseryman 89(46):16-17, 35-38.

Berghage, D.M., D.M. Krauskopf, D.D. Warncke, and I. Widders. 1987. Micronutrient testing of plant growth media: Extractant identification and evaluation. Commun. Soil Sci. Plant Anal. 18:1089-1109.

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peat moss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:1081-1084.

Bradshaw, M.H. 1989. Understanding your water test report- microbial, chemical, and nuisance contaminants. Kansas State University County Extension. MF-912. In: World wide web @ http://ingis:acn.purdue.edu:9999 /Wetnet/government / DIAGNOSE/standards.html.

Broschat, T. K. 1995. Nitrate, phosphate, and potassium leaching from container-grown plants fertilized by several methods. HortScience 30:74-77.

Broschat, T.K. and H.M. Donselman. 1985. Extractable Mg, Fe, Mn, Zn, and Cu from a peat-based container medium amended with various micronutrient fertilizers. J. Amer. Soc. Hort. Sci. 110:196-200.

Cole, J.C., V.L. Stamback, and C. Gray. 1993. Design for a simulated nursery for water runoff research. HortScience 28:952-953.

Conover, C.A. and R.T. Poole. 1992. Effect of fertilizer and irrigation on leachate levels of NH_4, NO_3, and P in container production of *Nephrolepsis exalta* 'Fluffy Ruffle'. J. Environ. Hort. 10:238-241.

Cox, D.A. 1985. Nitrogen recovery by seed geranium as influenced by nitrogen source. HortScience 20:923-925.

Dole, J.M., J.C. Cole, and R.M. Smith. 1992. Effect of controlled-release and constant liquid fertilization on leachate and plant quality. HortScience 27:582. (abstr.).

Dole, J.M., J.C. Cole, and S.L von Broembsen. 1994. Growth of poinsettias, nutrient leaching, and water-use efficiency respond to irrigation methods. HortScience 29:858-864.

Fonteno, W.C., D.K. Cassel, and R.A. Larson. 1981. Physical properties of three container media and their effect on poinsettia growth. J. Amer. Soc. Hort. Sci. 106:736-741.

Hershey, D.R. and J.L. Paul. 1982. Leaching-losses of nitrogen from pot chrysanthemums with controlled-release or liquid fertilization. Scientia Hort. 17:145-152.

Holcomb, E.J. 1980. How to increase fertilizer efficiency through slow-release formulations. Amer. Nurseryman 152(7):9,38,40,42.

Hornby, A.G. 1986. Ground water: The hidden resource. Proc. Water Quality and Agriculture's Role for the Future. Okla. Coop. Ext. Serv., Circ. E-891:71-74.

Horowitz, W. 1980. Official methods of analysis of the Association of Analytical Chemists, 13^{th} ed. Assoc. of Official Anal. Chem., Washington D.C., p.15. section 2.058.

Isaac, R.A. and Johnson, W.C., Jr. 1975. Collaborative study of wet and dry techniques for the elemental analysis of plant tissue by atomic absorption spectrophotometry. Assoc. Offic. Anal. Chem. 58:436.

Johnson, J.R. 1991. Nutrient runoff from nurseries- Is it a problem? Proc. Intl. Plant Prop. Soc. 41:428-431.

Karam, N.S. and A.X. Niemiera. 1994. Cyclic sprinkler irrigation and pre-irrigation substrate water content affect water and N leaching from containers. J. Environ. Hort. 12:198-202.

Karla, Y.P. and D.G. Maynard. 1994. A comparison of extractants for the determination of cation exchange capacity and extractable cations by a mechanical vacuum extractor. Commun. Soil Sci. Plant Anal. 25:1505-1515.

Ku, C.S.M. and D.R. Hershey. 1991. Leachate electrical conductivity and growth of potted poinsettia with leaching fractions of 0 to 0.4. J. Amer. Soc. Hort. Sci. 116:802-806.

Marconi, D.J. and P.V. Nelson. 1984. Leaching of applied phosphorus in container media. Scientia Hort. 22:275-285.

Markus, D.K., J.E. Steckel, and J.R. Trout. 1981. Micronutrient testing in artificial mix substrates. Acta Hort. 126:219-235.

Maynard, D.N. and O.A. Lorenz. 1979. Controlled-release fertilizers for horticultural crops. In: J. Janick (ed.). Horticultural Reviews, Vol. 1. AVI Publishing, Westport, Conn.

Milks, R.R., W.C. Fonteno, and R.A. Larson. 1989. Hydrology of horticultural substrates: I. Mathematical models for moisture characteristics of horticultural container media. J. Amer. Soc. Hort. Sci. 114:48-52.

Molitor, H.D. 1990. The European perspective with emphasis on subirrigation and recirculation of water and nutrients. Acta Hort. 272:165-173.

Morvant, J.K. 1995. Effects of irrigation method on plant growth, water and nutrient efficiency, and run-off. M.S. Thesis, Oklahoma State Univ., Stillwater.

Morvant, J.K., J.M. Dole, and E. Allen. 1997. Irrigation systems alter distribution of roots, soluble salts, nitrogen, and pH in the root medium. HortTechnology 7:156-159.

Nelson, P.V. 1991. Greenhouse operations and management. 4th ed. Prentice Hall, Englewood Cliffs, N.J.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus, p. 404-430. In: A.L Page, R.H. Miller and P.R. Keeney (eds.). Methods of Soil Analysis. Part 2. Chemical and Microbial Properties. Amer. Soc. Agron., Inc. and Soil Sci. Amer. Inc., Madison, Wis.

Pill, W.G., S. Bing, H.D. Tilmon, and R.W. Taylor. 1995. Leaching losses and plant uptake of nitrogen in soilless media containing ground kenef (*Hibiscus cannabinus* L.) stem core. J. Hort. Sci. 70:833-840.

Rathier, T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and Alberta spruce under different irrigation and N fertilization regimes. J. Environ. Hort. 7:32-35.

Sanderson, K.C. 1987. Selecting the right fertilizers for container-grown woody ornamentals. Amer. Nurseryman 165(1):160-177.

Spinks, D.O. and W.L. Pritchett. 1956. The downward movement of phosphorus in potting soils as measured by P^{32}. Proc. Fla. State Hort. Soc. 69:385-388.

Stolzenburg, W. 1992. The mussels' message. Nature Conservancy 42(6):17-23.

U.S. Environmental Protection Agency. 1982. Manual of individual drinking water systems. U.S. Environmental Protection Agency, Office of Drinking Water, Washington D.C. EPA-570/9-82-004.

Warncke, D.D. 1986. Analyzing greenhouse growth media by the saturation extraction method. HortScience 21:223-225.

Warncke, D.D. 1990. Testing artificial growth media and interpreting the results, p.337-357. In: R.L. Westerman (ed.). Soil testing and plant analysis. Soil Sci. Soc. of Amer. Inc., Madison, Wis.

Warncke, D.D. and D.M. Krauskopf. 1983. Greenhouse growth media: Testing and nutrition guidelines. Michigan State University Ext. Bul. 736.

Weatherspoon, D.M. and C.C. Harrell. 1980. Evaluation of drip irrigation for container production of woody landscape plants. HortScience 15:488-489.

White, J.W. 1993. Geraniums IV. The grower's manual. 4th ed. Ball Publishing, Geneva, Ill.

Wilkerson, D.C. 1990. Developing a management plan for irrigation runoff. GrowerTalks 53(12):62-68.

Williams, B.J., J.C. Peterson, and J.D. Utzinger. 1988. Liming reactions in sphagnum peat-based growing media. J. Amer. Soc. Hort. Sci. 113:210-214.

Yeager, T.H. and J.E. Barrett. 1984. Phosphorus leaching from ^{32}P-superphosphate-amended soilless container media. HortScience 19:216-217.

Yeager, T. H. and G. Cashion. 1993. Controlled-release fertilizers affect nitrate nitrogen runoff from container plants. HortTechnology 3:174-177.

Yeager, T., R. Wright, D. Fare, C. Gilliam, J. Johnson, T. Bilderback and R. Zondag. 1993. Six state survey of container nursery nitrate nitrogen runoff. J. Environ. Hort. 11:206-208.

Yelanich, M.V. and J.A. Biernbaum. 1990. Effect of fertilizer concentration and method of application on media nutrient concentration, nitrogen runoff and growth of *Euphorbia pulcherrima* 'V-14 Glory'. Acta Hort. 272:185-189.

Yelanich, M.V. and J.A. Biernbaum. 1993. Root-medium nutrient concentration and growth of poinsettia at three fertilizer concentrations and four leaching fractions. J. Amer. Hort. Sci. 188:771-776.

Yelanich, M.V. and J.A. Biernbaum. 1994. Fertilizer concentration and leaching affect nitrate-nitrogen leaching from potted poinsettia. HortScience 29:874-875.

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