Phlox paniculata 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer': Cultural Guidelines for Greenhouse Growth and Powdery Mildew Control

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ABSTRACT

Little information is available about greenhouse production requirements of *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer', both of which are extremely susceptible to powdery mildew. Some plant growth regulators (PGRs) have been reported to reduce severity of certain plant diseases. The objectives of these experiments were to: 1) define optimal fertilizer, irrigation rates, and media types for these cultivars; 2) determine optimal PGR rates for size control; and 3) determine effects of PGRs on powdery mildew severity on inoculated plants grown under optimal greenhouse conditons.

When looking at the variables height, average width, quality rating, and shoot dry weight, *Phlox paniculata* 'Blue Boy' grew best at 200 $mg \cdot L^{-1}$N in Fafard 3B medium and was not responsive to irrigation rate. Also, when looking at the same variables mentioned above, *Rudbeckia hirta* 'Indian Summer' grew best at 300 $mg \cdot L^{-1}$N in Scott's Sierra Perennial Mix at a high irrigation rate. The PGRs chlormequat chloride, daminozide/chlormequat chloride, and paclobutrazol were effective in controlling size of *Phlox*. During the first *Rudbeckia* experiment, paclobutrazol and uniconazole were effective in controlling plant size; in the second experiment daminozide, uniconazole and flurprimidol were effective.

In the fall experiment, 160 $mg \cdot L^{-1}$ paclobutrazol was effective in reducing disease severity in *Phlox*; in the spring experiment, 4000 $mg \cdot L^{-1}$ chlormequat chloride and 60 $mg \cdot L^{-1}$ uniconazole were effective in reducing disease severity. In the *Rudbeckia* fall experiment, 160 $mg \cdot L^{-1}$ of two forms of paclobutrazol were effective in reducing disease severity; in the spring experiment, only one of those forms (Bonzi) was effective.

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Today's Perennial Market

Perennials are becoming increasingly popular additions to our landscapes. In 2003, the USDA reported that total wholesale value of floriculture crops was about $5.07 billion which had fallen in value less than 1% since 2002 (Agricultural Statistics Board, 2003). The wholesale value of herbaceous perennial plants, however, experienced a 1% increase (since 2002) to $620 million. A survey performed by Behe et al. (2001a) reported that in 2000, garden plant (including annuals and perennials) sales averaged $2.2 million out of average total gross sales of $2.4 million for the United States horticulture industry. The participants in that same survey reported *Phlox* and *Rudbeckia* as two species in the list of top ten perennials (Behe et al., 2001b). The plants were "graded", 1=A or excellent, and 2=B or very good. *Phlox* received a 2.2 and *Rudbeckia* received a 1.8. Bedding plant sales have continued to increase for many years; however, that rate has begun to slow down. Future sales depend upon the economy as a whole. A recession could help out the industry, keeping more people at home and interested in tending their landscapes.

Introduction

Phlox paniculata and *Rudbeckia hirta* are popular native North American wildflowers, grown for their showy inflorescences (Ellis, 1999 and 2000). In the greenhouse, both quickly outgrow their containers if not controlled. Growth regulators are successful in controlling height of many herbaceous perennials. Unfortunately, some selections of *Phlox paniculata* and *Rudbeckia hirta* are extremely susceptible to powdery mildew (Chase et al., 1995), and the disease can have devastating effects, which can cause severe financial loss to a grower. Fungicides are available for control but often become a costly management practice. Some plant growth regulators (PGRs), which are applied to plants for height control, are known to have fungicidal properties. The purpose of this project is to investigate the value of these PGRs as secondary agents for the control of powdery mildew. Effective chemicals and rates will be determined and applied under optimal growing conditions. From a grower's standpoint, this will ultimately lead to production of the highest quality plant in a greenhouse setting. Agriculture as a whole will benefit by providing growers with more information to grow the best crops with minimal financial loss. Also, since plants have the best chance of fighting off a pathogen when growing under the least stressful cultural conditions or practices, the best fertilizer rates, irrigation rates, and media types will be determined to optimize growth during production.

Phlox paniculata **'Blue Boy'**

Phlox paniculata is a widely grown perennial in the Polemoniaceae family (Nau, 1996). The cultivar Blue Boy is one of the *P. paniculata* cultivars that is closest to a true blue color. When in flower, the plants reach 75 to 90 cm in height. The plants prefer warm, dry areas. This particular cultivar was chosen for our study because it has been shown to be extremely susceptible to powdery mildew (R. Bir, personal communication) (Bir and Conner, 2002).

Planting cultivars resistant to powdery mildew is the best way to reduce infection on plants. A few powdery mildew resistant *Phlox paniculata* cultivars include Starfire, David, Orange Perfection, Prime Minister, Bright Eyes and Rosalinde (UMASS Extension, 2003). Different cultivars have different levels of resistance. A resistant cultivar can still get powdery mildew, but the symptoms are generally less severe, and the rate of infection is usually slowed.

Rudbeckia hirta **'Indian Summer'**

Rudbeckia hirta, a member of the Asteraceae family, is a native plant that is known for its sensitivity to powdery mildew (Nau, 1996). The cultivar Indian Summer was an All-America Selections Award winner and has large golden orange flowers on plants that grow to heights of 76 to 91 cm. The plants perform best in full-sun. 'Indian Summer' was chosen for our experiments because it is susceptible to powdery mildew, and because it is one of the taller *R. hirta* cultivars, it would be advantageous to identify the plant's response to PGRs.

Rudbeckia is important in the horticulture industry because it is an adaptable and attractive native plant that requires little maintenance (Fulcher et al., 2003).

Cultural Conditions

Not a lot of cultural information is known about perennials because relatively little research has been conducted on them until recently (Pilon, 2002a).

Fertilization. Seventeen essential elements are required by plants for growth and development, and three of these are obtained by air and water (carbon, hydrogen, and oxygen) (Reed, 1996). The 14 remaining essential elements are referred to as nutrients (divided into two groups, macronutrients and micronutrients) and are supplied as fertilizers. Growing medium, irrigation, and fertilizer must be managed properly so that the minerals required for plant growth can be taken up by the plant in the correct amounts (Nelson, 1980).

The amount of fertilizer that needs to be applied to a crop is dependent on the crop being grown because some crops have a greater need for nitrogen than others (Boodley, 1996). It is also important to take into consideration the stage of development of the plant. For example, young, tender seedlings need little fertilizer, and are very sensitive to fertilizer salts (Nelson, 1994). A lack of fertilizer does not limit root growth, except in some extreme situations, but roots can become severely damaged when too much fertilizer is applied (Nelson, 1980). According to Nelson (1980), since roots are the means of fertilizer uptake, a major concern is to maintain continuous root growth.

Water-soluble fertilizers are used most frequently in the fertilization of bedding plants (Armitage, 1994). The fertilizers generally come in a concentrated mix and are diluted before being applied to the plants. With the loss of minerals from the media, there is good reason to apply some fertilizer with each irrigation (Nelson, 1980). The frequent, small applications of minerals should provide a uniform source of nutrients required by plants, if handled properly.

Nutrient availability in the soil varies with the pH (Nelson, 1980), and nitrogen fertilizers can change the pH of the soil (Boodley, 1996). pH refers to the logarithm of the reciprocal of hydrogen ion activity, which means it is a measure of the alkalinity or acidity of water (Armitage, 1994). The scale extends from 1 to 14, where a neutral pH lies at 7.0. A pH greater than 7.0 is considered basic, and below 7.0 is considered acidic. A pH that is too low or too high can make some nutrients unavailable to the plant. Optimal media pH for production of perennial plants is generally within a range of 5.6 to 6.3 (Pilon, 2002b). The pH level of water by itself is not that important, but it may adversely affect the pH level of the substrate (Nelson, 1994).

Electrical conductivity (EC) is a measure of the soluble salts level or the salinity of water (Dole and Wilkins, 1999). The higher the soluble salt concentration is, the more easily an electrical current can pass through a solution, giving a higher EC reading. Water with a low EC (0.1 to 0.5 dS/m) will reduce future problems from a buildup of soluble salts in the medium. Tolerance to high soluble salts levels in the medium varies with plant species. A plant's growth may be stunted, and marginal necrosis of the leaf can occur on plants with lower tolerances. Frequent leaching can help manage high salt levels. An EC of 0.75 to 1.5 $mS \cdot cm^{-1}$ is a generally acceptable range for nursery crops (including herbaceous plants) to grow when calculating EC using the Virginia Tech Extraction Method (University of Georgia Fact Sheet). The suggested EC target range for growing *Phlox* is a PourThru EC of 2.0 to 3.5 $mS \cdot cm^{-1}$ (Whipker et al., 2000).

Irrigation. Water plays a critical role in the growth and development of plants. A plant's need for water is greater than that of any nutrient (Boodley, 1996). A plant can contain as little as 10% water when it is in the form of a seed, or as much as 95% of its fresh weight in water in leafy, succulent plants, such as lettuce and cabbage. On average, a plant will absorb 500 units of water for each unit of dry weight produced, a ratio commonly known as the water requirement of the plant. The amount of irrigation controls plant growth, plant size, and quality (Langhans and Paparozzi, 1994). Physiologically, water is very important to a plant (Kramer, 1995). It serves several major functions: 1) water is a major constituent of plants; 2) water acts as a solvent in plants in which gases, minerals, and other solutes are able to enter plant cells; 3) water is a reactant in many critical processes, including photosynthesis; and 4) water helps the plant to maintain turgor which is important in the opening and closing of stomata, where transpiration and gas exchange takes place.

Most of the water a plant takes up is through the roots; however, some water is absorbed through the leaves and stems (Boodley, 1996). Plants take up more water than the amount of water of which they are composed because most of the water is lost through the stomata by transpiration or the evaporation of water from the surface of leaves and stems (Nelson, 1980). Leaves are cooled as water evaporates from the stomates, which is why transpiration is so important (Langhans and Papzrozzi, 1994). Nutrients dissolved in solution are carried to plant cells by the transpiration stream. Transpiration is also important in carbon dioxide uptake. A small amount of water is held onto by the cells, creating a pressure that allows the cells to enlarge and permits the plant to grow. This is known as turgor pressure, and gives stems and leaves support. By limiting water, this pressure is lost, and a plant will wilt. By denying a plant water, growth is essentially reduced and damage can occur to the plant, resulting in an overall lower quality. However, overwatering can also produce adverse effects. It is possible for a medium to be completely saturated with water, and yet that water cannot be absorbed by the plant. This is because roots, as living tissues, need an adequate supply of oxygen for growth (Boodley, 1996). If too little oxygen is available to those roots, injury and eventual death can occur. An even smaller amount of water than that used for turgor pressure is used in photosynthesis (Langhans and Papzrozzi, 1994). The sugars created during photosynthesis are used as a source of energy for plant growth and development.

Irrigation frequency is based on the type and size of plant being grown (Nelson, 1980). Certain plants require more water than others, while other plants are sensitive to a limited air supply in the medium caused by too much water. Smaller plants require less water than larger plants, and different stages of plant growth require different quantities of water. For instance, a plant requires less water during bud formation than when it is in full flower. Whether applied with or without the addition of fertilizers, the amount of irrigation water applied to a crop affects nutrient and salt levels that are retained in the media (Pilon, 2002b). The amount of water lost from the container by leaching is referred to as the "leaching fraction", and at low leaching fractions more nutrients and salts are held on to by the media. Increasing the leaching fraction is important in order to remove increasing salt levels from the media before they reach a dangerous level.

Media. A medium is an environment in which a crop can grow or flourish (Boodley, 1996). No single growing medium is best for the production of bedding plants (Fonteno, 1994). Plants can be successfully grown in an assortment of media. A medium must provide water, supply nutrients, permit gas exchange to and from the roots, and provide support for the plant.

Plant roots must be provided water and air through the medium in which they are growing (Dole and Wilkins, 1999). Pore spaces within a medium accomplish both objectives at once, and total pore space within a medium is referred to as total porosity. Small micropores retain water after irrigation is completed, while the water filling the larger macropores drains out of the bottom of the pot due to gravitational pull. The majority of organically-based substrates contain between 75% and 85% pore space (Fonteno, 1994). The majority of soilless media available contains a total pore space of about 40% to 70%, which, after irrigation, should be between 10% and 30% (Pilon, 2002b). A media with a total porosity of 50% to 60% (or 20% to 25% after irrigating) is adequate for perennial production. Container capacity is the amount of water held in a container after a plant has been irrigated and free water has drained away (Dole and Wilkins, 1999). The key to optimum plant growth is to maintain a balance between the water-holding capacity and aeration (Pilon, 2002b).

A medium's bulk density refers to dry weight relative to the volume (Dole and Wilkins, 1999). Sand has a high bulk density while perlite has a low bulk density. Substrates for bedding plants should have a light bulk density to ease shipping and handling (Fonteno, 1994).

Media are commonly composed of two or more of the following components: mineral soil, sand, sphagnum peat moss, vermiculite, pine bark, perlite, polystyrene beads, and rockwool (Fonteno, 1994). Peat moss is a component that can provide a medium with excellent water-holding capacity (Pilon, 2002b). Components such as bark and perlite encourage drainage.

Plant Growth Regulators

Plant growth regulators (PGRs) are used in agriculture to increase production efficiency (Steffens, 1980). The earliest successful application of PGRs dates back to the 1930's and involved the use of auxins for promoting root formation on cuttings (Bruinsma, 1982). Many of the PGRs most widely used in agriculture are used in the horticulture industry on high-value crops. Most affect plant morphology and are not directly linked to increased yields (Steffens, 1980). PGRs are used extensively throughout the floriculture industry, primarily to control plant height (Gent and McAvoy, 2000). Most growth retardant-type PGRs cause dwarfing in plants by inhibiting gibberellin biosynthesis. Gibberellins promote stem elongation and cell division in plants. Growth retardants reduce internode elongation, resulting in more compact, desirable plants. These chemicals are primarily used to control stem elongation of ornamental plants growing in containers during crop production, shipping, and marketing. When using PGRs, ornamental bedding plant quality is commonly enhanced by keeping plants compact, which, in turn, reduces bench space for production (Rademacher, 2000). Growth regulators also make most plants appear darker green in color (Davis and Andersen, 1989). PGRs can be applied as sprays, sprenches, drenches, and even as bulb or liner soaks.

Cycocel, B-Nine, TopFlor, Bonzi, Piccolo, and Sumagic are all trade names of the PGRs that were used in this study. They were applied as foliar sprays.

Chlormequat chloride (Cycocel, Olympic Horticultural Products Co., Mainland, PA) [(2-chloroethyl) trimethylammonium chloride]: The first report on the activity of chlormequat was in the early 1960's (Steffens, 1980). Chlormequat has been used for a number of years in the floriculture industry (Latimer et al., 2001), and is perhaps the most extensively used PGR in agriculture where its primary use is to manage lodging of grain crops (Davis and Andersen, 1989). Chlormequat can be phytotoxic to plants even when applied at low rates. Except for specific crop uses (*Pelargonium* x *hortorum* Bailey, *Hibiscus rosa-sinensis* L., and *Euphorbia pulcherrima* Willd.), chlormequat is rarely used alone; it is generally combined with daminozide, creating a tank mix that is more effective in retarding growth than either chlormequat or daminozide used individually. The chemical is, for the most part, not persistent; therefore, multiple applications may be necessary when growing a crop over a long period of time (Davis and Andersen, 1989). In studies with *Canna* x *generalis* L. H. Bailey 'Florence Vaughan', a daminozide /chlormequat tank mix ranging from 2500/1500 to 7500/1500 ppm effectively controlled vegetative growth when applied as a foliar spray, and was more effective at the higher rates (Bruner et al., 2001). At 30 days after treatment (DAT), heights of treated plants were 5% to14% less than untreated plants. Vegetative shoot heights of *Dianthus* 'Snowfire' (taxonomy unknown) were significantly less relative to nontreated controls in plants treated with 1500, 3000, or 6000 ppm chlormequat as a foliar spray (Messinger and Holcomb, 1986). All plants treated with the chemical had symptoms of phytotoxicity, ranging from minor leaf curling at 1500 ppm to chlorosis and necrosis of the leaves at 6000 ppm.

Daminozide (B-Nine, Uniroyal Chemical Co., Inc., Middlebury, CT) [butanedioic acid mono (2,2-dimethylhydrazide)]: The most commonly used PGR in floriculture is daminozide, which is generally not phytotoxic to plants and has a low activity, meaning multiple applications are usually necessary (Latimer et al., 2001). Daminozide was first reported to be active in the early 1960's (Steffens, 1980). This chemical is used in many aspects of horticulture because of its low cost and long history of use (Gent and McAvoy, 2000). Its primary use in agriculture was on tree fruits; however, its safety for use on edible crops was questioned resulting in its removal from that market (Davis and Andersen, 1989). Daminozide applications applied alone or in combination with chlormequat, ranging from 1000 to 5000 ppm, were successful in reducing height of *Salpiglossis sinuata* R. *et* P. when applied foliarly (Needham and Hammer, 1990). Two or three foliar applications of daminozide at 5000 ppm and three applications at 2500 ppm restricted growth of *Salpiglossis* by 12%, 34%, and 16% respectively; however, the applications at 5000 ppm also restricted corolla diameter by 44%. Burnett et al. (2000) found that shoot height of 'American Dream' pink coreopsis (*Coreopsis rosea* Nutt.) was suppressed 17% to 29% with applications ranging from 2500 to 7500 ppm daminozide, and plant quality increased 52% to 61% with an increase in application rate compared to the controls.

Flurprimidol (TopFlor, SePRO Corp., Carmel, IN) ((α-1-methylethyl)-α4-(trifuloromethoxy) phenyl-5-pyrimidinemethanol): TopFlor is registered for use on floriculture crops in the European market, but here in the United States, flurprimidol has been used for many years in the turf market under the name Cutless (Dow AgroSciences, LLC, Indianapolis, IN). Introduced in the 1980's, flurprimidol has an activity similar to that of the triazole chemicals and may be quite persistent (Davis and Andersen, 1989). McDaniel (1986) found flurprimidol to be effective in suppressing plant height to 46 to 50 cm compared to the average of 64 cm of the control with a

25 or 12.5 ppm foliar spray on 'Annette Hegg Dark Red' poinsettia (*Euphorbia pulcherrima* Willd.). At the 50 ppm rate, foliage puckering was noticed. At high rates, flowering was delayed up to 5 days, and significant decreases in stem dry weights and inflorescence diameters were observed. On *Canna* x *generalis* 'Florence Vaughn', Bruner et al. (2001) found that flurprimidol suppressed vegetative height 20% to 39% and 21% to 33% at first and second flower with increasing rates of 15 to 45 ppm compared to the controls. Increasing rates of flurprimidol reduced shoot height at first flower of *Coreopsis rosea* 'American Dream' 13% to 34% at rates ranging from 25 to 150 ppm (Burnett et al., 2000). Control plants were considered unmarketable, while those treated with the PGRs were considered marketable based on visual observations.

Paclobutrazol [Bonzi (Syngenta Turf and Ornamentals, Greensboro, NC) and Piccolo (Fine Agrochemicals, Worcester, UK)] [(±)-(R*,R*)-β-((4-chlorophenyl) methyl)-α-(1,1,-dimethylethyl)-1H-1,2,4,-triazole-1-ethanol)]**:** This chemical belongs to a class of PGRs known as triazoles. It originated in the 1980's, and is highly active in small doses (Davis and Andersen, 1989). Generally, only one application is necessary, due to its persistence. In a study by Gad and Gerzson (1997), paclobutrazol was applied as a foliar spray at rates of 0, 250, 500, or 1000 ppm to rooted tip cuttings of *Rudbeckia laciniata* L., and plant height was suppressed by 54.1%, 59.6%, and 66.7%, respectively. The shortest plants were those treated with 1000 ppm. Internode lengths also decreased as the rate of paclobutrazol increased. Plant fresh weight decreased when using the PGR, but there was no significant effect on leaf number or number of branches per plant. Banon et al. (2002) found paclobutrazol drenches to be effective in controlling plant height of *Dianthus caryophyllus* L. cv. Mondriaan with height reductions of 9.2% to 45.2% at rates of 0.16, 0.35, 0.51 and 0.65 mg of the active ingredient per pot. A darkening of the foliage, quantified with a colorimeter, was also characteristic of the treated plants. Paclobutrazol greatly suppressed growth of *Chrysanthemum coreanum* L. 'Jantar', *Phlox* sp., and *Dahlia* sp. (tuberous dahlia) sprayed with 25 to 50 ppm (Rounkova, 1989). *Lantana camara*, treated as a drench at rates of 0, 20, 40, 80, and 160 ppm paclobutrazol, had a smaller growth index in comparison to the controls, and all treated plants had more flowers than untreated ones (Matsoukis et al., 2001). The growth index was calculated by adding the height to the maximum plant diameter, the perpendicular width, and the maximum plant diameter, then dividing the sum by three. Foliar applications of paclobutrazol (12.5 to 100 ppm) reduced plant height of *Euphorbia pulcherrima* 'Eckespoing C-1 Red', 'Annette Hegg Dark Red', and 'Gutbier V-Glory' (McDaniel, 1986). Desirable plant heights of 42 to 50 cm of the poinsettia plants were achieved with applications of 25 to 50 ppm paclobutrazol, whereas a foliar spray of 100 ppm often resulted in misshapen leaves, reducing overall plant quality. Latimer (1991) found that *Zinnia elegans* Jacq. 'Peter Pan Scarlet' seedlings responded to treatments of paclobutrazol at 40 or 90 ppm with stem length reductions of 30% and 51% respectively. In the same experiment, stem elongation in *Impatiens wallerana* Hook 'Accent Red' was significantly reduced (by 32%) with 20 ppm paclobutrazol. Stem length and leaf area of marigold (*Tagetes erecta* L.) 'Papaya Crush' seedlings treated with 40 ppm were 16% to 24% less than controls. Zinnia and marigold experienced increased root growth in response to the lower rates of paclobutrazol.

Uniconazole (Sumagic, Valent USA, Marysville, Ohio) ((E)-1-(P-chlorphenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl-1-penten-3-ol)): Uniconazole is a much more active chemical than paclobutrazol, sometimes resulting in extreme stunting (Latimer et al., 2001). Because uniconazole is also a triazole, it shares many of the characteristics of paclobutrazol. Uniconazole has been around since the 1980's. It is highly active in small doses and generally only one application is necessary due to its persistence. In an experiment by Needham and Hammer (1990) of Purdue University, uniconazole applications of 10, 20, 40, or 100 ppm were unsuccessful in controlling height of *Salpiglossis sinuata* R. *et* P. Uniconazole suppressed the growth of *Canna* x *generalis* 'Florence Vaughan' by 28% to 33% at 30 days after treatment and 50% to 52% at 60 days after treatment with rates ranging from 20 to 60 ppm (Bruner et al., 2001). Along with height suppression came a change in leaf orientation and a reduction in the number of inflorescences that was considered excessive, reducing marketability of the plants. Uniconazole foliar spray at rates of 10 to 40 ppm reduced shoot height of *Coreopsis rosea* 'American Dream' by 25% to 31% at first flower compared to controls (Burnett et al., 2000). Plant quality also increased with an increase in application rate (57% to 61% higher than controls). Plants appeared darker green, less leggy and more densely branched, and had more flowers than controls.

Powdery Mildew

Some selections of *Phlox paniculata* and *Rudbeckia hirta* are highly susceptible to powdery mildew infections (Chase et al., 1995). *Golovinomyces magnicellulatus* (U. Braun) VP Gelyuta is the powdery mildew pathogen that attacks *Phlox paniculata*, and *Golovinomyces* *cichoracearum* is the pathogen that attacks *Rudbeckia hirta*. Powdery mildew is a fungus that is an obligate parasite, meaning it requires a living plant host to complete its life cycle (Daughtrey et al., 1995). Because the symptoms are apparent and unattractive, powdery mildew is probably one of the most troublesome diseases of annuals and perennials (Chase et al., 1995). Powdery mildew infection rarely kills plants, but aesthetic value of the plants is frequently reduced (Coyier, 1985). New growth, stems, flowers or fruit are usually attacked, although older tissues can often be more susceptible on certain plants. Powdery mildew produces distinguishable whitish, powdery growth on the host plant (Dole and Wilkins, 1999). The pathogen is generally found on the upper leaf surfaces, but can occur on the undersides (Daughtrey et al., 1995). The disease looks very similar regardless of the type of plant affected; even so, different species of the powdery mildew fungus are responsible for infections on different plants (Chase et al., 1995). Thus, having one species of plant infected with powdery mildew will not necessarily mean that another species of plant growing nearby will become infected. All powdery mildews react similarly to environmental factors and fungicidal controls.

Symptoms of powdery mildew occur later in the year during drier conditions, rather than during the rainy days of spring (Chase et al., 1995). The powdery mildew fungus sporulates when humidity is high rather than when the leaves are wet. The fungus rarely germinates in free water (Daughtrey et al., 1995). Most powdery mildews on greenhouse crops develop best at humidities greater than 95% and at an optimum temperature of 20ºC. In the greenhouse, powdery mildew is generally spread by air currents and splashing water.

The mycelium of powdery mildew grows on the surface of the host tissue (Daughtrey et al., 2004). Haustoria, or specialized feeding structures, penetrate the epidermis of the host. Conidiophores develop from the mycelium located on the host surface during the entire growing season, producing infective conidia one at a time or in short chains. The spores are typically released following a diurnal pattern with the highest number of conidia released around midday due to a decrease in relative humidity. Many species of the *Erysiphales* (the old comprehensive grouping of powdery mildews) need two compatible individuals to mate before asci can be formed. Compatibility is determined genetically by the mating type locus. Once mating is complete, usually near the end of the summer, ascomata are made on the outer surface of the host. They can be important in the overwintering of the fungus in temperate climates.

Appendages on the ascocarps assist in dispersal by allowing them to adhere to plant surfaces and leaf hairs.

Powdery mildews are identified by looking at the morphology of cleistothecial appendages, number of asci within the cleistothecium, number and shape of conidia, type of conidial germination, germ tube characteristics, and host plant species (Daughtrey et al., 1995). Recently, however, scanning electron microscopy (SEM) and molecular examinations provided better insight into the phylogenetic interpretation of the genus *Erysiphe* (Braun et al., 2002).

Powdery Mildew Control and Cultural Conditions

One way to control powdery mildew through cultural practices is to increase air flow around the plants since that will decrease relative humidity (Daughtrey et al., 1995). Irrigating plants overhead, especially late in the day, keeps humidity around the plants high, promoting the disease (Chase et al., 1995). The use of resistant cultivars, when available, allows the crop to be grown in the presence of the pathogen with minimal loss and minimal chemical applications. Today, fungicides have become the most common means of treating powdery mildew (Daughtrey et al., 1995).

Fertilization can also play a role in the rate of infection. In an experiment performed by David et al. (2003), greenhouse-grown *Hiemalis* begonia (*Begonia* x *Hiemalis* Fotsch 'Hilda') were grown at three N rates. The results determined that high N fertilizer rates could be a contributing factor in the development of powdery mildew on those plants, and the high rate of N caused powdery mildew severity to be greater than disease severity of the control plants. This was not the case, however, with *Vitis vinifera* L. 'Sauvignon Blanc' that were fertigated with various concentrations of N:P:K (Reuveni, et al., 1993). The vines that had been fertilized at a low NPK concentration were significantly more susceptible to powdery mildew than those that were fertilized at high levels.

Higher levels of irrigation were unfavorable to the development of powdery mildew on hybrid squash (*Cucurbita maxima* Duchesne x *Cucurbita moschata* Duchesne ex Poir.) (Coelho et al., 2000). In contrast, powdery mildew severity increased at higher irrigation levels on mustard (*Brassica juncea* L.) (Nakhate et al., 1996).

Experiments have not yet been performed on the effects of media type on powdery mildew severity.

Plant Growth Regulators and Disease Control

A group of triazole derivatives has been developed for use as either fungicides or as plant growth regulators (Fletcher et al., 1986). To varying degrees, the chemicals exhibit both fungicidal and growth regulating properties. Fletcher et al. (1986) state that the triazole derivatives are equally effective as plant growth regulators or fungicides, suggesting that such chemicals may be broad-spectrum biocides, and appear to have similar modes of action to one another. Paclobutrazol, which belongs in the class of triazoles, has delayed the onset of wilting and reduced the incidence of fusarium wilt (*Fusarium oxysporum* f. sp. *melonis*) on melon (*Cucumis melo* L. cv. Ananas Yoqneam) seedlings (Cohen, 1987). Total wilt incidence was significantly reduced, and paclobutrazol delayed the appearance of wilt symptoms during the first 10 days. The author suggests this resistance to wilt is due to an effect the compound has on the metabolic processes of the plant, not directly due to a chemical effect on the pathogen. Paclobutrazol has also been tested on black spruce (*Picea mariana* (Mill.) B. S. P.) seedlings where it helped to control the environmental predisposition of the seedlings to infection, as well as decreased sporulation of *Botrytis cinerea* (Zhang, 1994). The environmental stresses that predispose the spruce seedlings to disease are the stresses associated with high temperature plus darkness, as well as drought. Zhang et al. (1994) believe paclobutrazol to be effective in decreasing *Botrytis* sporulation, not because of its fungicidal properties, but because it offers stress protection. An experiment performed by Blaedow et al. (2003) showed that a one-time foliar application of paclobutrazol (0.02 g a.i. ml^{-1}) reduced the severity of apple scab (*Venturia inaequalis*) on two mature crabapple (*Malus* sp. P. Mill) cultivars, Hopa and Snow Drift, and on 'Indian Magic' saplings. Flurprimidol and paclobutrazol significantly lowered disease ratings (dy/dt, where y = amount of disease and t = time) of dollar spot (*Sclerotinia homeocarpa* F. T. Bennett) epidemics in creeping bentgrass (*Agrostis palustris* Huds. cv. Penncross) compared to non-treated turf (Burpee et al., 1996). The authors suggest dollar spot was suppressed by paclobutrazol and flurprimidol primarily as a result of fungistatic activity because both are chemically related to fungicides that are inhibitors in the fungal sterol biosynthesis pathway. However, Burpee et al. (1996) also suggest that changes in environmental effects due to inhibition of shoot growth, such as changes in canopy temperature and duration of leaf wetness, cannot be ruled out. The results of an experiment performed by Copas and Williams (1987) led these researchers to believe that growth regulator sprays of paclobutrazol to the foliage of cider apple (*Malus* sp.) cvs. Michelin and Sweet Coppin for control of vegetative growth could have additional advantages in orchards infected with *Chondrostereum purpureum*, the cause of silverleaf. Research conducted by Rempel and Hall (1995) reported that split applications of uniconazole reduced blackleg (*Leptosphaeria maculans* (Desm.) Ces & de Not.) of canola (*Brassica napus* L.). *Rudbeckia hirta* L. 'Plainview Farm' plants treated with a drench at rates of 4 ppm (120 mL/pot) paclobutrazol did not have powdery mildew, but the controls did (Yang and Zhang, 2003).

On the other hand, some studies have shown no effect of PGRs on the control of disease. Paclobutrazol and flurprimidol applied individually to tall fescue (*Fetusca arundinacea* Schreb., cv. Rebel II) showed no significant decrease in the incidence of Rhizoctonia blight (*Rhizoctonia solani*) (Burpee, 1998). The author suggested that higher rates of the PGRs could have had suppressive effects on the disease. Chlormequat and ethephon applied to the spring wheat (*Triticum aestivum* L.) cultivar Max had no significant effect on the progress of head blight, caused by *Fusarium graminearum* (Fauzi, 1994). Fauzi (1994) suggests this may have to do with unfavorable environmental conditions the year the experiment was performed. Daminozide, when applied to potato (*Solanum tuberosum* L.), stunted the plants, causing them stress as well as providing no protection against Verticillium wilt (*Verticillium dahliae* Kleb.) (Corsini, 1989).

Rationale

Powdery mildew can be a severe problem in a greenhouse setting. We have found no previously published research specifically addressing the effects of plant growth regulators on disease severity of powdery mildew on *Phlox*, but we have found limited information on *Rudbeckia* (Yang and Zhang, 2003). Also, most of the current literature in this area relates to field crops, not ornamentals. The objective is to narrow down specific PGRs and rates that can be applicable to growers growing containerized *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer' in the greenhouse. This information would be useful for times of the year when the plants being grown are most susceptible to powdery mildew, when PGRs that are already being sprayed on the *Phlox* and *Rudbeckia* for size control can be used secondarily to reduce or eliminate the use of fungicides. Since plants have the best chance of fighting off pathogen attack by growing in the least stressful conditions, the best media type, irrigation frequency, and fertilizer rates will be determined to minimize stress during production.

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Chapter Two: Optimal greenhouse cultural requirements for *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer'

Abstract. *Phlox* and *Rudbeckia*, popular native North American wildflowers, are grown for their showy inflorescences. Little cultural research has been performed on *Phlox paniculata* and *Rudbeckia hirta* cultivars for greenhouse production. Three greenhouse experiments with *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer' were conducted in Summer 2003 to determine optimal fertilizer rate, irrigation rate, and media type for each of the species. Four fertilizer rates (0, 100, 200, and 300 mg·L^{-1} N), three irrigation rates (Low: plants watered when average moisture content of medium reaches 20% or below; Medium: 30% or below; High: 40% or below), and four media types (Fafard 3B, Daddy Pete's, Fafard 52, and Scott's Sierra Perennial Mix) were evaluated in separate experiments. Height, average width, and quality ratings (on a scale of 0 to 4, 0=dead, and 4=healthy, vigorous growth) were measured for all plants. Media pH and electrical conductivity (EC) were also measured. *Phlox* plants were harvested at 6 weeks after treatment (WAT), and *Rudbeckia* plants were harvested at 4 and 5 WAT. Shoot dry weights were measured. The 200 mg·L^{-1} N treatment produced plants with significantly greater average widths, quality ratings, and shoot dry weights in the *Phlox* experiment. The 300 mg·L^{-1} N treatment produced plants with the greatest height, average width, quality rating, and shoot dry weight in the *Rudbeckia* experiment. In the *Phlox* irrigation experiment, the plants overall did not seem to be responsive to irrigation rate. Media pH and EC were also significant over time. At 6 WAT, the low irrigation rate had the highest EC levels, while the high rate had the lowest EC levels. For the *Rudbeckia* experiment, the highest irrigation rate produced the tallest plant with the highest quality rating and the greatest shoot dry weight. Media type significantly affected shoot dry weight in the *Phlox* experiment, with the Fafard 3B media resulting in plants with the highest dry weights. The Fafard 3B treatment also tended to have plants with the greatest heights, average widths, and quality ratings. The Scott's Perennial Mix produced the plants with the greatest dry weights in the *Rudbeckia* experiment, and tended to produce plants with greater heights, average widths, and quality ratings in comparison to the other treatments.

Introduction

Phlox paniculata and *Rudbeckia hirta* are popular native floriculture crops. The cultivar Blue Boy is one of the *P. paniculata* cultivars that is closest to a true blue color (Nau, 1996). The cultivar Indian Summer of *Rudbeckia hirta* was an All-America Selections Award winner and has large golden orange flowers (Nau, 1996).

Perennials are becoming increasingly popular additions to our landscapes. In 2003, the USDA reported that total wholesale value of floriculture crops was about $5.07 billion (Agricultural Statistics Board, 2003). The wholesale value of herbaceous perennial plants experienced a 1% increase (since 2002) to $620 million. A survey performed by Behe et al. (2001a) reported that in 2000, garden plant (including annuals and perennials) sales averaged $2.2 million out of average total gross sales of $2.4 million for the United States horticulture industry. The participants in that same survey reported *Phlox* and *Rudbeckia* as two species in the list of top ten perennials (Behe et al., 2001b). The plants were "graded", 1=A or excellent, and 2=B or very good. *Phlox* received a 2.2 and *Rudbeckia* received a 1.8. Bedding plant sales have continued to increase for many years. Future sales depend upon the economy as a whole. A recession could help out the industry, keeping more people at home and interested in tending their landscapes.

Traditional cultural practices (fertilizer, irrigation, and media) used with greenhouse crops are not always sufficient with many of our perennial crops (Pilon, 2002b). Not a lot of cultural information is known about perennials because relatively little research has been conducted on them until recently (Pilon, 2002a). *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer' are two such crops where little to no cultural information is available for their production in a greenhouse setting. Growing medium, irrigation, and fertilizer must be managed properly so that the minerals required for plant growth can be taken up by the plant in the correct amounts (Nelson, 1980).

Therefore, the objective of the following experiments was to determine optimal fertilizer rates, irrigation rates, and media types for greenhouse production of *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer', in order to define possible guidelines for growers to follow.

Materials and Methods

All experiments below were conducted in glass greenhouses at Virginia Polytechnic Institute and State University using plugs of *Phlox paniculata* L. 'Blue Boy' and *Rudbeckia hirta* L. 'Indian Summer' (72 cells/tray; Yoder Green Leaf Perennials, Leola PA), that were grown at a daytime temperature range of 26 to 33ºC (79 to 91ºF) and a nighttime temperature range of 18 to 22ºC (65 to 71ºF). The plugs were planted in 10.8 cm (4.25 in) diameter (1180 cm^3) plastic containers on 11 June 2003. Plants were fertigated with 15N-2.2P-12.5K (15-5-15) Peter's Cal Mag (The Scotts Co., Marysville, OH) over the course of each experiment.

Heights were measured from the rim of the pot to the highest point of the plant. Average widths were obtained by measuring the maximum width of a plant, then taking another width measurement perpendicular to the initial measurement, and averaging the two numbers.

Quality ratings were also taken. These ratings were based on what we determined was acceptable for the sale of a plant based on commercial standards. Each plant was given a rating of 0 to 4, comparing plants within a species. A plant was rated according to the following standards: 0=dead; 1=barely alive; 2=acceptable but not thriving; 3=looks good, very little chlorosis or necrosis; 4=excellent, healthy and vigorous growth. The plants were not necessarily rated based on the overall quality of the group of plants, but instead how an optimal quality plant would appear.

Media pH and electrical conductivity (EC) were monitored using the PourThru method (Whipker et al., 2000). The PourThrus were not performed all at once because plants were watered according to treatment, so they were executed across the week when a specific treatment was watered.

Plants were harvested by removing shoots at the soil line. Each plant was placed in its own paper bag and put into a dryer that was kept at an average temperature of 65.5ºC (150ºF). The shoots were removed from the dryer when they had dried completely, generally two to three days, then dry weights were measured. The *Rudbeckia* experiments were terminated sooner than the *Phlox* experiments because they quickly outgrew their containers.

Each species of plant was treated as a separate experiment. The experiments were arranged in a completely randomized design with six single plant replicates. Data were analyzed using the Statistical Analysis System (SAS) Version 8 (SAS Institute, Inc., Cary, N.C.).

Fertilizer Rate. Plugs were potted in Fafard 3B media [(45% peat moss, 25% pine bark, 15%

perlite, and 15% vermiculite) (Conrad Fafard, Inc. Agawam, MA)]. The plugs were grown for two weeks to allow for the starter charge of the media to diminish before beginning treatments, and plants were irrigated with clear water until treatments began. The experiments began 25 June 2003. Four fertilizer rates/treatments were used, with 15-5-15 Cal Mag: 0 $mg \cdot L^{-1}$ N, 100 $mg \cdot L^{-1}$ N, 200 $mg \cdot L^{-1}$ N, and 300 $mg \cdot L^{-1}$ N. There were a total of 24 plants in each species. Plants were hand-irrigated with 350 mL when moisture content of the media reached 30% or below, measured by the ThetaProbe (ML2x; Delta-T Devices Ltd, Cambridge, U.K.). The ThetaProbe measures volumetric soil moisture content, which is the ratio between the volume of water present in the soil and the total volume of the soil sample. The 350 mL amount was determined by factoring in a 20% to 30% leaching fraction when irrigating. This leaching fraction was monitored over the course of the experiment. All plants in a treatment were tested daily, and if 50% of the plants in a specific treatment had reached the treatment threshold, then all plants of that treatment were irrigated.

Media pH and electrical conductivity (EC) were monitored at weeks 2, 4, and 6 for *Phlox* and weeks 2 and 4 for the *Rudbeckia*. Initial plant heights were measured prior to treatment. Plant heights, average widths, and quality ratings were taken at harvest time. Shoots were harvested 6 weeks after treatment (WAT) (6 August 2003) for *Phlox* and 4 WAT (23 July 2003) for *Rudbeckia*. Dry weights were taken at harvest.

Data for height, average width, quality ratings and dry weights were analyzed by linear and multiple regressions. Media pH and EC data were analyzed using repeated measures analysis of variance (ANOVA), with contrasts for the EC data for the *Rudbeckia* experiment.

Irrigation Rate. Plugs were potted in Fafard 3B media. The plugs were grown for one week; during this time the plants were irrigated with clear water, not fertigated. The experiments began 16 June 2003. Three irrigation rates were used: low, in which plants were watered when the medium moisture content reached 20% or below; medium, in which plants were watered when moisture content reached 30% or below; high, in which plants were watered when moisture content was 40% or below. The ThetaProbe was used daily on each plant, and all plants were fertigated when 50% or more of the plants in a given treatment had reached the treatment threshold. All plants in that treatment were hand-irrigated with 200 $mg \cdot L^{-1}$ N, and were given 350 mL. The 350 mL amount was determined by factoring in a 20% to 30% leaching fraction when irrigating. This leaching fraction was monitored over the course of the experiment. A total of 18 plants were used for each species.

Media pH and electrical conductivity (EC) were monitored at weeks 2, 4, and 6 for *Phlox* and weeks 2 and 4 for the *Rudbeckia*. Initial plant heights were measured prior to treatment. Plant heights, average widths, and quality ratings were taken at harvest time. Shoots were harvested 6 WAT (1 August 2003) for *Phlox* and 5 WAT (23 July 2003) for *Rudbeckia*. Dry weights were taken at harvest.

Data for height, average width, quality ratings and dry weights were analyzed by linear and multiple regressions. Media pH and EC were analyzed using ANOVA and an LSD for weeks 2 and 4 for the *Rudbeckia* experiment because there were only two measurements taken, and repeated measures ANOVA for the *Phlox* experiment because more than two measurements were taken. A correlation often exists when measurements are taken over time on the same plants. Univariate ANOVA F-tests concerning week and interactions with week depend on the Huynh-Feldt (H-F) condition (Huynh and Feldt, 1970), which requires that all pairs of measurements have a certain correlation structure. Therefore, the H-F condition may not hold. The PRINTE option of the REPEATED statement of SAS's GLM Procedure was used to evaluate the H-F condition using the sphericity test for the variables pH and EC (Marini et al., 1995). If the sphericity test was rejected for any of the variables, then these data were analyzed using a multivariate repeated-measures analysis using the REPEATED statement of SAS's GLM Procedure. Multivariate analysis of variance (MANOVA) requires no assumptions concerning the covariance structure of the repeated measures. *P* values from the MANOVA are presented for the main effect of WEEK and all interactions involving WEEK. *P* values for the main effects of pH and EC, and their interactions with week, were obtained from tests of hypotheses for between-subjects effects from repeated measures ANOVA. *P* values for contrast variables are also presented generated with the PROFILE transformation of the SUMMARY option in the REPEATED statement of SAS's GLM Procedure. Because of the correlation of measurements taken over time on the same plants, this type of analysis was used on the pH and EC data.

Media. Plugs were potted using four different types of soilless media: Fafard 3B; Daddy Pete's Perennial Pleaser [(60% pine bark fines, 20% Daddy Pete's composted cow manure, 15% peat moss, and 5% perlite) (Daddy Pete's Farm, Stony Point, NC)]; Fafard 52 [(24% peat, 60% bark, 8% perlite, 8% vermiculite) (Conrad Fafard, Inc.)]; and Scott's Sierra Perennial Mix [(25% peat, 65% bark, and 10% perlite) (The Scotts Company, Marysville, OH)]. These media were chosen because they are common commercial greenhouse and nursery mixes (excluding Daddy Pete's). They also provided a range of peat and pine bark components. The experiments began the day the plugs were potted (11 June 2003).

A total of 24 plants were used for each species. Plants were fertigated when moisture content of the media reached 30% or below, measured by the ThetaProbe. All plants in a treatment were tested daily, and if 50% of the plants in a specific treatment had reached the treatment threshold, then all plants of that treatment were watered. Each plant was given enough water for a leaching fraction of 20% to 30%.

Media pH and electrical conductivity (EC) were monitored at weeks 2, 4, and 6 for *Phlox* and weeks 2 and 4 for the *Rudbeckia*. Initial plant heights were measured prior to treatment. Plant heights, average widths, and quality ratings were taken at harvest time. Shoots were harvested 6 WAT (1 August 2003) for *Phlox* and 5 WAT (23 July 2003) for *Rudbeckia*. Dry weights were taken at harvest.

The variables pH and EC in the *Phlox* experiment were analyzed using repeated measures ANOVA because there were more than two measurements taken, and pH and EC in the *Rudbeckia* experiment were analyzed using ANOVA with means and an LSD for pH and EC for weeks 2 and 4 because there were only two measurements taken. ANOVA was used to analyze all other variables in both experiments.

Results

Phlox Experiments.

Fertilizer concentration significantly affected height, average width, quality rating, and dry weight of *Phlox paniculata* 'Blue Boy' at 6 WAT (Table 2.1). The 100 $mg \cdot L^{-1}$ N treatment produced the tallest plant, while the 200 $mg \cdot L^{-1}$N treatment produced plant with the greatest average width, shoot dry weight, and quality rating (Fig. 2.1). The large increase in mean EC at 6 WAT could explain why the 300 $mg \cdot L^{-1}$ N treatment reduced height, dry weight, and quality rating on average compared to the 200 $mg \cdot L^{-1}$N treatment (Fig. 2.2). Media pH had a significant with a quadratic relationship with fertilizer rate. There was a significant increase in EC between 2 and 4 WAT, and 4 and 6 WAT (Fig. 2.2) with respect to fertilizer rate. An EC of 0.75 to 1.5 $mS \cdot cm^{-1}$ is a generally acceptable range for nursery crops (including herbaceous plants) to grow when calculating EC using the Virginia Tech Extraction Method (University of Georgia Fact Sheet). Optimal media pH for production of perennial plants is generally within a range of 5.6 to

6.3 (Pilon, 2002b).

Irrigation rate significantly affected height at 6 WAT in the *Phlox* experiment (Table 2.1). There was a quadratic relationship between irrigation rate and height. The medium irrigation rate produced the shortest plant, whereas the low irrigation rate produced the tallest plant (Fig. 2.3). There were no significant differences in average width, quality rating and dry weight. For the variable pH, treatment and week were both significant, as well as the treatment x week interaction. The sphericity tests for pH were significant (P<0.0001), and repeated measures was necessary. Using MANOVA, treatments were significantly different for the variable pH (P=0.0001), and the univariate test also reports pH as significant (P=0.0002). There was also a significant change in pH from 2 WAT to 4 WAT, and 4 to 6 WAT (P=0.0288 and P=0.0014, respectively) (Fig. 2.4). The same is true for EC. The sphericity tests were significant (P<0.0001), MANOVA test was significant (P=0.0001), the univariate test was significant (P=0.0002), and there were significant differences in irrigation rates between 2 and 4 WAT, and 4 and 6 WAT (P=0.0288 and P=0.0014, respectively) (Fig. 2.5).

Media type significantly affected shoot dry weight in the *Phlox* experiment (6 WAT) (Table 2.1). Fafard 3B produced plants with the greatest dry weights. Fafard 3B also tended to produce plants with the greatest heights, average widths, and quality ratings (Fig. 2.6). For pH and EC, the sphericity tests were significant (P<0.0001 for both), so repeated measures was needed. The MANOVA test for pH was significant (P=0.0005) as well as the repeated measures ANOVA univariate test for within subject effects (P=0.0002). According to repeated measures ANOVA contrast, there was no significant change in pH between measurements at 2 WAT to 4 WAT, but there were significant changes between 4 WAT and 6 WAT (P=0.0007) (Fig. 2.7). The same holds true for EC. The MANOVA test was significant (P=0.0005), repeated measures ANOVA univariate test was significant (P=0.0002), and there were significant changes in pH between 4 WAT and 6 WAT (P=0.0007) (Fig. 2.8).

***Rudbeckia* Experiments.**

Fertilizer concentration significantly affected height, average width, quality rating, and dry weight of *Rudbeckia hirta* ‘Indian Summer’ measured at 4 WAT (Table 2.2). The 300 $mg \cdot L^{-1}$N treatment produced the plant with the greatest height, average width, quality rating, and dry weight (Fig. 2.9). There was a significant quadratic response of pH to fertilizer rate (P<0.0001), but pH was not affected by time and there was no rate x time interaction. Media pH remained constant over the times measured during the experiment for the 300 mg·L^{-1}N treatment (Fig. 2.10). Neither rate nor time affected EC (no data shown).

Irrigation rate significantly affected height, quality rating, and shoot dry weight at 5 WAT in the *Rudbeckia* experiment (Table 2.2). The high irrigation rate produced the tallest plant with the greatest quality rating and the greatest shoot dry weight (Fig. 2.11). Media pH was significantly different between irrigation rates at 2 WAT (*P*=0.0147) but not at 4 WAT (Table 2.2), and EC was significant at 2 (*P*<0.0001) and 4 WAT (*P*<0.0001). Occasionally, wilting was observed later on in the experiment in the plants treated at the high irrigation rate.

Media type significantly affected dry weight in the *Rudbeckia* experiment (5WAT) (Table 2.2). The Scott's Perennial Mix treatment resulted in the plants with the greatest dry weights. The Scott's Perennial Mix treatment also tended to result in the plants with the greatest height, average width, and quality ratings. Treatment differences in media pH were significant at 2 WAT but not at 4 WAT, with Scott's Perennial Mix having significantly lower pHs than the other treatments. (Table 2.2). EC was not significantly affected by media at 2 or 4 WAT.

Discussion

Fertilizer Summary: The amount of fertilizer that needs to be applied to a crop is dependent on the crop being grown because some crops have a greater need for nitrogen than others (Boodley, 1996). In an experiment performed by Jacques et al. (1992), marigolds (*Tagetes patula* L.) 'Honeycomb' and impatiens (*Impatiens wallerana* Hook.) 'Novette Red' were fertilized with four fertilizer rates: 0, 100, 200, and 300 mg·L^{-1}N. Fertilization of both the marigolds and impatiens grown at N levels in excess of 100 mg·L^{-1}N did not improve overall growth but did reduce shelf-life; i.e., plants grown with lower N concentrations had better visual quality and shelf life. These results are not consistent with our results from the *Rudbeckia* experiment, where plants continued to linearly increase in quality, dry weight, and overall plant size with an increase in N concentration. The *Phlox* plants, however, acted similarly to the marigolds and impatiens in that average width, shoot dry weight, and quality ratings reached a maximum at 200 mg·L^{-1}N, and began to decrease at the higher concentration of 300 mg·L^{-1}N. Plant height was greatest at 100 mg·L^{-1}N. The increase of mean EC at 6 WAT could possibly explain why there was a reduction in height, dry weight, and quality rating averages in the 300 mg·L^{-1}N treatment of the *Phlox* experiment. An EC of 0.75 to 1.5 mS·cm^{-1} is a generally acceptable range for nursery crops (including herbaceous plants) to grow when calculating EC using the Virginia

Tech Extraction Method (University of Georgia Fact Sheet). The suggested EC target range for growing *Phlox* is a PourThru EC of 2.0 to 3.5 $mS \cdot cm^{-1}$ (Whipker et al., 2000), which indicates that the 300 $mg \cdot L^{-1}$N treatment has passed the limits of acceptable EC range. The overall increase of plant height, average width, and quality of the 300 $mg \cdot L^{-1}$N treatment in the *Rudbeckia* experiment may not only be due to the extra fertilizer the plants were receiving, but also the fact that that treatment was irrigated more frequently than the other treatments (Table 2.3). Also, as mentioned above, the pH of the 300 $mg \cdot L^{-1}$N treatment remained constant between the two measurement times (2 and 4 WAT) of the *Rudbeckia* experiment. The maintenance of a steady pH could have contributed to the greater heights, average widths, quality ratings, and shoot dry weights of that treatment.

Overall, it appears that *Phlox paniculata* 'Blue Boy' grows best at 200 $mg \cdot L^{-1}$N Cal Mag 15-5-15, and 300 $mg \cdot L^{-1}$N is the most favorable rate to use when growing *Rudbeckia hirta* 'Indian Summer'.

Irrigation Summary: Water plays a critical role in the growth and development of plants. A plant's need for water is greater than that of any nutrient (Boodley, 1996). For best growth, it is necessary that plants have ample water at all times (Stinson et al., circa 1969). On the downside, overwatering can also produce adverse effects. It is possible for a medium to be completely saturated with water and yet for the water not to be absorbed by the plant. This is because roots, as living tissues, need an adequate supply of oxygen for growth (Boodley, 1996). If too little oxygen is available to those roots, injury and eventual death can occur. Irrigation frequency is based on the type and size of plant being grown (Nelson, 1980). Certain plants require more water than others, while other plants are sensitive to a limited air supply in the medium, caused by too much water. It could be that *Phlox* can tolerate small or large amounts of water and remain healthy. *Rudbeckia*, on the other hand, prefers to be irrigated more frequently. An increase in *Rudbeckia* height, quality rating, and shoot dry weight could have to do with the fact that the plants in the high irrigation treatment were also given more fertilizer than the other treatments because they were irrigated more frequently, and each time a treatment was irrigated, it was also being given fertilizer (Table 2.3).

The differences in pH and EC are difficult to interpret for the *Rudbeckia* experiment (Table 2.2). The medium and high rates were significantly different from one another at the 2 WAT measurement, but no differences existed at 4 WAT. Even though statistical differences existed between the pHs at 2 WAT, those averages were very similar and it is possible that they may not have impacted the treatment differences in height, average width, quality rating, and dry weight. It appears that the EC could have played a role, however, in those differences, because the high irrigation rate resulted in low ECs at 2 and 4 WAT compared to those of the low irrigation rate, where the plants were not growing as quickly therefore were not using up as much fertilizer.

It appears that any of the irrigation rates (low, medium, or high) would be appropriate for the growth of *Phlox*, and that the high irrigation rate is optimal for growth of *Rudbeckia*.

Media Summary: No single growing medium is best for the production of bedding plants, which can be successfully grown in an assortment of substrates or media (Fonteno, 1994). A substrate must provide water, supply nutrients, permit gas exchange to and from the roots, and provide support for the plant. The *Phlox* results are in line with an experiment performed by Thomas and Latimer (1995), where *Catharanthus roseus* (L.) G. Don were grown in two media types: one containing 25% pine bark, and another containing no pine bark. Plants that were grown in the medium containing pine bark had significant reductions in stem length and reduced shoot and root dry weights. It was possible *Phlox* grew best in Fafard 3B because of the lower percentage of pine bark in the medium. Although Fafard 3B has a lower amount of pine bark, it has a very high percentage of peat, which would give the medium the ability to hold on to nutrients. The EC was the highest at 6 WAT for Fafard 3B compared to that of the rest of the media. The *Rudbeckia* could have been most successful growing in the Scott's Sierra Perennial Mix because of the moderate amount of peat, which provided good moisture retention, and the high percentage of pine bark, which allowed for good aeration for the roots. The differences in pH were significant at 2 WAT, with Scott's Perennial Mix having a significantly lower pH than the other types of media, probably due to the components of the medium.

The *Phlox* results indicate that the plants seemed to grow optimally in the Fafard 3B media, and the *Rudbeckia* results indicate that the plants appear to grow optimally in Scott's Sierra Perennial Mix.

Cultural Summary.

In our studies, we determined that *Phlox paniculata* 'Blue Boy' grew best at a rate of 200 $mg \cdot L^{-1}N$ when using 15-5-15 Peter's Cal Mag, that it was not responsive to the irrigation rates we tested, and that it grew best in Fafard 3B media out of the four media we tested. We also determined that *Rudbeckia hirta* 'Indian Summer' grew best at a rate of 300 $mg \cdot L^{-1}$N, with a high moisture regime, and using Scott's Sierra Perennial Mix. Just because we found the above to be optimal cultural conditions for greenhouse production of *Phlox* and *Rudbeckia* does not mean that a grower is limited to growing these plants in these conditions. A plethora of fertilizer formulations are available for commercial use, and these fertilizers are not necessarily applied as constant liquid feed as in our studies. A grower is also not limited irrigating by hand, as we have done. And many media mixes are available for production of these crops, where a grower has the ability to add his or her own components to make their own unique blend if they choose to do so. These studies were performed as general guidelines to assist the grower in the greenhouse production of *Phlox* and *Rudbeckia*.

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Table 2.1. Linear and multiple regression summary for fertilizer concentration effect and irrigation rate effect, and analysis of variance summary for media effect on mean plant height, average width, quality rating, and shoot dry weight of *Phlox paniculata* 'Blue Boy' at harvest 6 weeks after treatment (WAT).

Treatment		Height (cm)	Average width (cm)	Quality rating[z]	Dry weight (g)
N Rate (mg·L^{-1})					
0		24.8	19.6	1.0	5.8
100		34.9	29.9	2.0	11.6
200		31.4	31.4	2.3	13.0
300		33.5	25.4	2.1	11.7
	Linear *P*-value	**0.0124**			
	Quadratic *P*-value		**<0.0001**	**0.0002**	**<0.0001**
	R^2	**0.25**	**0.60**	**0.75**	**0.81**
Irrigation rate					
Low (<20%)		29.8	35.3	2.7	10.0
Medium (<30%)		24.5	35.5	2.7	10.0
High (<40%)		25.2	35.6	2.7	11.4
	Linear *P*-value		**NS**	**NS**	**NS**
	Quadratic *P*-value	**0.0486**			
	R^2	**0.46**			
Media					
Fafard 3B		29.2	34.7	2.9	13.2a[y]
Daddy Pete's		24.7	23.6	2.5	7.7c
Fafard 52		25.6	31.1	2.5	11.5ab
Scott's Perennial Mix		25.0	31.2	2.8	9.2bc
	***P*-value**	**NS**	**NS**	**NS**	**0.0309**

[z]Quality ratings were given to all plants in a treatment. They were rated on a scale of 0 to 4; 0=dead, and 4=excellent, healthy and vigorous growth.
[y]Mean separation within a column using least square means.

Table 2.2. Linear regression summary for fertilizer concentration effect (4 WAT), linear and quadratic regression summary for irrigation effect (5 WAT), and analysis of variance summary for media effect (5 WAT) on mean plant height, average width, quality rating, and shoot dry weight of *Rudbeckia hirta* 'Indian Summer. Also, repeated measures analysis of variance summary for media effect and irrigation rate effect on pH and EC data at 2 and 4 WAT.

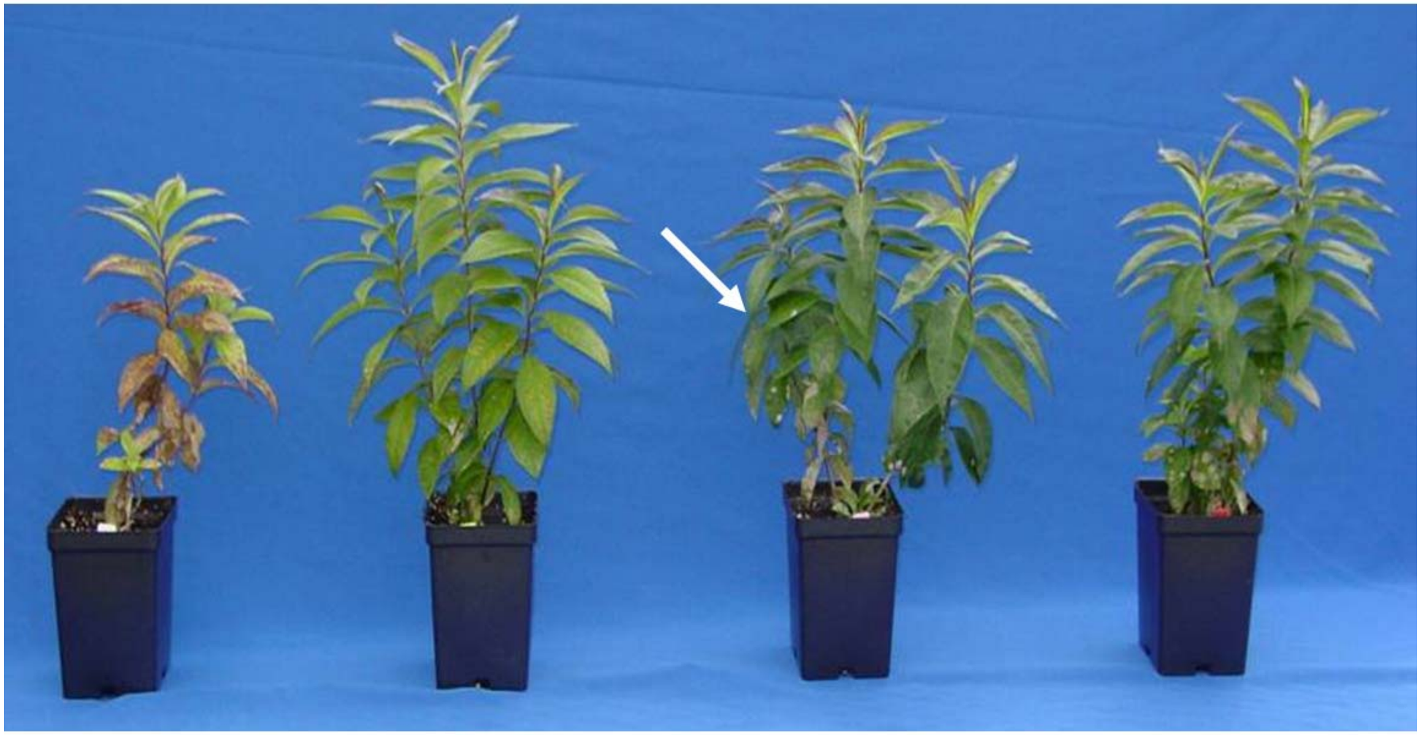
Treatment		**Height (cm)**	**Average width (cm)**	**Quality rating**[z]	**Dry weight (g)**		**pH 2WAT**	**pH 4WAT**	**EC ($mS \cdot cm^{-1}$) 2WAT**	**EC ($mS \cdot cm^{-1}$) 4WAT**
N rate ($mg \cdot L^{-1}$)										
0		32.2	26.8	1.0	6.4					
100		45.8	32.5	2.5	14.6					
200		46.7	38.0	3.0	19.5					
300		51.8	43.7	3.8	27.4					
	Linear *P*-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**					
	R^2	**0.60**	**0.80**	**0.81**	**0.90**					
Irrigation Rate										
Low (<20%)		37.2	41.2	2.3	12.2		6.3ab[y]	5.7	1.29a	0.63b
Medium (<30%)		44.3	56.8	2.5	13.0		6.2b	5.8	0.70b	1.49a
High (<40%)		47.8	55.0	3.0	22.8		6.4a	5.7	0.55b	0.81b
	Linear *P*-value	**0.0518**	**NS**	**0.0543**		***P*-value**	**0.0150**	**NS**	**<0.0001**	**<0.0001**
	Quadratic *P*-value				**0.0029**	**LSD**	**0.1178**		**0.2147**	**0.2709**
	R^2	**0.22**		**0.23**	**0.81**					
Media										
Fafard 3B		34.1	41.6	2.9	17.0ab		6.3a	5.4	0.74	0.95
Daddy Pete's		34.0	35.3	2.9	13.5b		6.2ab	5.5	0.94	0.96
Fafard 52		33.7	37.4	2.5	12.8b		6.1b	5.5	0.76	0.90
Scott's Perennial Mix		41.4	37.9	3.4	20.6a		5.6c	5.3	0.92	0.82
	***P*-value**	**NS**	**NS**	**NS**	**0.0043**		**<0.0001**	**NS**	**NS**	**NS**
						LSD	**0.1793**			

[z]Quality ratings were given to all plants in a treatment. They were rated on a scale of 0 to 4; 0=dead, and 4=excellent, healthy and vigorous growth.
[y]Mean separation within a column by the *t* test.

Table 2.3. Number of times irrigated for the fertilizer, irrigation, and media experiments on *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer'.

Treatment	**Number of times watered**	
mg·L^{-1} N	***Phlox***	***Rudbeckia***
0	9	8
100	14	15
200	17	16
300	15	20
Irrigation Rate		
Low (<20%)	13	9
Medium (<30%)	16	12
High (<40%)	30	20
Media Type		
Fafard 3B	9	8
Daddy Pete's	14	15
Fafard 52	17	16
Scott's Perennial Mix	15	20

Figure 2.1. Lineup of *Phlox paniculata* ‘Blue Boy’ at 4 weeks after treatment in the fertilizer experiment, Summer 2003. The arrow indicates the treatment that produced the optimal plant.



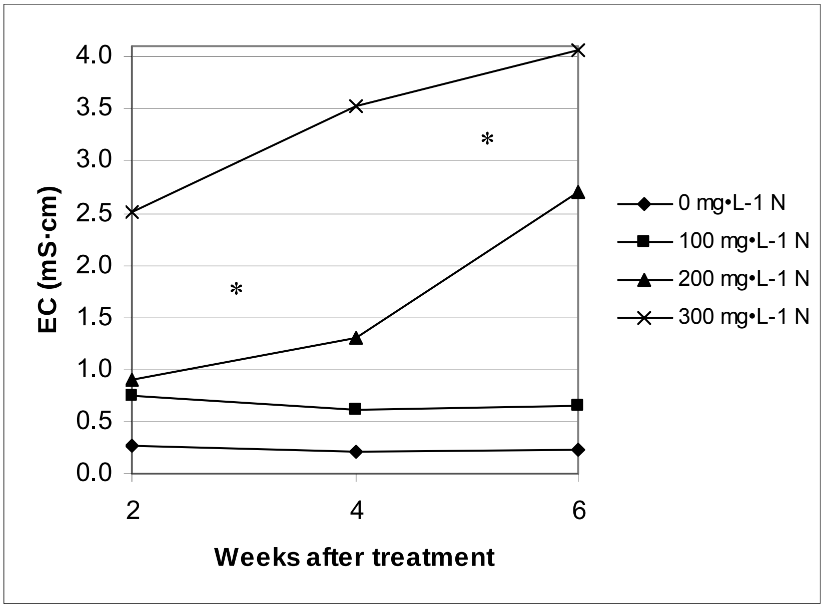


Figure 2.2. Mean electrical conductivity (EC) over time in weeks at four fertilizer concentrations (0, 100, 200, and 300 mg•L^{-1}N) for *Phlox paniculata* 'Blue Boy' in the fertilizer experiment.

*****Indicates that the change in EC from week 2 to week 4, and week 4 to week 6, is not the same for all concentrations.

Figure 2.3. Lineup of *Phlox paniculata* ‘Blue Boy’ at 4 weeks after treatment in the irrigation experiment, Summer 2003.

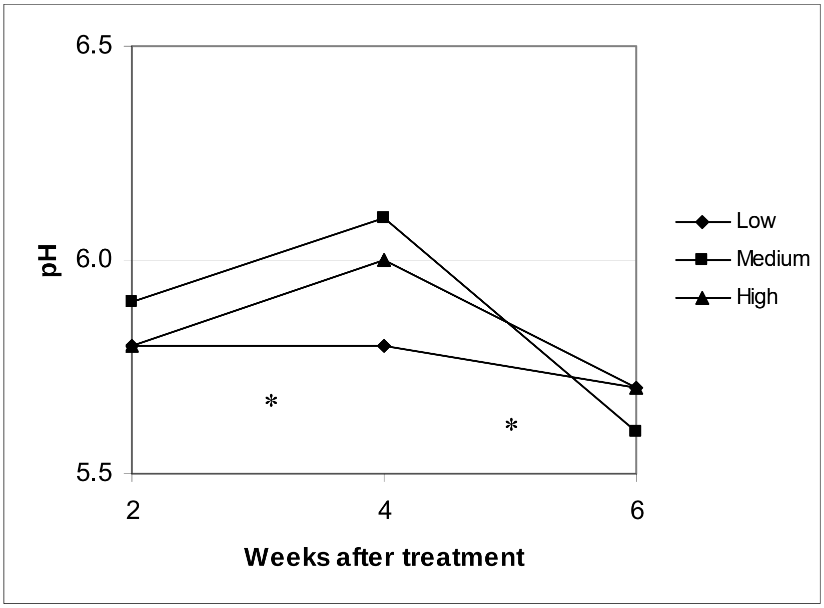


Figure 2.4. Mean pH over time in weeks at three irrigation rates (Low, Medium, and High) for *Phlox paniculata* 'Blue Boy' in the irrigation experiment.

*****Indicates that the change in pH from week 2 to week 4, and week 4 to week 6, is not the same for all concentrations.

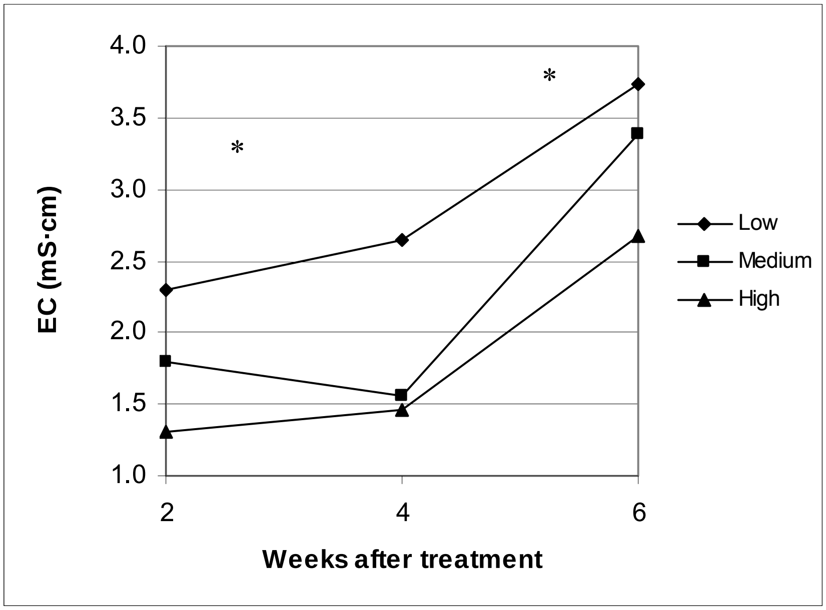


Figure 2.5. Mean electrical conductivity (EC) over time in weeks at three irrigation rates (Low, Medium, and High) for *Phlox paniculata* 'Blue Boy' in the irrigation experiment. ***Indicates that the change in EC from from week 2 to week 4, and week 4 to week 6, is not the same for all concentrations.

Figure 2.6. Lineup of *Phlox paniculata* ‘Blue Boy’ at 5 weeks after treatment in the media experiment, Summer 2003. The arrow indicates the treatment that produced the optimal plant. (See text for media components and sources.)

Fafard 3B | Daddy Pete’s | Fafard 52 | Sierra Mix

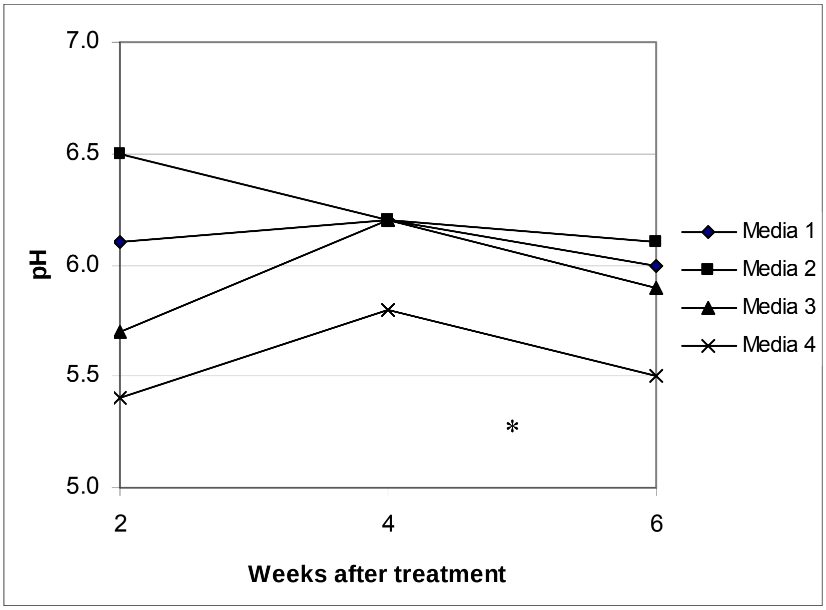


Figure 2.7. Mean pH over time in weeks at four media types for *Phlox paniculata* 'Blue Boy' in the media experiment. 1=Fafard 3B; 2=Daddy Pete's; 3=Fafard 52; 4=Scott's Perennial Mix. *****Indicates that the change in pH from week 4 to week 6 is not the same for all media.

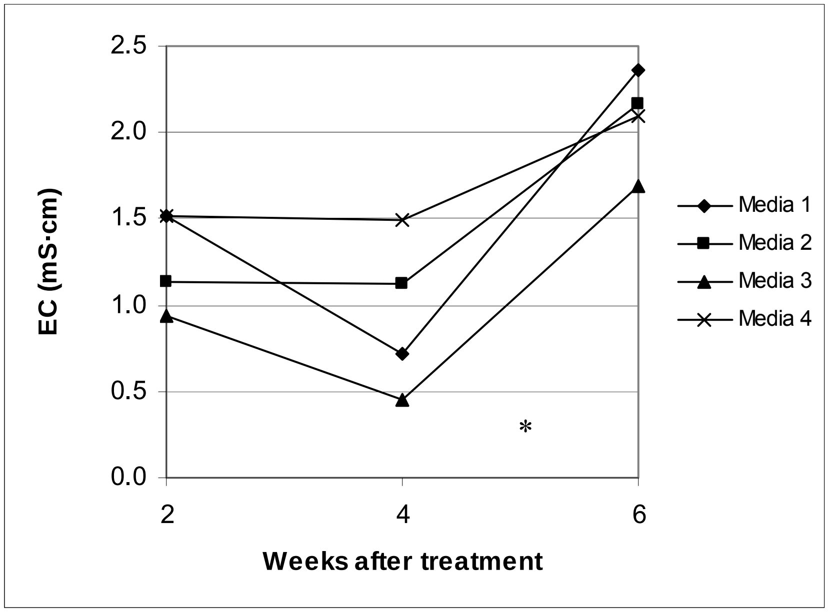
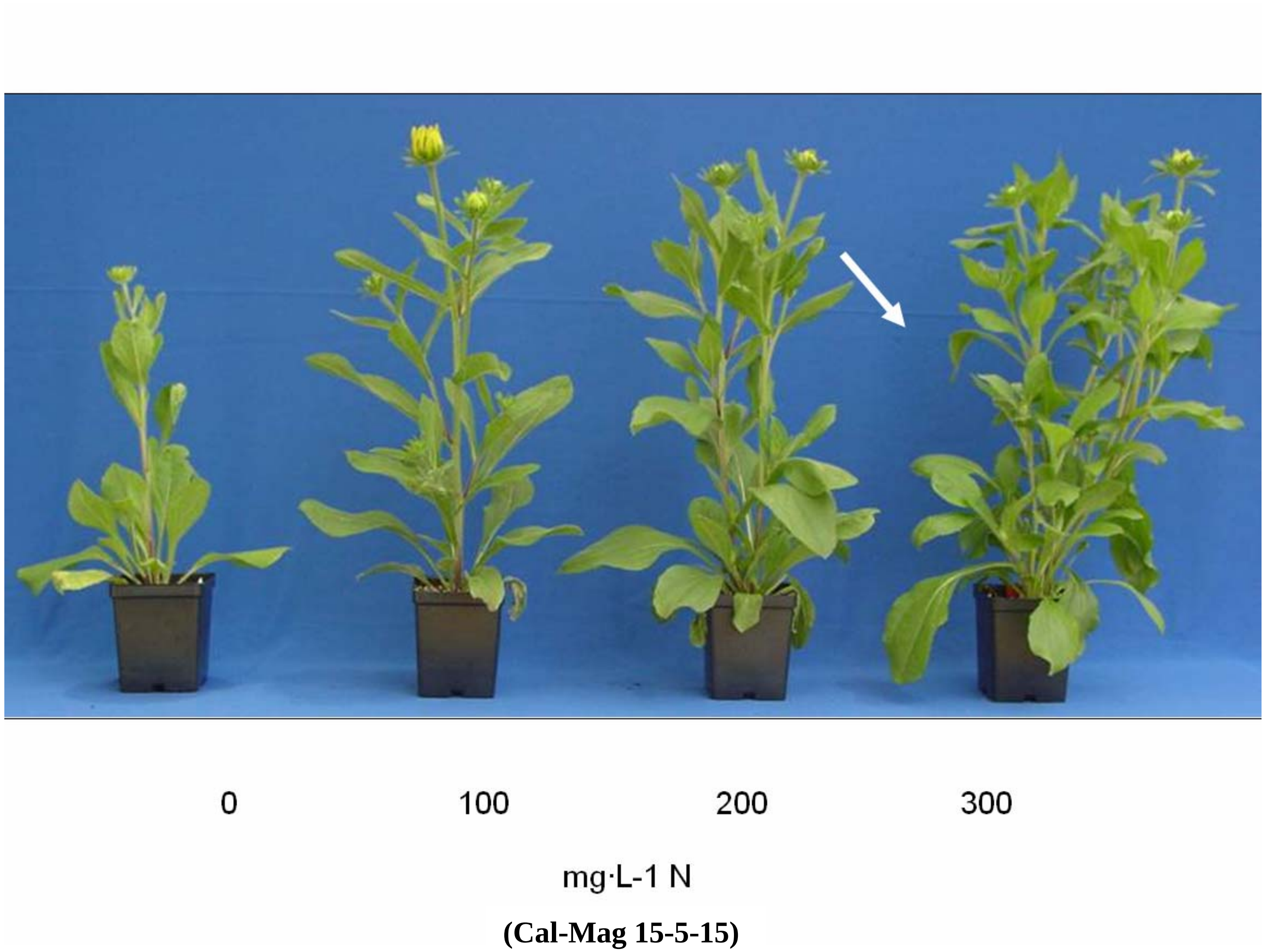


Figure 2.8. Mean electrical conductivity (EC) over time in weeks at four media types for *Phlox paniculata* ‘Blue Boy’ in the media experiment 1=Fafard 3B; 2=Daddy Pete’s; 3=Fafard 52; 4=Scott’s Perennial Mix.

*****Indicates that the change in EC from week 2 to week 4 is not the same for all concentrations.

Figure 2.9. Lineup of *Rudbeckia hirta* ‘Indian Summer’ at 4 weeks after treatment in the fertilizer experiment, Summer 2003. The arrow indicates the treatment that produced the optimal plant.



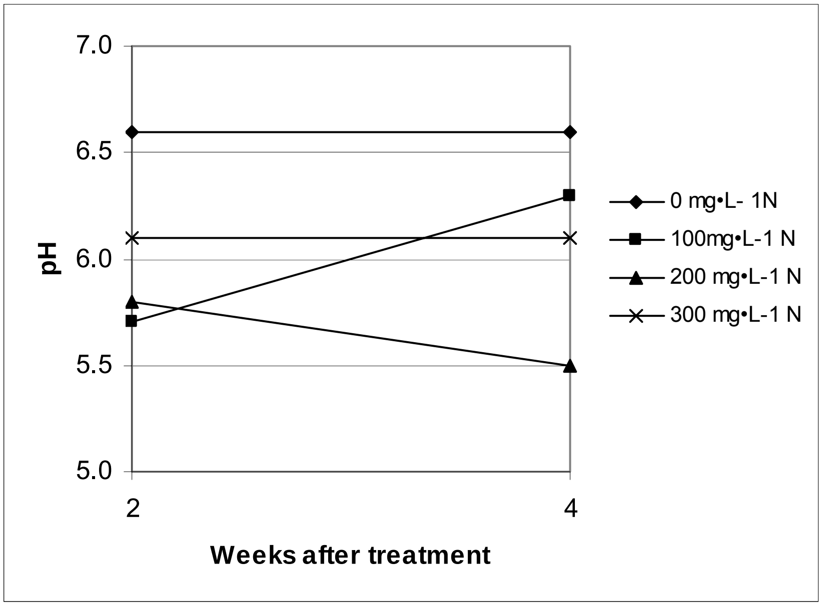
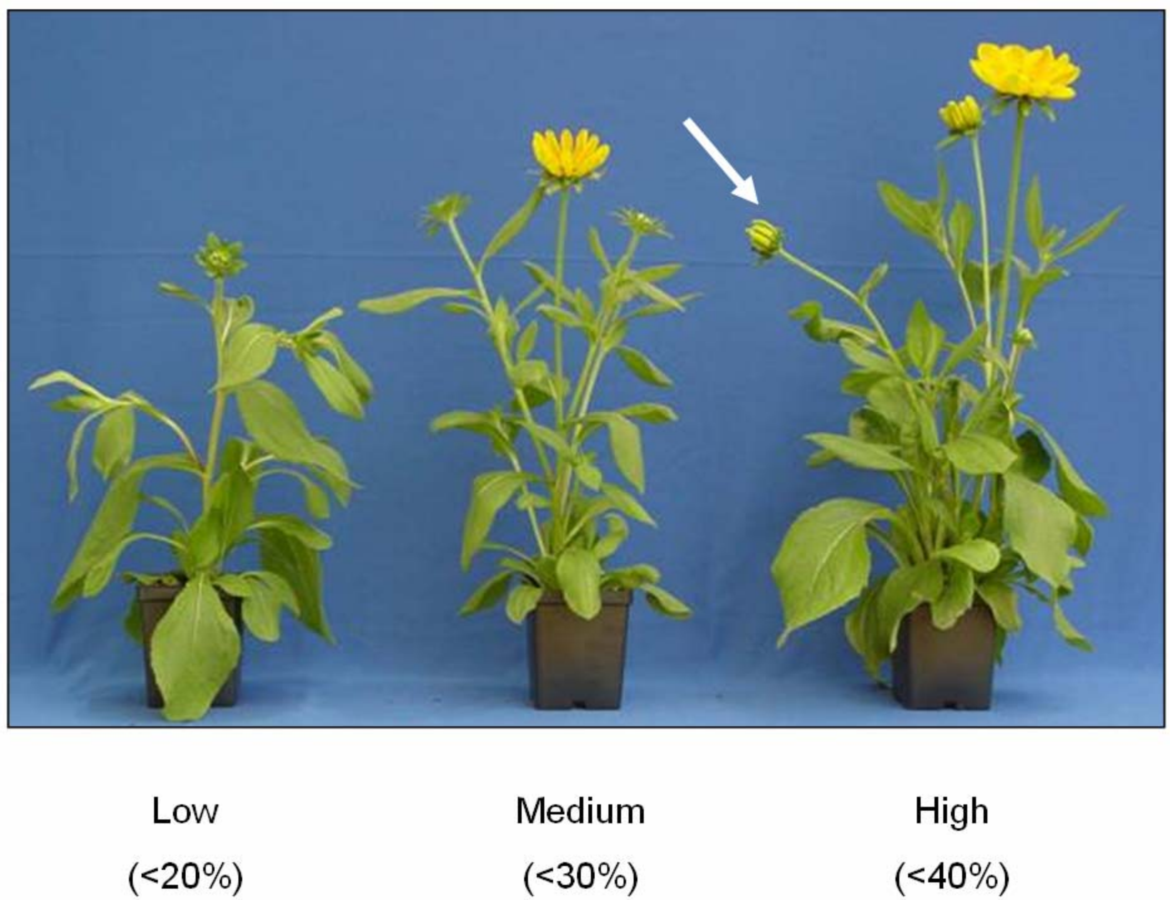


Figure 2.10. Mean pH over time in weeks at four fertilizer concentrations (0, 100, 200, and 300 mg•L^{-1} N) for *Rudbeckia hirta* 'Indian Summer' in the fertilizer experiment.

Figure 2.11. Lineup of *Rudbeckia hirta* ‘Indian Summer’ at 4 weeks after treatment in the irrigation experiment, Summer 2003. The arrow indicates the treatment that produced the optimal plant.



Chapter Three: Optimal PGR rates for *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer'

Abstract: Phlox paniculata and *Rudbeckia hirta* are popular native North American wildflowers, grown for their showy inflorescences. Plant growth regulators (PGRs) are used extensively throughout the floriculture industry, primarily to control plant height. Growth retardants reduce internode elongation, resulting in more compact, desirable plants. Three greenhouse experiments were conducted in Summer 2003 and Spring 2004 on *Phlox paniculata* L. 'Blue Boy' and *Rudbeckia hirta* L. 'Indian Summer' to examine the effects of several different PGRs on these species and to select appropriate rates. The following PGRs were applied as foliar sprays with the number of applications in parenthesis: daminozide: 0, 5000 (3), 7500 (3), or 10000 (3) mg•L^{-1}; chlormequat chloride: 0, 1000, 2000, 3000, or 4000 mg•L^{-1}, daminozide/chlormequat chloride tank mix: *Phlox*: 0, 5000/1500 (2), 5000/1500 (3), 7500/1500 (2), or 7500/1500 (3) mg•L^{-1}, and *Rudbeckia* (experiment 1 only): 0, 5000/1500 (1), 5000/1500 (2), 7500/1500 (1), or 7500/1500 (2) mg•L^{-1}; paclobutrazol: 0, 40, 80, 120, and 160 mg•L^{-1}; uniconazole: 0, 15, 30, 45, or 60 mg•L^{-1}; flurprimidol: 0, 15, 30, 45, and 60 mg•L^{-1}, and two paclobutrazol chemicals (another formulation, second *Rudbeckia* experiment only): 0, 40, 80, 120, or 160 mg•L^{-1}. Heights, average widths, and shoot dry weights were recorded. For *Phlox*, chlormequat chloride, the tank mix, and paclobutrazol were effective in controlling height. The tank mix reduced shoot dry weight in the *Phlox* experiment (at 6 weeks after treatment, or WAT). For the first *Rudbeckia* experiment, paclobutrazol and uniconazole were effective in controlling height, but none of the PGRs significantly affected shoot dry weights (4 WAT). There were significant differences in quality ratings for plants treated with chlormequat chloride and flurprimidol. For the second *Rudbeckia* experiment, daminozide was the only PGR that significantly reduced height. Uniconazole and flurprimidol significantly reduced dry weight (7 WAT).

[Chemicals used: Daminozide: butanedioic acid mono (2,2-dimethylhydrazide); chlormequat chloride: (2-chloroethyl) trimethylammonium chloride; paclobutrazol: (±)-(R*,R*)-β-((4-chlorophenyl) methyl)-α-(1,1,-dimethylethyl)-1H-1,2,4,-triazole-1-ethanol); uniconazole: (E)-1-(P-chlorphenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl-1-penten-3-ol); and flurprimidol: (α-1-methylethyl)-α4-(trifuloromethoxy) phenyl-5-pyrimidinemethanol)]

Introduction

Perennials are becoming increasingly popular additions to our landscapes. In 2003, the USDA reported that total wholesale value of floriculture crops was about $5.07 billion (Agricultural Statistics Board, 2003). A survey conducted by Behe et al. (2001) reported *Phlox* and *Rudbeckia* as two species in the list of top ten perennials. The plants were "graded": *Phlox* received a 2.2 (2=B, or very good) and *Rudbeckia* received a 1.8 (1=A, or excellent). Bedding plant sales have continued to increase for many years. Not a lot of cultural information is known about perennials because relatively little research has been conducted on them until recently (Pilon, 2002). *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer' are two such crops where little to no cultural information is available for their production in a greenhouse setting.

Many potential floriculture crops have the tendency to grow too large for standard container culture (Davis and Anderson, 1989). Plant growth regulators (PGRs) can be useful in manipulating size, shape, and form of floriculture crops. PGRs are used extensively throughout the floriculture industry, primarily to control plant height (Gent and McAvoy, 2000). Most growth retardant-type PGRs cause dwarfing in plants by reducing gibberellin biosynthesis. Gibberellins promote stem elongation in plants. Growth retardants reduce internode elongation, resulting in more compact, desirable plants. These chemicals are primarily used to control stem elongation of ornamental plants growing in containers during crop production, shipping, and marketing. PGRs can be applied as sprays, sprenches, drenches, and even as bulb or liner soaks.

PGRs could become very useful with these crops, which can become somewhat unmanageable when grown as a containerized greenhouse crop. Daminozide (B-Nine) and uniconazole (Sumagic) have shown the most response over the greatest range of plant species (Pilon, 2002). The use of PGRs has resulted in overall improved crop uniformity and a longer shelf life. Unfortunately, PGRs have not given us adequate levels of control for several species researched.

The objectives of the following experiments were to examine several different height-controlling PGRs on *Rudbeckia hirta* and *Phlox paniculata* and determine the most appropriate rates for the best overall size control and the least aesthetic damage to the plants.

Materials and Methods

The experiments were conducted in greenhouses at Virginia Polytechnic Institute and

State University using plugs of *Phlox paniculata* L. 'Blue Boy' and *Rudbeckia hirta* L. 'Indian Summer' (72 cells/tray; Yoder Green Leaf Perennials, Leola PA), which were grown at a daytime temperature range of 26 to 33ºC (79 to 91ºF) and a nighttime temperature range of 18 to 22ºC (65 to 71ºF). The plugs were potted into 10.8 cm (4.25 in) diameter (1180 cm^3) plastic containers filled with Fafard 3B media (Fafard, Inc., Anderson, S.C.) and were fertigated with 15N-2.2P-12.5K (15-5-15) Cal Mag (The Scotts Co., Marysville, OH). The *Phlox* plugs were potted on 11 June 2003. The *Rudbeckia* plugs for the first experiment were potted on 23 June 2003. The *Rudbeckia* experiment was repeated the following spring (2004) because the plugs in the first experiment were overgrown upon receipt and were treated with the growth regulators later in development they normally would be. The *Rudbeckia* plugs were potted in Scott's Sierra Perennial Mix (Scott's Co., Merrifield OH) on 9 March 2004. This particular medium was used for the repeat experiment because earlier experiments showed that Scott's was the optimal medium for *Rudbeckia*. Spring daytime temperatures ranged 23ºC to 33ºC (74ºF to 92ºF), and nighttime temperatures ranged from 17ºC to 20ºC (62ºF to 68ºF). Plants were grown in a double layer polyethylene greenhouse on the Virginia Tech campus.

Plants were initially sprayed with the growth regulators approximately two weeks after transplant. For treatments that required multiple applications, they were applied at two-week intervals. The treatments were as follows:

1) Daminozide (B-Nine, Uniroyal Chemical Co., Inc., Middlebury, CT: 0, 5000, 7500, or 10000 mg•L^{-1} (at 0, 2 and 4 weeks after initial treatment (WAT))
2) Chlormequat chloride (Cycocel, Olympic Horticultural Products Co., Mainland, PA): 0, 1000, 2000, 3000, or 4000 mg•L^{-1} (applied at week 0); for *Rudbeckia*, treatments applied only in experiment 1
3) Daminozide/chlormequat chloride tank mix: *Phlox*: 0, 5000/1500 (2), 5000/1500 (3), 7500/1500 (2), or 7500/1500 (3) mg•L^{-1} (applied at 0, 2, 4 WAT, as indicated by number of applications in parenthesis); for *Rudbeckia* (experiment 1 only): 0, 5000/1500 (1), 5000/1500 (2), 7500/1500 (1), or 7500/1500 (2) mg•L^{-1} (applied at 0, 2 WAT)
4) Paclobutrazol (Bonzi, Syngenta Chem. Co., Greensboro, NC): 0, 40, 80, 120, or 160 mg•L^{-1} (applied at week 0)

5) Uniconazole (Sumagic, Valent USA, Marysville, Ohio): 0, 15, 30, 45, or 60 mg•L^{-1} (applied at week 0)
6) Flurprimidol (TopFlor, SePRO Corp., Carmel, IN): 0, 15, 30, 45, or 60 mg•L^{-1} (applied at week 0)
7) Paclobutrazol (Piccolo, Fine Agrochemicals, Worcester, UK): 0, 40, 80, 120, or 160 mg•L^{-1} (applied at week 0)

A hand-held CO_2 pressurized sprayer (R & D Sprayer, Opelousas LA) with an 800VS Nozzle was used to apply the growth regulators. During the *Phlox* experiment, the nozzle pressure was 22 p.s.i. The weather was sunny and the temperature was 31ºC (87.8°F) with 44% relative humidity. Plants to be sprayed were placed in a square meter area without overlapping. Each PGR solution was evenly applied as a foliar spray at 210 ml·m^{-2} [manufacturers suggested rate 2 qt/100 ft^2 (1.89 L·9.3 m^{-2})] over that square meter area. During the first *Rudbeckia* experiment, the nozzle pressure was 20 p.s.i., the weather was sunny, and the temperature was 34ºC (93.2°F) with a 51% relative humidity. During the second *Rudbeckia* experiment, the nozzle pressure was 24 p.s.i.; it was sunny, 32ºC (89.6°F) with a 22% relative humidity.

The *Phlox* treatments began 24 June, the treatments for the first *Rudbeckia* experiment began 8 July 2003, and treatments for the second *Rudbeckia* experiment began 26 March 2004. Plants were fertigated as needed.

Heights were measured from the rim of the pot to the highest point of the plant. Average widths were obtained by measuring the maximum width of the plant, then taking another width measurement perpendicular to the initial measurement, and averaging the two numbers. Quality ratings were based on what we deemed acceptable for the sale of a plant. Each plant was given a rating of 0 to 4, comparing within a species. It was rated according to the following standards: 0=dead; 1=barely alive; 2=acceptable but not thriving; 3=looks good, very little chlorosis or necrosis; 4=excellent, healthy and vigorous growth. The plants were not necessarily rated based on the overall quality of the group of plants, but instead on how an optimal plant would appear. Quality ratings were not given to *Rudbeckia* plants in the second experiment because there were not any differences detected between treatments during the first experiment, except for those chemicals that caused phytotoxicity.

Media pH and electrical conductivity (EC) were monitored using the PourThru method (Whipker et al., 2000). The pH and EC of the media were monitored at weeks one and 6 for

Phlox and weeks 0 and 4 for the first *Rudbeckia* experiment, and at week 6 for the second *Rudbeckia* experiment.

Plants were harvested by removing shoots at the soil line. Each plant was placed in its own paper bag and put into a dryer that was kept at an average temperature of 65.5ºC (150ºF). The plants were removed from the dryer when they had dried completely, and dry weights were measured. Shoots were harvested 6 weeks after treatment (WAT) (5 August 2003) for *Phlox* and 4 WAT (1 August 2003) for the first *Rudbeckia* experiment. The second *Rudbeckia* experiment ended 10 May 2004 (7 WAT).

The experiments were arranged in a completely randomized design with six replicates. Data were analyzed by ANOVA using the Statistical Analysis System (SAS) Version 8 (SAS Institute, Inc., Cary, N.C.). Height and average width were analyzed using repeated measures analysis of variance (ANOVA). Quality ratings were analyzed using regression except for the tank mix in which ANOVA was used. Media pH and EC were analyzed using ANOVA with LSD for each PGR, as well as linear and quadratic regression. Dry weights were analyzed using linear and quadratic regression except for the tank mix in which ANOVA was used.

Results and Discussion

Phlox experiment.

Daminozide: There was a significant week effect for height (P<0.0001), but no rate effect (data not presented). Dry weights were not significantly different between rates (Table 3.1).

Chlormequat chloride: For the variable height, there was a significant week effect (P<0.0001), a week x rate effect (P=0.0164), a repeated measures ANOVA between-subjects rate effect (P=0.0304), as well as a linear effect of time between measurements at week 0 to week 2, week 2 to 4, and week 4 to 6 (data not presented). The slopes of the rates were significantly different between weeks 0 and 2, and between weeks 2 and 4 for chlormequat chloride (Fig. 3.1). The 4000 mg•L^{-1} treatment resulted in the shortest plants. Quality ratings (data not presented) and dry weights were not significantly different between rates (Table 3.1).

Daminozide/chlormequat chloride tank mix: There was a significant week effect (P<0.0001) for height, as well as a significant rate x week effect (P<0.0001), and a significant rate effect (P=0.0003) for between subjects (data not presented). Contrasts reported a significance in slope for rate from weeks 0 to 2 (P<0.0001) and 2 to 4 (P=0.0018) (Fig. 3.2). All treatments greater than the control were effective in reducing height. There was also a significant rate effect for average width, a significant week x rate effect (*P*=0.0029), and the between subjects effect was significant (*P*=0.0109) (data not presented). ANOVA contrasts were also significant for average width between weeks 2 to 4 (*P*=0.0099) (Fig. 3.3). There was a significant difference for quality rating (*P*=0.0053) (Table 3.2), the 5000/1500 x 3 mg•L^{-1} treatment with the greatest quality rating. Near the end of the experiment the plants were attacked by spider mites and it is difficult to tell whether those ratings were related to the rates of PGR applied or the spider mite damage. There was significant difference in dry weight (*P*=0.0044) (Table 3.1), resulting in the controls with the greatest dry weights, and the 7500/1500 x 3 mg•L^{-1} treatment with the lowest dry weight.

<u>Paclobutrazol</u>: For the variable height there was a significant week effect (*P*<0.0001), a significant rate effect for between-subjects (*P*=0.0504), and a significant difference in slopes for rates between weeks 4 and 6 (*P*=0.0227) (Fig. 3.4). The 160 mg•L^{-1} treatment resulted in the plants with the greatest height at the end of the experiment. No significant differences were found between treatments for average width, quality (data not presented) or dry weight (Table 3.1).

<u>Uniconazole</u>: There was a significant week effect for height (*P*<0.0001), but no rate effects (data not presented). No significant differences were found between treatments for average width, quality (data not presented) or dry weight (Table 3.1).

<u>Flurprimidol</u>: For height there were significant week effects (*P*<0.0001), but no rate effects (data not presented). No significant differences were found between treatments for average width, quality ratings (data not presented) or dry weight (Table 3.1).

Rudbeckia experiment 1.

<u>Daminozide</u>: There was a significant week effect for height (*P*<0.0001), but no rate effect (data not presented). Significant differences were not found for quality ratings (data not presented) or dry weights (Table 3.1).

<u>Chlormequat chloride</u>: For height there was a significant week effect (*P*<0.0001), but no rate effect (data not presented). There is a negative linear relationship between quality rating and PGR rate (*P*<0.0001) (Table 3.2). Differences in quality ratings were also found when analyzed with ANOVA (*P*=0.0004). All rates of chlormequat chloride were phytotoxic to the *Rudbeckia* plants. Phytotoxicity included a severe chlorosis of the foliage in which chemical contact occurred, and the plants did not entirely grow out of the phytotoxicity by the end of the four

week experiment. The controls received the highest ratings, while all other treatments were statistically similar. Dry weights were not significantly different (Table 3.1).

Daminozide/chlormequat chloride tank mix: A significant week effect occurred for height ($P<0.0001$), but no rate effect occurred (data not presented). Significant differences were not found for dry weight (Table 3.1).

Paclobutrazol: A significant week effect occurred for height ($P<0.0001$), and the slopes for rates were significantly different ($P=0.0368$) between weeks 2 and 4 using ANOVA contrasts (Fig. 3.5). The 160 mg•L^{-1} treatment resulted in the plants with the shortest heights at the end of the experiment. Significant differences were not found for quality ratings (data not presented) or dry weights (Table 3.1).

Uniconazole: There was a significant week effect for height ($P<0.0001$), a significant rate effect ($P=0.0143$) for between-subjects effects, significant week x rate effect for within-subjects effects ($P=0.0097$), and the slopes for rates were significantly different ($P=0.0480$) between weeks 2 and 4 (Fig. 3.6) using ANOVA contrasts. Significant differences were not found for quality ratings (data not presented) or dry weights (Table 3.1).

Flurprimidol: For the variable height, a significant week effect occurred ($P<0.0001$), but there was no rate effect (data not presented). There was a significant linear relationship between quality rating and PGR rate ($P=0.0473$) (Table 3.2). The controls had the highest quality, with the 60 mg•L^{-1} treatment resulting in the lowest quality plants. It is possible that the control plants had a higher quality because their growth was less restricted and their overall appearance (fuller, bushier plants) was of a better quality than the treated plants. The range of the quality rating means, however, was only 3.6 to 4.0. If visually rating the plants, a 3.6 would not be distinguishable from a 4.0. Dry weights were not significantly different (Table 3.1).

Rudbeckia experiment 2:

Daminozide: There was a significant week effect for height ($P<0.0001$) as well as week x rate ($P=0.0340$), rate ($P=0.0502$) for between-subjects effects, and slopes for rates were significantly different between weeks 0 and 2 ($P=0.0540$), and 2 and 4 ($P=0.0055$) (Fig. 3.7) according to ANOVA contrasts. The plants in the 10000 mg•L^{-1} treatment appear to have grown out of the treatment more quickly than the other plants, having an even greater height than the controls at 4 WAT. Significant differences were not found for quality ratings (data not presented) and dry weights (Table 3.1).

Paclobutrazol (Bonzi): There was a significant week effect for height ($P<0.0001$), but no significant rate effects occurred (data not presented). Dry weights were not significantly different (Table 3.1).

Uniconazole: Significant week effects occurred for height ($P<0.0001$), but no significant rate effects occurred (data not presented). There were no significant differences found for quality rating (data not presented). There was a negative linear relationship between dry weight and rate ($P=0.0004$) (Table 3.1). The control treatment resulted in the plants with the greatest dry weight, with a decrease in dry weight as rate increased.

Flurprimidol: For height, significant week effects occurred ($P<0.0001$) but no significant rate effects (data not presented). There was a quadratic relationship between dry weight and rate ($P=0.0299$) (Table 3.1), with the control treatment resulting in the greatest dry weight and the 30 mg•L^{-1} treatment with the smallest dry weight.

Paclobutrazol (Piccolo): There was a significant weeks effect for height ($P<0.0001$), but no significant rate effects occurred (data not presented). Dry weights were not significantly different (Table 3.1).

Summary: The most commonly used PGR in floriculture is daminozide, which is generally not phytotoxic to plants. It has a low activity, meaning multiple applications are usually necessary (Latimer et al., 2001). This chemical is used in many aspects of horticulture because of its low cost and long history of use (Gent and McAvoy, 2000). Daminozide applications, ranging from 1000 to 5000 mg•L^{-1}, applied alone or in combination with chlormequat, were successful in reducing height of *Salpiglossis sinuata* R. *et* P. when applied foliarly (Needham and Hammer, 1990). Two or three foliar applications of daminozide at 5000 ppm or three applications at 2500 mg•L^{-1} restricted growth of *Salpiglossis* by 12%, 34%, and 16% respectively; however, the applications at 5000 mg•L^{-1}also restricted corolla diameter by 44%. Burnett et al. (2000) found that shoot height of 'American Dream' pink coreopsis (*Coreopsis rosea* Nutt.) was suppressed 17% to 29% with applications ranging from 2500 to 7500 mg•L^{-1} daminozide, and plant quality increased 52% to 61% with an increase in application rate compared to the controls. In our experiments, daminozide was not successful in controlling height of *Phlox*. There was a significant reduction in dry weight, however, between the 7500 x 3 mg•L^{-1} rate and the control. For the first *Rudbeckia* experiment, daminozide had no effect on height or dry weight, but in the second *Rudbeckia* experiment, there were significant reductions in height of plants treated with differing rates of daminozide. However, maximum height reductions were only 12% at 6 WAT for the 10000 mg•L^{-1} treatment compared to the controls. Dry weights were not impacted.

Chlormequat has been used for a long time in the floriculture industry (Latimer et al., 2001). Chlormequat can be phytotoxic to plants even at low rates. Except for specific crop uses (geranium: *Pelargonium* sp. L'Her. ex Aiton; hibiscus: *Hibiscus* sp. L.; and poinsettia: *Euphorbia pulcherrima* Willd.), chlormequat is rarely used alone on floricultural crops; it is generally combined with daminozide, creating a tank mix that is more effective in retarding growth than either chlormequat or daminozide individually. In studies with *Canna* x *generalis* L. H. Bailey 'Florence Vaughan', a daminozide /chlormequat tank mix ranging from 2500/1500 to 7500/1500 mg•L^{-1} effectively controlled vegetative growth when applied as a foliar spray, and was more effective at the higher rates (Bruner et al., 2001). At 30 days after treatment (DAT), heights of treated plants were 5% to14% less than untreated plants. Vegetative shoot heights of *Dianthus* 'Snowfire' (taxonomy unknown) of plants treated with 1500, 3000, and 6000 mg•L^{-1} chlormequat as a foliar spray (Messinger and Holcomb, 1986). All plants treated with the chemical had symptoms of phytotoxicity, ranging from minor leaf curling at 1500 mg•L^{-1} to chlorosis and necrosis of the leaves at 6000 mg•L^{-1}. In our studies, chlormequat chloride used alone caused phytotoxicity on *Phlox* and *Rudbeckia*. It also caused phytotoxicity on *Rudbeckia* in the first experiment when used in the tank mix. The second *Rudbeckia* study did not include either of the chlormequat treatments because of this. Chlormequat chloride was effective in controlling height of *Phlox* but not of *Rudbeckia*. The 4000 mg•L^{-1} treatment resulted in the shortest plants in the *Phlox* experiment. The tank mix was also effective in controlling height, average width, and dry weights of *Phlox* at any of the rates above 0 mg•L^{-1} in our studies. Quality ratings were also impacted by treatment. The 5000/1500 x 3 mg•L^{-1} rate resulted in the highest quality *Phlox* plants; but the ratings ranged from 2.3 to 2.8, and those differences would not have been distinguishable when looking at the plants. In the first *Rudbeckia* experiment, all rates higher than 0 mg•L^{-1} had lower quality ratings than that of the control due to the phytotoxicity.

In a study by Gad and Gerzson (1997), paclobutrazol was applied as a foliar spray at rates of 0, 250, 500, or 1000 mg•L^{-1} to rooted tip cuttings of *Rudbeckia laciniata* L., and plant height was suppressed by 54.1%, 59.6%, and 66.7%, respectively. The shortest plants were those being treated with 1000 mg•L^{-1}. Internode lengths also decreased as the rate of paclobutrazol (common name of Bonzi) increased. Plant fresh weight decreased when using the PGR, but there was no significant effect on leaf number or number of branches per plant. In our experiments, *Phlox* heights were significantly different between rates, and there was a significant difference in slopes of rates between weeks 4 and 6. Interestingly, the 160 mg•L^{-1} rate resulted in the tallest plants, and the 40 mg•L^{-1} rate resulted in the smallest plants at the end of the *Phlox* experiment. In the first (but not the second) *Rudbeckia* experiment, rate effects were found, and the 160 mg•L^{-1} treatment resulted in the plants with the shortest heights at the end of the experiment.. Between weeks 2 and 4, heights were significantly different from one another.

Uniconazole foliar spray at rates of 10 to 40 mg•L^{-1} reduced shoot height of *Coreopsis rosea* Nutt. 'American Dream' by 25 to 31% at first flower compared to controls (Burnett et al., 2000). Plant quality also increased with an increase in application rate (57 to 61% higher than controls). Plants appeared less leggy and more densely branched, with darker green foliage and more flowers than controls. Uniconazole had no effect on height of *Phlox* in our experiments, but did have a significant effect on height of *Rudbeckia* in the first experiment. Between weeks 2 and 4, slopes of the rates were significantly different from one another, with 60 mg•L^{-1} treatment resulting in the shortest plant at the end of the experiment. In the second *Rudbeckia* experiment, dry weights were significantly different from one another. The 0 mg•L^{-1} treatment produced the plant with the greatest dry weight, while the 30, 45, and 60 mg•L^{-1} treatments resulted in plants with significantly smaller dry weights.

Flurprimidol has been used for many years in the turf market under the name Cutless (Dow AgroSciences, LLC, Indianapolis, IN). McDaniel (1986) found flurprimidol to be effective in suppressing plant height to 46 to 50 cm compared to an average of 64 cm for the control with a 25 or 12.5 mg•L^{-1} foliar spray on 'Annette Hegg Dark Red' poinsettia (*Euphorbia pulcherrima* Willd.). At the 50 mg•L^{-1} rate, foliage puckering was noticed. At high rates, flowering was delayed up to 5 days, and significant decreases in stem dry weights and inflorescence diameters were observed. On *Canna* x *generalis* 'Florence Vaughn', Bruner et al. (2001) found that flurprimidol suppressed vegetative height 20% to 39% and 21% to 33% at first and second flower with increasing rates of 15 to 45 mg•L^{-1} compared to the controls. Increasing rates of flurprimidol at rates ranging from 25 to 150 mg•L^{-1} reduced shoot height at first flower of *Coreopsis rosea* 'American Dream' 13% to 34% (Burnett et al., 2000). Control plants were considered unmarketable, while those treated with the PGRs were considered marketable based on visual observations. Flurprimidol had no effect on height of either *Phlox* or *Rudbeckia* in any of our experiments. Quality ratings were affected by treatment in the first *Rudbeckia* experiment. The controls had the highest quality ratings, with the 60 mg•L^{-1} treatment resulting in the lowest quality plants. Dry weights were significantly different, however, in the second *Rudbeckia* experiment. The control plants had the greatest dry weights, while those treated with the 30, 45, and 60 mg•L^{-1} rates resulted in significantly smaller dry weights than the controls.

Overall, *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer' do not respond well to spray applications of growth regulators. For *Rudbeckia*, some treatments were more effective during the first experiment than the second and vice versa. This could be related to the time of the year the experiments were conducted—the first being in the fall, and the second in the spring. It would be useful to repeat the experiments at the same time of year to see if PGR effects are consistent. It would also be interesting to see whether or not the growth regulators that were somewhat effective showed persistence in the landscape. Latimer et al. (2001) reported that applications of uniconazole showed some persistence of the chemical on *Phlox paniculata* 'Joliet' when placed into the landscape.

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Table 3.1. Dry weight means for the *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer' experiments.

Treatment ($mg \bullet L^{-1}$)	***Phlox*** **Dry weight (g), 6 WAT**[z]	***Rudbeckia*** **Experiment 1 Dry Weight (g), 4 WAT**	***Rudbeckia*** **Experiment 2 Dry Weight (g), 7 WAT**
Daminozide			
0	9.2	15.3	18.9
5000	10.4	16.0	17.8
7500	8.1	16.9	17.2
10000	9.2	14.7	18.1
Regression	**NS**[y]	**NS**	**NS**
Chlormequat Chloride			
0	8.6	13.6	
1000	10.1	11.2	
2000	11.3	12.2	
3000	7.7	12.0	
4000	8.2	10.3	
Regression	**NS**	**NS**	
Daminozide/Chlormequat chloride tank mix			
0	8.8	15.6	
5000/1500x2 *Phlox*, x1 *Rudbeckia*	7.3	16.4	
5000/1500x3 *Phlox*, x2 *Rudbeckia*	6.6	14.3	
7500/1500x2 *Phlox*, x1 *Rudbeckia*	7.3	14.1	
7500/1500x3 *Phlox*, x2 *Rudbeckia*	6.6	13.4	
***P*-value**	**0.0044**	**NS**	
LSD	**1.2446**		
Paclobutrazol (Bonzi)			
0	9.6	8.7	16.1
40	8.9	8.0	16.2
80	9.2	8.6	16.0
120	9.0	9.8	16.3
160	9.0	9.8	15.5
Regression	**NS**	**NS**	**NS**
Uniconazole			
0	7.8	12.1	20
15	8.4	11.1	17.9
30	8.3	14.1	16.9
45	8.8	9.2	15.9
60	8.1	10.5	15.8
Regression	**NS**	**NS**	**L****
Flurprimidol			
0	8.8	13.0	19.6
15	9.8	15.5	17.9
30	12.7	14.9	16.3
45	10.0	10.9	17.0
60	9.4	11.7	17.3
Regression	**NS**	**NS**	**Q***
Paclobutrazol (Piccolo)			
0			15.6
40			17.4
80			16.1
120			15.5
160			17.1
Regression			**NS**

[z]WAT=Weeks After Treatment

[y]Significance levels using linear (L) or quadratic (Q) regression: $P<0.05$ (*), 0.01 (**), or not significant (NS) at $P=0.05$.

Table 3.2. Quality rating means at 5 rates of tank mix, chlormequat chloride, and flurprimidol in the *Phlox paniculata* 'Blue Boy' experiment (6 weeks after treatment or WAT), and the first *Rudbeckia hirta* 'Indian Summer' (4 WAT) experiment.

	mg•L^{-1}	**Quality Rating**
Phlox	**Daminozide/chlormequat chloride**	
	0	2.3
	5000/1500 x 2	2.6
	5000/1500 x 3	2.8
	7500/1500 x 2	2.5
	7500/1500 x 3	2.4
	***P*-value**	**0.0308**
	LSD	**0.3192**
Rudbeckia	**Chlormequat chloride**	
	0	3.4
	1000	2.8
	2000	2.8
	3000	2.5
	4000	2.3
	Linear *P*-value	**<0.0001**
	Flurprimidol	
	0	4.0
	15	3.6
	30	3.8
	45	3.6
	60	3.6
	Quadratic *P*-value	**0.0473**

[z]Means separation within a column using LSD.

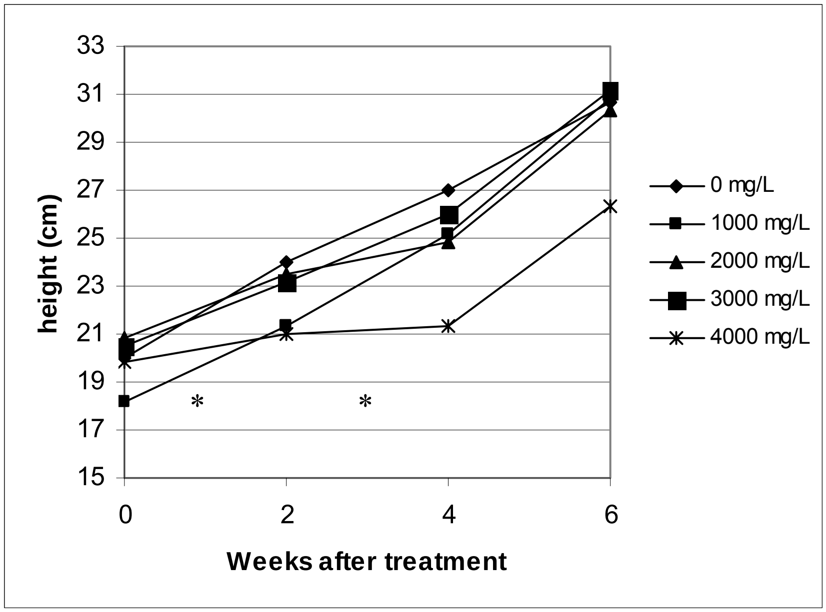

Figure 3.1. Heights over time at five rates (0, 1000, 2000, 3000, and 4000 mg•L^{-1}) of chlormequat chloride for *Phlox paniculata* 'Blue Boy'.

*Indicates that the change in height from week 0 to week 2, and week 2 to week 4 is not the same for all concentrations.

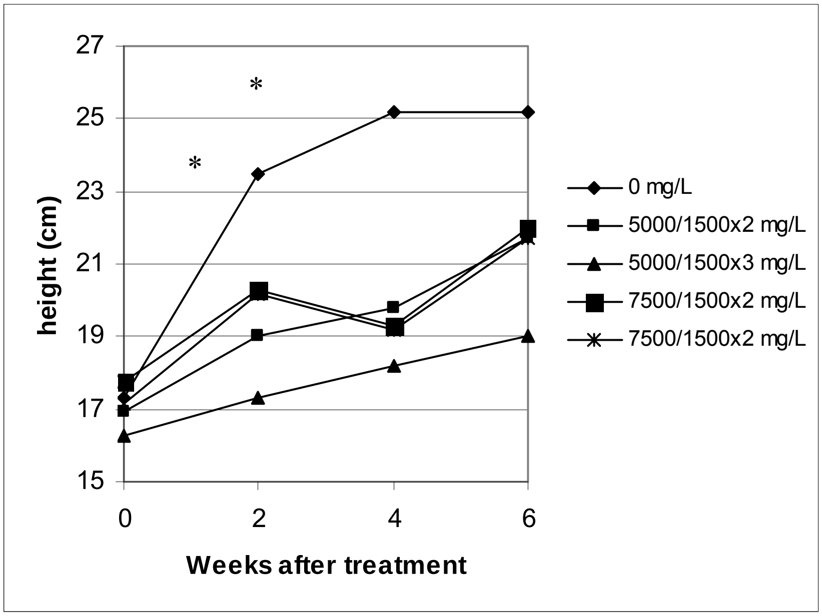

Figure 3.2. Heights over time at five rates (0, 5000/1500x2, 5000/1500x3, 7500/1500x2, 7500/1500x3 mg•L^{-1}) of daminozide/chlormequat chloride tank mix for *Phlox paniculata* 'Blue Boy'.

*Indicates that the change in height from week 0 to week 2, and week 2 to week 4 is not the same for all concentrations.

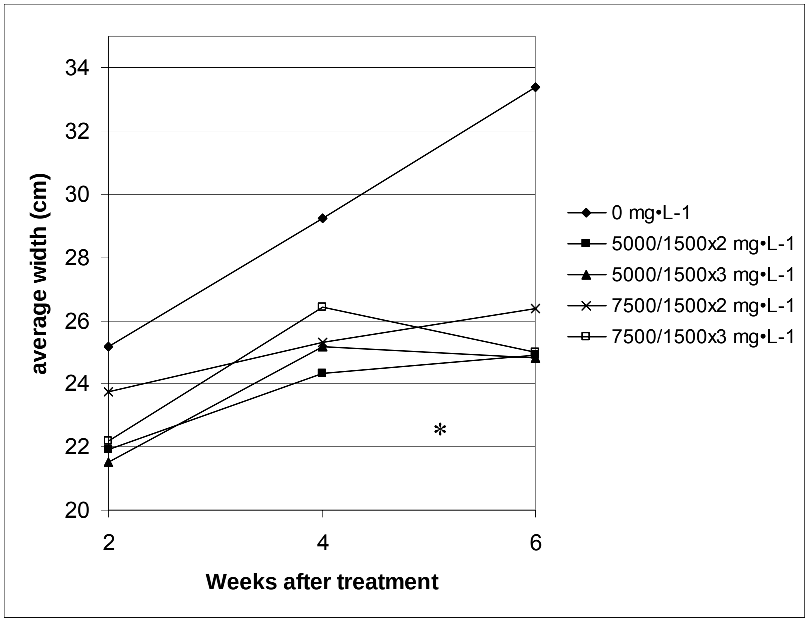

Figure 3.3. Average widths over time at five rates (0, 5000/1500x2, 5000/1500x3, 7500/1500x2, 7500/1500x3 mg•L^{-1}) of daminozide/chlormequat chloride tank mix for *Phlox paniculata* 'Blue Boy' in the PGR experiment.

*Indicates that the change in height from week 0 to week 2, and week 2 to week 4 is not the same for all concentrations.

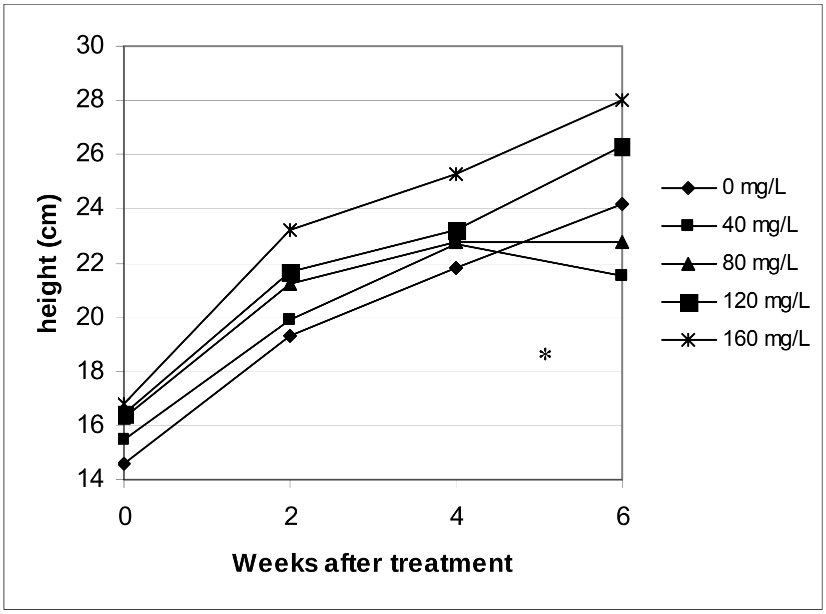

Figure 3.4. Heights over time at five rates (0, 40, 80, 120, and 160 mg•L^{-1}) of paclobutrazol for *Phlox paniculata* 'Blue Boy'.

*Indicates that the change in height from week 4 to week 6 is not the same for all concentrations.

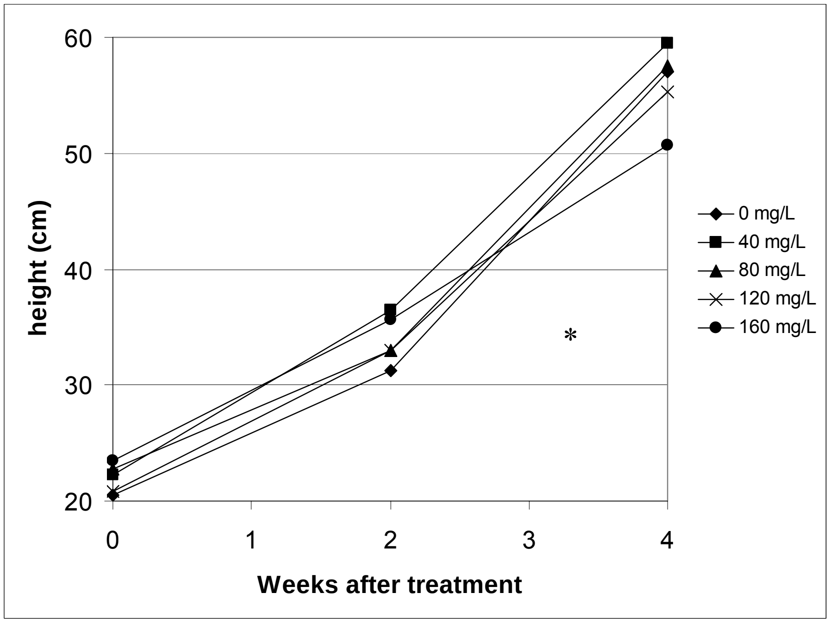

Figure 3.5. Heights over time at five rates (0, 40, 80, 120, and 160 mg•L^{-1}) of paclobutrazol for the first *Rudbeckia hirta* 'Indian Summer' experiment.

*Indicates that the change in height from week 4 to week 6 is not the same for all concentrations.

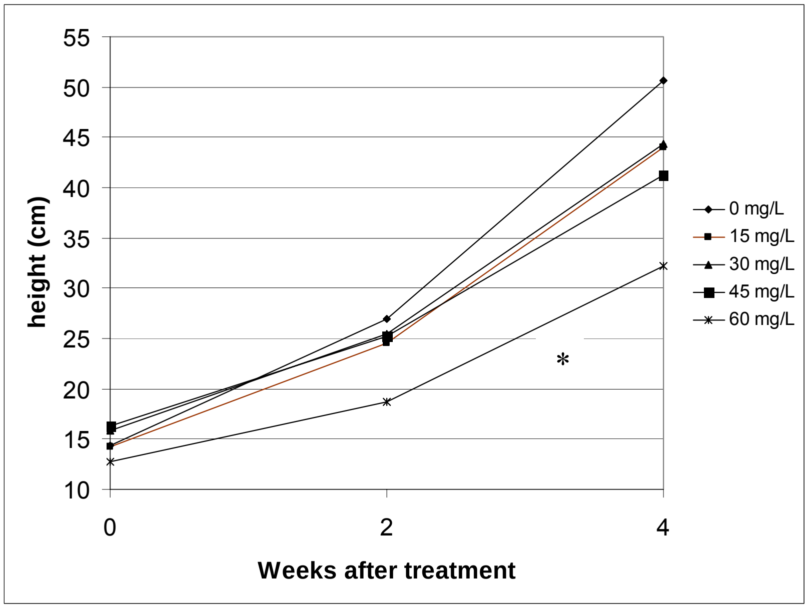

Figure 3.6. Heights over time at five rates (0, 15, 30, 45, and 60 mg•L^{-1}) of uniconazole for *Rudbeckia hirta* ‘Indian Summer’ in the first experiment.

*Indicates that the change in height from week 2 to week 4 is not the same for all concentrations.

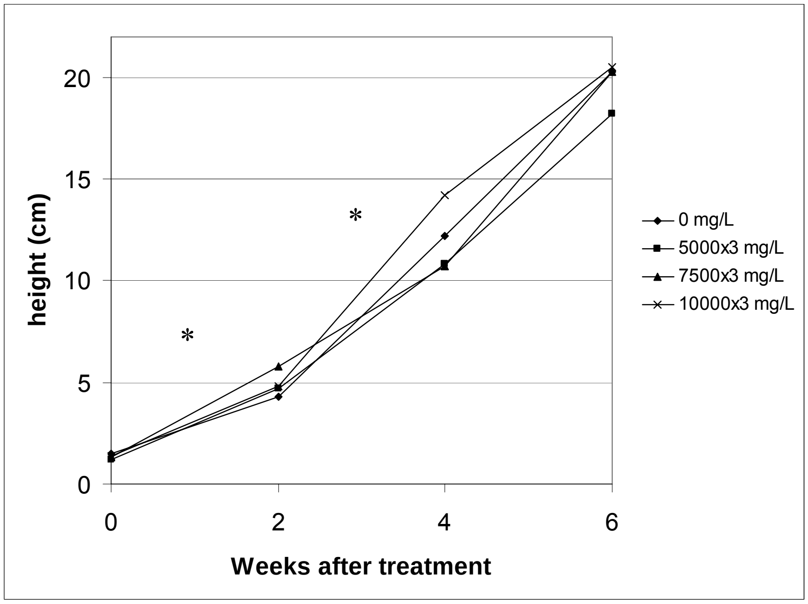

Figure 3.7. Heights over time in weeks at four rates (0, 5000 x 3, 7500 x 3, and 10000 x 3 mg•L^{-1}) of daminozide for the *Rudbeckia hirta* 'Indian Summer' Spring 2004 experiment. * Indicates that the change in height from week 0 to week 2, and week 2 to week 4, is not the same for all concentrations.

Chapter Four: Effects of plant growth regulators on the severity of powdery mildew on *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer'

Phlox paniculata L. and *Rudbeckia hirta* L. are popular North American native herbaceous perennials in the landscape. Perennials in general have a tendency to quickly outgrow their containers in the greenhouse. Chemical plant growth regulators (PGRs) are commonly used to control plant size in the horticulture industry. Unfortunately, both *Phlox* and *Rudbeckia* are extremely susceptible to powdery mildew. Certain PGRs, namely the triazoles, have been shown to reduce the severity of some plant diseases. The effects of PGRs on powdery mildew severity on *P. paniculata* 'Blue Boy' and *R. hirta* 'Indian Summer' were investigated. Two greenhouse experiments were conducted on each species, in Fall 2003 and Spring 2004. Based on preliminary rate studies, actively growing *Rudbeckia* and *Phlox* plants were sprayed with the following growth regulator treatments: 10,000 $mg \cdot L^{-1}$ daminozide (B-Nine) applied twice; 160 $mg \cdot L^{-1}$ paclobutrazol (Bonzi or Piccolo); 60 ppm flurprimidol (Topflor); 60 $mg \cdot L^{-1}$ uniconazole (Sumagic); 4000 $mg \cdot L^{-1}$ chlormequat chloride (Cycocel) on *Phlox* only; two applications of a tank mix of daminozide/chlormequat tank mix at a rate of 7500/1500 $mg \cdot L^{-1}$ (applied to *Rudbeckia* in the Fall experiment only); and a nontreated control. The second sprays of the growth regulator treatments that were applied more than once were applied two weeks after the initial PGR application. Half of the plants in each experiment were harvested 2 weeks after initial treatments of PGRs to determine whether or not there were statistical differences in height, average width, and shoot dry weights of the plants. At that time, the remaining plants were inoculated with powdery mildew and disease severity was monitored several times using the Horsfall-Barratt Scale for assessing disease beginning approximately one week following inoculation. Inoculated plants were harvested at the end of the experiment (7 weeks after PGR treatment for both Fall studies and the Spring *Phlox* study, and 6 weeks after PGR treatment for the *Rudbeckia* Spring study) to look for shoot dry weight differences across treatments, as well as differences in height and average width. Our results indicate that for the *Phlox* studies, the Bonzi and Piccolo paclobutrazol treatments significantly reduced powdery mildew severity compared to the controls in the Fall experiment, and chlormeqaut and uniconazole significantly reduced powdery mildew severity in the Spring experiment. In the *Phlox* studies, chlormequat chloride, tank mix, uniconazole, and flurprimidol treatments were effective in reducing height compared to the control. In the Fall experiment, daminozide, chlormequat chloride, tank mix, daminozide, chlormequat chloride, tank mix, paclobutrazol (Bonzi and Piccolo), uniconazole, and flurprimidol were effective in reducing average widths of *Phlox*, and in the Spring, daminozide, chlormequat chloride, and the tank mix were effective. For the *Rudbeckia* experiments, the Bonzi and Piccolo treatments significantly reduced disease severity compared to the control at the end of the Fall experiment, and Bonzi significantly reduced severity of powdery mildew at the end of the Spring experiment. Uniconazole was effective in reducing disease severity up until the final disease rating. Only average widths were affected in the *Rudbeckia* studies. In both the Fall and Spring experiments, paclobutrazol (Bonzi) and flurprimidol effectively reduced average widths; in the Fall experiment, paclobutrazol (Piccolo) was effective, and in the Spring experiment, uniconazole was effective. At the termination of the experiments, dry weights were significantly reduced in plants treated with daminozide, chlormequat, daminozide/chlormequat tank mix, or uniconazole treatments during the Fall experiment, and with chlormequat, and daminozide/ chlormequat, tank mix treatments in the Spring experiment relative to untreated controls.

[Chemicals used: Daminozide: butanedioic acid mono (2,2-dimethylhydrazide); chlormequat chloride: (2-chloroethyl) trimethylammonium chloride; paclobutrazol: (±)-(R*,R*)-β-((4-chlorophenyl) methyl)-α-(1,1,-dimethylethyl)-1H-1,2,4,-triazole-1-ethanol); uniconazole: (E)-1-(P-chlorphenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl-1-penten-3-ol); and flurprimidol: (α-1-methylethyl)-α4-(trifuloromethoxy) phenyl-5-pyrimidinemethanol)]

Introduction

Phlox paniculata and *Rudbeckia hirta* are popular native herbaceous floriculture crops. One reason for their popularity is that they are easy to grow and can tolerate harsh environments in our landscapes. They also have showy, attractive inflorescences. In the greenhouse, both can grow to unmanageable heights if not controlled. Growth regulators are successful in controlling the size of many herbaceous perennials and could potentially be used on *Phlox* and *Rudbeckia*. Unfortunately, many selections of *Phlox paniculata* and *Rudbeckia hirta* are extremely susceptible to powdery mildew (Chase et al., 1995), a disease that decreases salability of these crops. Because the symptoms are obvious and unattractive, powdery mildew is probably one of the most troublesome diseases of annuals and perennials. Powdery mildew infection rarely kills plants, but the aesthetic value is frequently reduced (Coyier, 1985). New growth, stems, flowers or fruit are usually attacked, although older tissues can often be more susceptible on certain plants. Powdery mildew produces distinguishable whitish, powdery growth on the host plant (Dole and Wilkins, 1999). The pathogen is generally found on the upper leaf surfaces, but can occur on the undersides (Daughtrey et al., 1995). The disease looks very similar regardless of the type of plant affected; even so, different species of the powdery mildew fungus are responsible for infections on different plants (Chase et al., 1995). Thus, having one species of plant infected with powdery mildew will not necessarily mean that another species of plant growing nearby will become infected. All powdery mildews react similarly to environmental factors and fungicidal controls.

Symptoms of powdery mildew occur later in the year during drier conditions, rather than during the rainy days of spring (Chase et al., 1995). The powdery mildew fungus sporulates when humidity is high rather than when the leaves are wet. The fungus rarely germinates in free water (Daughtrey et al., 1995). Most powdery mildews on greenhouse crops develop best at humidities greater than 95% and at an optimum temperature of 20ºC. In the greenhouse, powdery mildew is generally spread by air currents and splashing water.

One way to control the disease culturally is to increase air flow around the plants since that will decrease relative humidity (Daughtrey et al., 1995). Irrigating plants overhead, especially late in the day, keeps humidity around the plants high, promoting the disease (Chase et al., 1995). The use of resistant cultivars, when available, allows the crop to be grown in the presence of the pathogen with minimal loss and minimal chemical applications. Today, fungicides have become the most popular means of treating powdery mildew (Daughtrey et al., 1995); however, fungicides often become a costly management practice. A group of triazole derivatives have been developed for use as either fungicides or as plant growth regulators (Fletcher et al., 1986). To varying degrees, the chemicals exhibit both fungicidal and growth regulating properties.

Studies have been performed to determine whether PGRs are effective in reducing disease; however, most of the current literature in this area relates to field crops and horticultural crops, such as tree fruits, rather than ornamentals. Previously published research has found paclobutrazol to be effective in reducing powdery mildew on *Rudbeckia hirta* (Yang and Zhang, 2003), but not on *Phlox*. The objective of this study was to identify specific PGRs that are effective in reducing plant size of containerized *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer' during times of the year when the plants are susceptible to powdery mildew, in the hopes that a grower can reduce or eliminate the use of fungicides.

Materials and Methods

The first set of experiments was conducted in a glass-covered greenhouse on the campus of Virginia Tech in Blacksburg, Virginia. *Phlox paniculata* L. 'Blue Boy' and *Rudbeckia hirta* L. 'Indian Summer' plugs were used in the experiments. Liners were potted into 10.8 cm (4.25 in) diameter (1180 cm^3) plastic containers on 9 Sept. 2003 (72 cell size; Yoder Green Leaf Perennials, Leola PA). PGR treatments began 25 Sept. Plants were fertigated with Cal Mag 5-5-15 (The Scotts Co., Marysville, OH). The plants were treated with the following plant growth regulators (PGRs):

- nontreated control
- 10000 $mg \cdot L^{-1}$ daminozide (B-Nine, Crompton/Uniroyal Chemical Co., Inc., Middlebury, CT)
- 4000 $mg \cdot L^{-1}$ chlormequat chloride (Cycocel, Olympic Horticultural Products Co., Mainland, PA), *Phlox* experiments only
- 7500/1500 $mg \cdot L^{-1}$ daminozide/chlormequat chloride tank mix, both *Phlox* experiments, but only *Rudbeckia* Fall experiment
- 160 $mg \cdot L^{-1}$ paclobutrazol [Bonzi (Syngenta Chem. Co., Greensboro, NC)]
- 60 $mg \cdot L^{-1}$ uniconazole (Sumagic, Valent USA, Marysville, OH)
- 60 $mg \cdot L^{-1}$ flurprimidol (TopFlor, SePRO Corp., Carmel, IN)

- ❖ 160 mg·L^{-1} paclobutrazol [Piccolo (Fine Agrochemicals, Worcester, U.K.)], with the same active ingredient as Bonzi

These rates were selected from previous PGR experiments that were performed on *P. paniculata* 'Blue Boy' and *R. hirta* 'Indian Summer' (see Chapter 3).

The ThetaProbe soil moisture sensor (ML2x; Delta-T Devices Ltd, Cambridge, U.K.) was used to determine when plants needed to be watered. The ThetaProbe measures volumetric soil moisture content, which is the ratio between the volume of water present in the soil and the total volume of the soil sample. Different moisture regimes were selected for the growth of the *Phlox* and *Rudbeckia* plants, determined by previous work that was performed on both species. Ten percent of the plants in an experiment were randomly selected and probed daily. If half of those plants that were probed reached a predetermined percentage (20% or less for *Phlox*, 30% or less for *Rudbeckia*), then all of the plants in the experiment were watered.

Heights were measured from the rim of the pot to the highest point of the plant. Average widths were obtained by measuring the maximum width of a plant, then taking another width measurement perpendicular to the initial measurement, and averaging the two numbers. Media pH and electrical conductivity (EC) were monitored using the PourThru method (Whipker et al., 2000).

Two weeks after treatment (WAT) with the growth regulators, when the PGRs had had time to take effect, half of the plants in each experiment were harvested and plant heights and average widths were measured. Plants were harvested for shoot dry weights by removing shoots at the soil line. Each plant was placed in its own paper bag and put into a dryer that was kept at an average temperature of 65.5ºC (150ºF). The plants were removed from the dryer when they had dried completely, and dry weights were measured.

The remainder of the plants were inoculated with powdery mildew from similar plants that were naturally infected in the greenhouse (Fig. 4.1). An infected leaf with powdery mildew that covered 90% or more of the leaf was used to inoculate the plants in the experiment. One leaf was used to inoculate two leaves of each of two plants. The infected leaf was gently rubbed across an uninfected leaf (Nicot et al., 2002). Plants from all treatments were inoculated. In each of the experiments, the *Rudbeckia* plants were inoculated with *Golovinomyces cichoracearum* and the *Phlox* plants were inoculated with *Golovinomyces magnicellulatus* (U. Braun) VP Gelyuta.

Individual plants of *Phlox* and *Rudbeckia* were rated for disease severity using the Horsfall-Barratt Scale for assessing disease (Campbell and Madden, 1990) (Table 4.1). Each plant was rated according to the percent coverage of powdery mildew on the entire plant (Figs. 4.2 and 4.3). The number of times the plants were rated depended upon how quickly the powdery mildew spread. The more quickly the rate of the pathogen's growth, the more often the disease ratings were given. These ratings were given to the *Phlox* plants seven times for the fall experiment and four times for the spring experiment, and for the *Rudbeckia* plants eleven times for the fall experiment and four times for the spring experiment. All plants were rated on the same day.

A steady state porometer (LI-1600, LICOR, Inc., Lincoln, NE) was used to monitor water relations of the plant twice during the course of each experiment. Leaf temperature, relative humidity, light level (quantum), diffusive resistance, and transpiration data were recorded. If powdery mildew was present, disease ratings were also recorded on the same day, and an analysis of covariance was used to determine whether or not there was a correlation between the disease ratings of a specific treatment and the water relations of the plant.

The second set of experiments was conducted in a double layer polyethylene greenhouse on the Virginia Tech campus. The same plant type and plug size from the same grower were used. The *Rudbeckia* plugs arrived 9 March 2004, and the *Phlox* plugs arrived 1 April 2004. *Rudbeckia* PGR treatments began 26 March and the experiment ended 10 May (6 WAT); *Phlox* PGR treatments began 14 April and the experiment ended 3 June (7 WAT). Each species of plant was treated as a separate experiment in both the Fall and Spring studies.

The experiments were arranged in a completely randomized design with six single plant replicates. Different media types, irrigation rates, and fertilizer rates were selected for the *Phlox* and *Rudbeckia* experiments from preliminary experiments performed during Summer 2003. Data were analyzed using the Statistical Analysis System (SAS) Version 8 (SAS Institute, Inc., Cary, N.C.). Heights, average widths, pH, EC, water relations (porometer measurements: leaf temperature, relative humidity, light level /quantum, diffusive resistance, and transpiration), and dry weights were all analyzed using two-way analysis of variance (ANOVA) unless an interaction was significant. When interactions were significant, one-way ANOVA was used instead. One-way ANOVA was used to analyze the disease ratings, and analysis of covariance (ANCOVA) was used to determine if there was any correlation between the water relations data (leaf temperature, relative humidity, light level /quantum, diffusive resistance, and transpiration) and the disease ratings that were taken on or around those dates.

***Phlox experiments*:**

The day the PGR treatments began, 96 plugs were selected for uniformity. Plugs were potted in commercial medium, which consisted of 45% Canadian sphagnum peat moss, 25% aged pine bark, 15% perlite, 15% vermiculite, wetting agent, a liquid-starter nutrient, and had a pH of 5.5 to 6.5 (Fafard 3B, Fafard, Inc., Anderson, S.C.). Fall daytime temperatures ranged from 24ºC to 27ºC (75ºF to 81ºF), and nighttime temperatures ranged from16ºC to 18ºC (60ºF to 64ºF). Spring daytime temperatures ranged from 27ºC to 34ºC (80ºF to 94ºF), and nighttime temperatures ranged from 15ºC to 19ºC (59ºF to 67ºF). Media water status was monitored daily with the ThetaProbe and plants were fertigated with 200 $mg \cdot L^{-1}$ N when media reached 30% moisture or below. Water relations data (leaf temperature, relative humidity, light level/quantum, diffusive resistance, and transpiration) were recorded 9 Oct. and 30 Oct. 2003, 28 April 2004, and 27 May 2004.

***Rudbeckia experiments*:**

Seventy-two plugs were selected for uniformity on the day the PGR treatments began. Plugs were potted using a commercial medium consisting of 65 to 75% bark fines, 20 to 25% Canadian sphagnum peat moss, 9 to 15% perlite, and a starter charge (Scott's Sierra Perennial Mix, Scott's Co., Merrifield OH). Fall daytime temperatures ranged from 24ºC to 27ºC (75ºF to 81ºF), and nighttime temperatures ranged from 16ºC to 18ºC (60ºF to 64ºF). Spring daytime temperatures ranged from 23ºC to 33ºC (74ºF to 92ºF), and nighttime temperatures ranged from 17ºC to 20ºC (62ºF to 68ºF). Media water status was monitored daily with the ThetaProbe and plants were watered with 300 $mg \cdot L^{-1}$ N when media reached 40% moisture or below. Water relations data (leaf temperature, relative humidity, light level/quantum, diffusive resistance, and transpiration) were recorded 9 Oct. and 30 Oct. 2003, 9 April 2004, and 7 May 2004. Three disease ratings were given to the *Rudbeckia* plants before the inoculation took place (13, 3, and one day before inoculation) because the plants became infected naturally (before PGR application) prior to the inoculation. The tank mix treatments were not used in the spring experiment because of phytotoxicity to the plants in the fall experiment. Preliminary PGR rate work performed on the *Rudbeckia* plants indicated that phytotoxicity occurred on the chlormequat chloride treated plants; therefore, those treatments were removed from both the fall and spring disease studies.

Results

***Phlox experiments*:**

Experiment 1, Fall 2003. For the seven disease ratings taken, the first rating of the treated plants was not significant but the rest were (Table 4.2). Disease ratings of plants treated with either paclobutrazol chemical (Bonzi and Piccolo) were similar each time the plants were rated, and at the end of the experiment they were significantly lower than that of the controls and all of the other treatments. The daminozide and tank mix treated plants had significantly higher disease ratings compared to the controls, and the chlormequat chloride, uniconazole, and flurprimidol treated plants performed no better than the controls.

For the height and average width data, there were no significant differences in heights, but there were differences in average width for the first harvest (Table 4.3). The chlormequat chloride and tank mix treated plants had significantly smaller average widths from the control plants, but the daminozide, paclobutrazol (Bonzi and Piccolo), uniconazole, and flurprimidol treated plants were similar to the control average widths. For the second harvest, there were significant differences for heights and average widths (Table 4.3). Daminozide and paclobutrazol (both Bonzi and Piccolo) treated plants had similar heights as the controls, and the chlormequat chloride, tank mix, and uniconazole treated plants were significantly shorter than the controls. The average widths of plants treated with either paclobutrazol chemicals were similar to the controls, whereas plants treated with daminozide, chlormequat chloride, tank mix, uniconazole, or flurprimidol had average widths significantly smaller than the controls.

For shoot dry weights, interactions were significant, and one-way ANOVA was used. Shoot dry weights were significantly different between treatments for the second harvest but not for the first harvest (Table 4.2). Paclobutrazol or flurprimidol treatments produced plants with shoot dry weights similar to those of the control. The daminozide/chlormequat chloride tank mix treatment produced plants that had the smallest dry weights, which were significantly less than those of the control. Daminozide, chlormequat chloride, and uniconazole treatments also produced plants with shoot dry weights that were significantly lower than those of the controls.

The two porometer measurement times were significantly different for leaf temperature, relative humidity, diffusive resistance, and transpiration (all at $P<0.0001$), but not for light level. There were no interactions of water relations data and PGR, and no effects of PGRs. There was no correlation between disease ratings and any of the water relations variables (data not presented).

Experiment 2, Spring 2004. Chlormequat chloride and uniconazole treated plants had significantly lower disease ratings compared to the controls at the end of the experiment (Table 4.4). Significant differences were found for the second and fourth disease ratings, although for the second rating, ratings of the PGR treatments were not significantly different from those of the control; however, they were different from one another. For the fourth and final disease rating, plants treated with daminozide, tank mix, paclobutrazol and flurprimidol had similar ratings to the control, and plants treated with chlormequat chloride and uniconazole had significantly lower disease ratings than those of the control.

For the first harvest, significant differences were found for both height and average width data (Table 4.3). Plants treated with daminozide or paclobutrazol (Bonzi and Piccolo) had heights similar to the controls, but plants treated with chlormequat chloride, tank mix, uniconazole, and flurprimidol had significantly shorter heights than the control plants. The plants treated with daminozide, paclobutrazol (Bonzi and Piccolo), uniconazole and flurprimidol had average widths similar to the control plants, and the plants treated with chlormequat chloride and the tank mix had significantly smaller average widths than the control plants. For the second harvest, there were no significant differences found in the heights, but there were differences in average widths (Table 4.3). Plants treated with paclobutrazol (Bonzi and Piccolo), uniconazole, or flurprimidol had average widths similar to those of the control plants, and the plants treated with daminozide, chlormequat chloride, or the tank mix had significantly smaller average widths than the control plants.

Significant differences in shoot dry weight were found for the second harvest but not for the first (Table 4.4). Daminozide, paclobutrazol, and the control treatments all produced the plants with the greatest shoot dry weights. The chlormequat chloride, daminozide/chlormequat chloride, uniconazole and flurprimidol treatments produced plants with significantly smaller shoot dry weights compared to the controls.

The second and fourth disease ratings of the plants were significantly different (Table 4.4). There were significant time x PGR interactions for leaf temperature ($P<0.0001$), diffusive resistance ($P=0.0438$), and transpiration ($P=0.0539$); however, analyzed using one-way ANOVA, none of those variables was significant (data not presented). There was no correlation between disease ratings and leaf temperature, relative humidity, light level, diffusive resistance, or transpiration.

***Rudbeckia experiments*:**

Experiment 1, Fall 2003. Phytotoxicity occurred on the tank mix treatments. Phytotoxicity was indicated by a severe chlorosis of the foliage on which chemical contact occurred and the plants did not entirely grow out of it by the end of the four week experiment. The first three of the eleven disease ratings were not significant (those taken before inoculation) but all ratings following inoculation were significant (Table 4.5; the ratings 1-3, taken prior to inoculation, not included because they were not significant). Plants treated with the paclobutrazol chemicals (Bonzi and Piccolo) had the lowest powdery mildew severity throughout the text. The daminozide, tank mix, uniconazole, and flurprimidol treatments performed no better than the controls at the end of the experiment; however, uniconazole was effective in significantly reducing powdery mildew severity compared to the control plants until the final disease rating.

For the first harvest, there were no significant differences found in the heights, but there were significant differences in the average widths (P=0.0094) (Table 4.6). The average widths of the tank mix and uniconazole treatments were similar to those of the control plants, but the plants treated with daminozide, paclobutrazol (Bonzi and Piccolo), and flurprimidol had significantly smaller average widths than the control. For the second harvest, no significant differences were found for height or average width data (Table 4.6).

Harvest was significant for shoot dry weight data, but PGR treatments were not significantly different, and there was no significant interaction between harvest and PGR (data not presented). For leaf temperature, relative humidity, light level, diffusive resistance, and transpiration, there were no interactions and there were no significant differences between the PGR treatments, but the two measurement times were significantly different from one another for all the variables. The correlation between disease ratings and water relations data was significant only for the variables diffusive resistance and transpiration (P=0.0455 and P=0.0516 respectively) for the first porometer reading, but they were not affected by PGR (data not shown).

Experiment 2, Spring 2004: The first and fourth disease ratings showed significant differences with respect to PGR treatment, but the second and third ratings did not (Table 4.7).

For the first disease rating taken after inoculation, PGR treatments were not significantly different from the control, but differences occurred between one another. Daminozide or flurprimidol treated plants resulted in the highest disease ratings, and plants treated with paclobutrazol or uniconazole had the lowest disease ratings. Plants treated with paclobutrazol (Bonzi) had significantly less disease at the end of the experiment than plants treated with the other chemicals. For the first harvest, no significant differences were found for the height data, but there were significant differences for the average width data (Table 4.6). Plants treated with daminozide and paclobutrazol (Piccolo) had average widths similar to those of the controls, but the plants treated with paclobutrazol (Bonzi), uniconazole, and flurprimidol had significantly smaller average widths than the control plants. For the second harvest, there were no significant differences found for the height or average width data (Table 4.6).

For shoot dry weights, only harvest time was significant; PGRs and the PGR x time interactions were not significant. For the water relations data, time was significant in all cases except for diffusive resistance. No PGR or PGR x time interactions were significant. PGR and disease ratings were not significantly different for leaf temperature, relative humidity, light level, diffusive resistance, and transpiration (data not presented).

Discussion

Significant differences in the severity of powdery mildew did occur between treatments. Overall, the paclobutrazol chemical, Bonzi, maintained the lowest disease ratings over time, delaying the development of the pathogen. Piccolo performed similarly to Bonzi in the first *Rudbeckia* experiment, and in both of the *Phlox* experiments, but not in the spring *Rudbeckia* experiment.

Other studies have shown similar success in reducing disease severity using PGRs. Paclobutrazol, which belongs in the chemical class of triazoles, has delayed the onset of wilting and reduced the incidence of fusarium wilt (*Fusarium oxysporum* f. sp. *melonis*) on melon (*Cucumis melo* L. cv. Ananas Yoqneam) seedlings that were grown in soil pretreated with either 0.3 or 0.6 $\mu g \cdot g^{-1}$ paclobutrazol (Cohen, 1987). Total wilt incidence was significantly reduced, and paclobutrazol delayed the appearance of wilt symptoms during the first 10 days. Paclobutrazol applied as a soil drench at 20 or 40 mg/seedling pair helped to control the environmental predisposition of black spruce (*Picea mariana* (Mill.) B. S. P.) seedlings to *Botrytis* infection as well as to decrease sporulation of *Botrytis cinerea* (Zhang, 1994). Zhang et al. (1994) state that paclobutrazol is effective, not because of its fungicidal properties, but because it offers stress protection. The results of an experiment performed by Copas and Williams (1987) led these researchers to conclude that growth regulator sprays of paclobutrazol to the foliage of cider apple (*Malus* sp.) cvs. Michelin and Sweet Coppin at 2000 $mg \cdot L^{-1}$ (circa 4.0 g.a.i. per tree) for control of vegetative growth could have additional advantages in orchards infected with *Chondrostereum purpureum*, the cause of silverleaf, because colonization of the fungus was reduced in the treated trees. An experiment performed by Blaedow et al. (2003) showed that a one-time foliar application of paclobutrazol (0.02 g a.i. ml^{-1}) reduced the severity of apple scab (*Venturia inaequalis*) on two mature crabapple (*Malus* sp. P. Mill) cultivars, Hopa and Snow Drift, and on 'Indian Magic' saplings.

Flurprimidol and paclobutrazol significantly lowered disease ratings (dy/dt, where y = amount of disease and t = time) of dollar spot (*Sclerotinia homeocarpa* F. T. Bennett) epidemics in creeping bentgrass (*Agrostis palustris* Huds. cv. Penncross) compared to non-treated turf (Burpee et al., 1996). The authors suggest dollar spot was suppressed by paclobutrazol and flurprimidol primarily as a result of fungistatic activity because both are chemically related to fungicides that are inhibitors in the fungal sterol biosynthesis pathway. However, Burpee et al. (1996) also suggest that changes in environmental effects due to inhibition of shoot growth, such as changes in canopy temperature and duration of leaf wetness, cannot be ruled out. In our experiments, flurprimidol performed no better than the controls in controlling powdery mildew at the termination of the experiments.

Plants treated with uniconazole, another triazole chemical, had significantly lower disease ratings than the control in the spring *Phlox* experiment, but performed comparably to the control in the fall experiment and in the spring *Rudbeckia* experiment. In the fall *Rudbeckia* study, uniconazole was effective in reducing disease severity compared to the control up until the final disease rating. Similarly, research conducted by Rempel and Hall (1995) reported that split applications of uniconazole (2.12 and 5.64 $kg \cdot ha^{-1}$) reduced blackleg (*Leptosphaeria maculans* (Desm.) Ces & de Not.) of canola (*Brassica napus* L.).

Daminozide performed no better than the control during or at the end of the experiments, and in the first *Phlox* experiment there was significantly more disease with the daminozide treatment than the control at the end of the experiment. Chlormequat provided some protection in the spring *Phlox* experiment, but phytotoxicity occurred on all plants. Phytotoxicity also occurred on both species with the daminozide/chlormequat tank mix treatment, (to a lesser degree on the *Phlox* compared to the chlormequat chloride treatment), and in none of the experiments did the tank mix offer any protection against the pathogen compared to the control. In the fall *Phlox* experiment, the disease ratings of plants treated with the tank mix were higher than those of the control, and in the spring *Phlox* experiment the treatment performed similarly to the fall experiment. Comparatively, chlormequat chloride (500 and 1000 $mg \cdot L^{-1}$) and daminozide (1000 $mg \cdot L^{-1}$), when applied to potato (*Solanum tuberosum* L.), stunted the plants, causing them stress as well as providing no protection against verticillium wilt (*Verticillium dahliae* Kleb.) (Corsini, 1989). Also, chlormequat (1.2 kg a.i. ha^{-1}) applied to the spring wheat (*Triticum aestivum* L.) cultivar Max had no significant effect on the progress of head blight, caused by *Fusarium graminearum* (Fauzi, 1994). Fauzi (1994) suggests this may have to do with unfavorable environmental conditions the year the experiment was performed.

Both species responded similarly to the chemicals applied to them with respect to the disease present; however, it appeared as though the PGRs had a stronger effect on the *Rudbeckia* plants, where growth of the pathogen was more delayed (in the fall) than in the *Phlox* plants. Powdery mildew problems generally occur in the greenhouse at the end of the summer into the fall, when conditions are better for growth and development of the fungus. Just as the powdery mildew reacts differently during different times of the year, so do PGRs, as shown by these studies.

For the *Phlox* studies, chlormequat chloride and the tank mix were most effective in reducing heights and average widths. Daminozide, uniconazole, and flurprimidol occasionally reduced height and average width, and the paclobutrazol treatments (Bonzi and Piccolo) were consistently ineffective in reducing heights and average widths of *Phlox*. In the *Rudbeckia* studies, none of the treatments applied were effective in height control, and the treatments applied were only effective in controlling average width for the first harvests but not the second. The paclobutrazol (Bonzi) and flurprimidol treatments were effective in reducing average widths in both the Fall and Spring studies, and the daminozide, paclobutrazol (Piccolo) and uniconazole treatments were occasionally effective in reducing average widths of the *Rudbeckia* plants. The only significant shoot dry weight differences occurred in the fall and spring *Phlox* experiments. In the first experiment, flurprimidol and both paclobutrazol treatments produced the plants with the greatest dry weights, which were comparable to the controls. The tank mix treatment produced the plants with the smallest dry weights. In the second experiment, daminozide, both paclobutrazol PGRs, and uniconazole treatments produced dry weights similar to the control. The chlormequat and daminozide/chlormequat tank mix produced the plants with the smallest dry weights.

Summary. Several PGRs were found to reduce powdery mildew severity on *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer'. We also saw growth regulator effects on plant height and average width. Paclobutrazol has been proven to have fungicidal properties (Fletcher et al., 1986); but these studies have shown that other chemicals (chlormequat chloride and uniconazole) may have an indirect effect on disease severity. PGRs are known to increase cuticle thickness which could provide a barrier to pathogen attack. Further investigation to examine the effects of foliarly applied PGRs on diseases of other plant species that are also responsive to the growth regulator chemicals used in these studies would be beneficial.

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Table 4.1. Individual plants were rated for disease severity using the Horsfall-Barratt Scale for assessing disease.

Class/Rate	**Percent Coverage**
0	0
1	0-3
2	3-6
3	6-12
4	12-25
5	25-50
6	50-75
7	75-88
8	88-94
9	94-97
10	97-100
11	100

Table 4.2. Means for disease ratings and shoot dry weights for Experiment 1 of *Phlox paniculata* 'Blue Boy', Fall 2003.

Treatment (mg•L^{-1})	**Disease Ratings**							**Dry Weight (g)**	
								Harvest 1	**Harvest 2**
	6 DAI[z]	**11 DAI**	**15 DAI**	**18 DAI**	**22 DAI**	**27 DAI**	**32 DAI**	**(2 WAT[y])**	**(7 WAT)**
Control (0)	1.2	2.5bc	2.3bcd	3.7b	3.7bc	4.7bc	5.2b	1.4	3.8a
Daminozide (10000)	0.8	3.0ab	3.8a	4.5a	4.8a	5.3ab	5.7a	1.4	2.8b
Chlormequat chloride (4000)	0.7	2.3bcd	2.8b	3.7b	4.0b	4.2c	5.2b	1.1	2.1cd
Daminozide/chlormequat chloride (7500/1500)	1.2	3.7a	4.0a	4.8a	5.3a	5.5a	6.0a	1.3	1.7d
Paclobutrazol (Bonzi) (160)	0.5	1.7de	1.8cd	3.2bc	3.7bc	4.3c	4.5c	1.3	3.5a
Uniconazole (60)	1.0	1.8cde	2.3bcd	3.5b	3.7bc	4.3c	5.0b	1.2	2.5bc
Flurprimidol (60)	0.7	2.2cd	2.7bc	3.3bc	3.8bc	4.2c	5.0b	1.1	3.5a
Paclobutrazol (Piccolo) (160)	0.8	1.2e	1.5d	2.7c	3.2c	4.3c	4.5c	1.2	3.9a
***P*-value**	**NS**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0005**	**<0.0001**	**NS**	**<0.0001**
LSD		**0.7828**	**0.9039**	**0.6903**	**0.8217**	**0.6862**	**0.4519**		**0.5714**

[z]DAI, days after inoculation

[y]WAT, weeks after treatment

[x]Mean separation within a column by LSD.

Table 4.3. Main effect of PGR on height and average width for *Phlox paniculata* 'Blue Boy' fall and spring experiments.

	Fall 2003			
	Harvest 1 (2 WAT[z])		**Harvest 2 (7 WAT)**	
Treatment (mg•L^{-1})	**Height (cm)**	**Average width (cm)**	**Height (cm)**	**Average width (cm)**
Control (0)	11.5	14.0a[y]	15.8a	21.3a
Daminozide (10000)	11.7	12.9ab	13.7ab	18.4b
Chlormequat chloride (4000)	10.3	11.3cd	9.7c	14.9c
Daminozide/chlormequat chloride (7500/1500)	10.0	10.6d	10.3c	12.9c
Paclobutrazol [(Bonzi) (160)]	11.0	12.3bc	15.0a	20.4ab
Uniconazole (60)	10.3	11.8bcd	11.2c	18.4b
Flurprimidol (60)	11.5	12.5bc	12.0bc	19.8ab
Paclobutrazol [(Piccolo) (160)]	12.0	12.0bc	14.8a	21.9a
***P*-value**	**NS[x]**	**0.0022**	**<0.0001**	**<0.0001**
LSD		**1.4809**	**2.4825**	**2.6125**
	Spring 2004			
Control (0)	16.2ab	13.8a	43.2	22.5a
Daminozide (10000)	17.5a	14.1a	41.2	18.8bc
Chlormequat chloride (4000)	13.3c	12.0b	40.3	17.8c
Daminozide/chlormequat chloride (7500/1500)	12.7c	11.5b	36.0	17.0c
Paclobutrazol [(Bonzi) (160)]	17.7a	14.0a	41.5	22.3a
Uniconazole (60)	15.0b	13.5a	41.8	19.8abc
Flurprimidol (60)	15.8b	13.3a	40.0	22.0a
Paclobutrazol [(Piccolo) (160)]	17.7a	14.1a	39.0	21.3ab
***P*-value**	**<0.0001**	**0.0001**	**NS**	**0.0015**
LSD	**1.6506**	**1.1903**		**2.9738**

[z]WAT, weeks after treatment; [y]Mean separation within a column by LSD; [x]NS=Not Significant

Table 4.4. Means for disease ratings and shoot dry weights for Experiment 2 of *Phlox paniculata* 'Blue Boy', Spring 2004.

Treatment (mg•L^{-1})	**Disease Ratings**				**Dry Weight (g)**	
					Harvest 1	**Harvest 2**
	14 DAI[z]	**21 DAI**	**29 DAI**	**36 DAI**	**(7 WAT[y])**	**(7 WAT)**
Control (0)	1.2	2.3abc[x]	3.5	4.2a	1.5	10.0a
Daminozide (10000)	1.3	2.2abc	3.2	4.2a	1.5	9.0a
Chlormequat chloride (4000)	1.0	2.5ab	3.0	3.3b	1.6	6.5c
Daminozide/chlormequat chloride (7500/1500)	1.5	2.7a	3.3	3.8ab	1.4	6.1c
Paclobutrazol [(Bonzi) (160)]	0.7	1.8bc	2.8	4.0a	1.4	9.5ab
Uniconazole (60)	1.2	1.7c	2.8	3.3b	1.5	8.5b
Flurprimidol (60)	1.0	2.5ab	3.3	4.0a	1.7	8.4b
Paclobutrazol [(Piccolo) (160)]	1.3	2.8a	3.3	4.2a	1.4	8.6ab
***P*-value**	**NS**	**0.0523**	**NS**	**0.0125**	**NS**	**<0.0001**
LSD		**0.7718**		**0.5834**		**1.4728**

[z]DAI, days after inoculation

[y]WAT, weeks after treatment

[x]Mean separation within a column by LSD.

Table 4.5. Means for disease ratings for Experiment 1 of *Rudbeckia hirta* 'Indian Summer', Fall 2003.

Treatment (mg•L^{-1})	**Disease Ratings**							
	6 DAI[z]	**11 DAI**	**15 DAI**	**16 DAI**	**18 DAI**	**22 DAI**	**27 DAI**	**32 DAI**
Control (0)	2.7ab[y]	3.8a	4.7a	2.7ab	4.7a	5.2ab	5.7a	5.7ab
Daminozide	3.2a	3.8a	4.3a	3.2a	4.7a	5.7a	5.5a	6.2a
Daminozide/chlormequat chloride (7500/1500)	1.7bcd	2.3bc	2.7b	1.7bcd	4.0ab	4.7bc	5.0ab	5.2ab
Paclobutrazol [(Bonzi) (160)]	0.8d	1.0d	1.0c	0.8d	1.2c	1.2d	1.3d	2.8c
Uniconazole (60)	1.0cd	1.3cd	1.5c	1.0cd	3.0b	3.8c	4.3b	5.0b
Flurprimidol (60)	2.0bc	2.5b	2.7b	2.0bc	3.7ab	4.2c	4.8ab	5.2ab
Paclobutrazol [(Piccolo) (160)]	1.0cd	1.0d	0.7c	1.0cd	1.2c	2.0d	2.5c	3.8c
***P*-value**	**0.0004**	**<0.0001**	**<0.0001**	**0.0004**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
LSD	**1.0912**	**1.0821**	**1.0515**	**1.0912**	**1.0037**	**0.9706**	**0.9672**	**1.0761**

[z]DAI, days after inoculation

[y]Mean separation within a column by LSD.

Table 4.6. Main effect of PGR on height and average width for *Rudbeckia hirta* 'Indian Summer' Fall and Spring experiments.

	Fall 2003			
	Harvest 1 (2 WAT[z])		Harvest 2 (7 WAT)	
Treatment (mg•L^{-1})	**Height (cm)**	**Average width (cm)**	**Height (cm)**	**Average width (cm)**
Control (0)	4.7	25.3a[y]	11.0	36.8
Daminozide (10000)	5.8	21.6bcd	10.1	35.9
Daminozide/chlormequat chloride (7500/1500)	5.6	23.9ab	8.2	34.0
Paclobutrazol [(Bonzi) (160)]	5.3	20.7cd	11.3	40.0
Uniconazole (60)	3.8	22.9abc	9.2	39.3
Flurprimidol (60)	3.9	19.6d	10.2	37.7
Paclobutrazol [(Piccolo) (160)]	4.3	21.0bcd	10.9	37.8
***P*-value**	**NS[x]**	**0.0094**	**NS**	**NS**
LSD		**3.1294**		
	Spring 2004			
	Harvest 1 (2 WAT)		**Harvest 2 (6 WAT)**	
Control (0)	4.5	17.5a	19.0	43.8
Daminozide (10000)	4.3	15.3ab	18.0	40.8
Paclobutrazol [(Bonzi) (160)]	4.4	14.7bc	17.0	44.5
Uniconazole (60)	3.0	13.5c	20.8	42.8
Flurprimidol (60)	3.8	13.7c	17.2	42.3
Paclobutrazol [(Piccolo) (160)]	5.1	16.9ab	18.8	42.9
***P*-value**	**NS**	**0.0123**	**NS**	**NS**
LSD		**2.5442**		

[z]WAT, weeks after treatment; [y]Mean separation within a column by LSD; [x]NS=Not Significant

Table 4.7. Means for disease ratings for Experiment 2 of *Rudbeckia hirta* 'Indian Summer', Spring 2004.

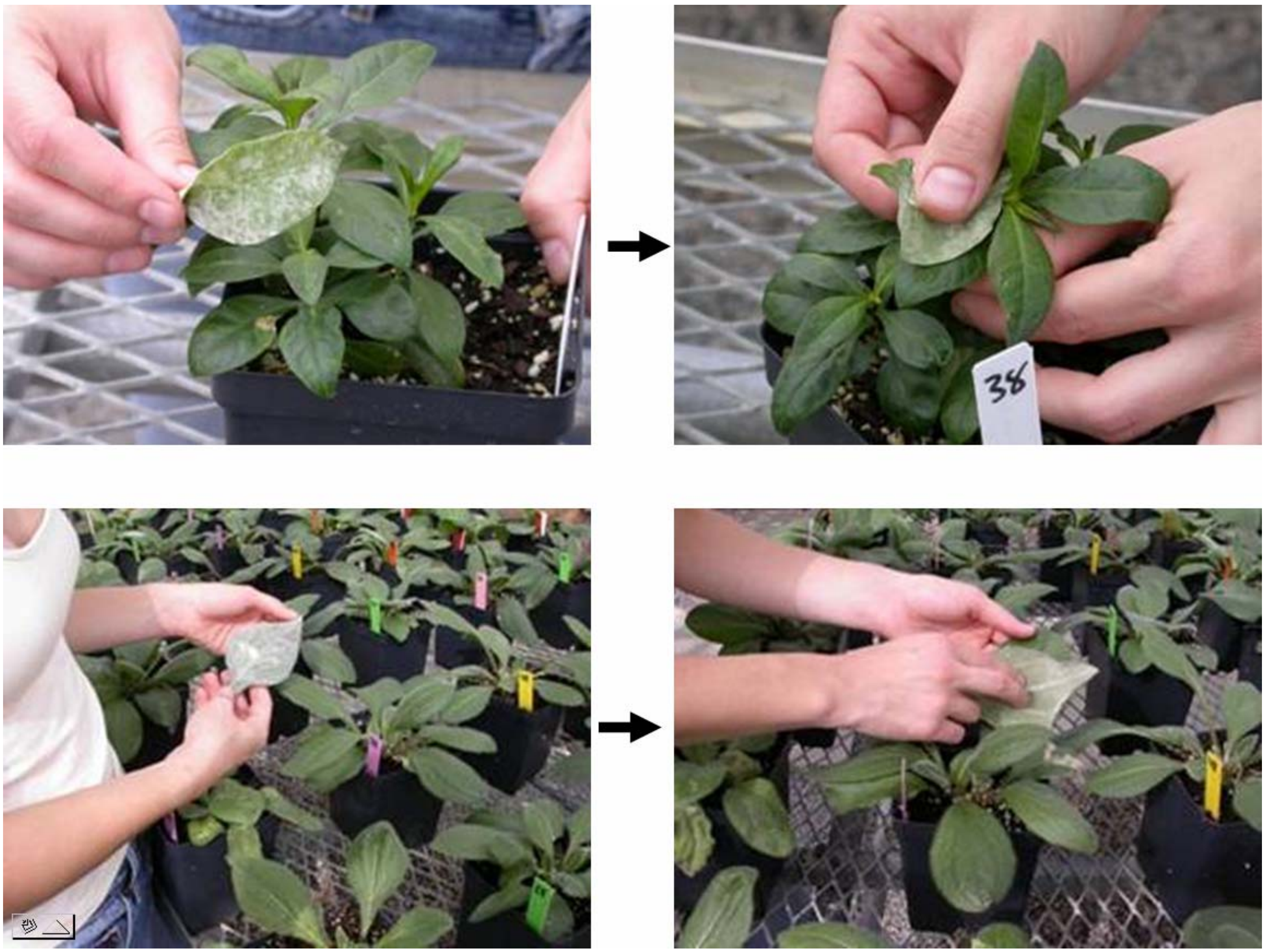
Treatment (mg•L^{-1})	**Disease ratings**			
	8 DAI[z]	**14 DAI**	**22 DAI**	**28 DAI**
Control (0)	0.7abc[y]	1.2	1.5	3.0a
Daminozide (10000)	1.2a	1.5	1.5	2.5a
Paclobutrazol [(Bonzi) (160)]	0.3bc	0.3	0.7	1.0b
Uniconazole (60)	0.2c	0.5	0.8	2.2a
Flurprimidol (60)	1.0ab	1.2	1.7	2.7a
Paclobutrazol [(Piccolo) (160)]	0.2c	0.8	1.0	3.0a
***P*-value**	**0.0492**	**NS**	**NS**	**0.0047**
LSD	**0.7811**			**1.0473**

[z]DAI, days after inoculation

[y]Mean separation within a column by LSD.

Figure 4.1. Technique for inoculation of powdery mildew on *Phlox paniculata* ‘Blue Boy’ (A, B) and *Rudbeckia hirta* ‘Indian Summer’ (C, D). A, C: An infected leaf from a naturally diseased plant was chosen to inoculate the treatment plant. B, D: The infected leaf was used to inoculate two leaves on one plant, and was gently rubbed onto the treatment plant.

A. B.



C. D.

Figure 4.2. Disease severity ratings given to powdery mildew infected *Phlox paniculata* 'Blue Boy' plants using the Horsfall-Barratt Scale for assessing disease severity.

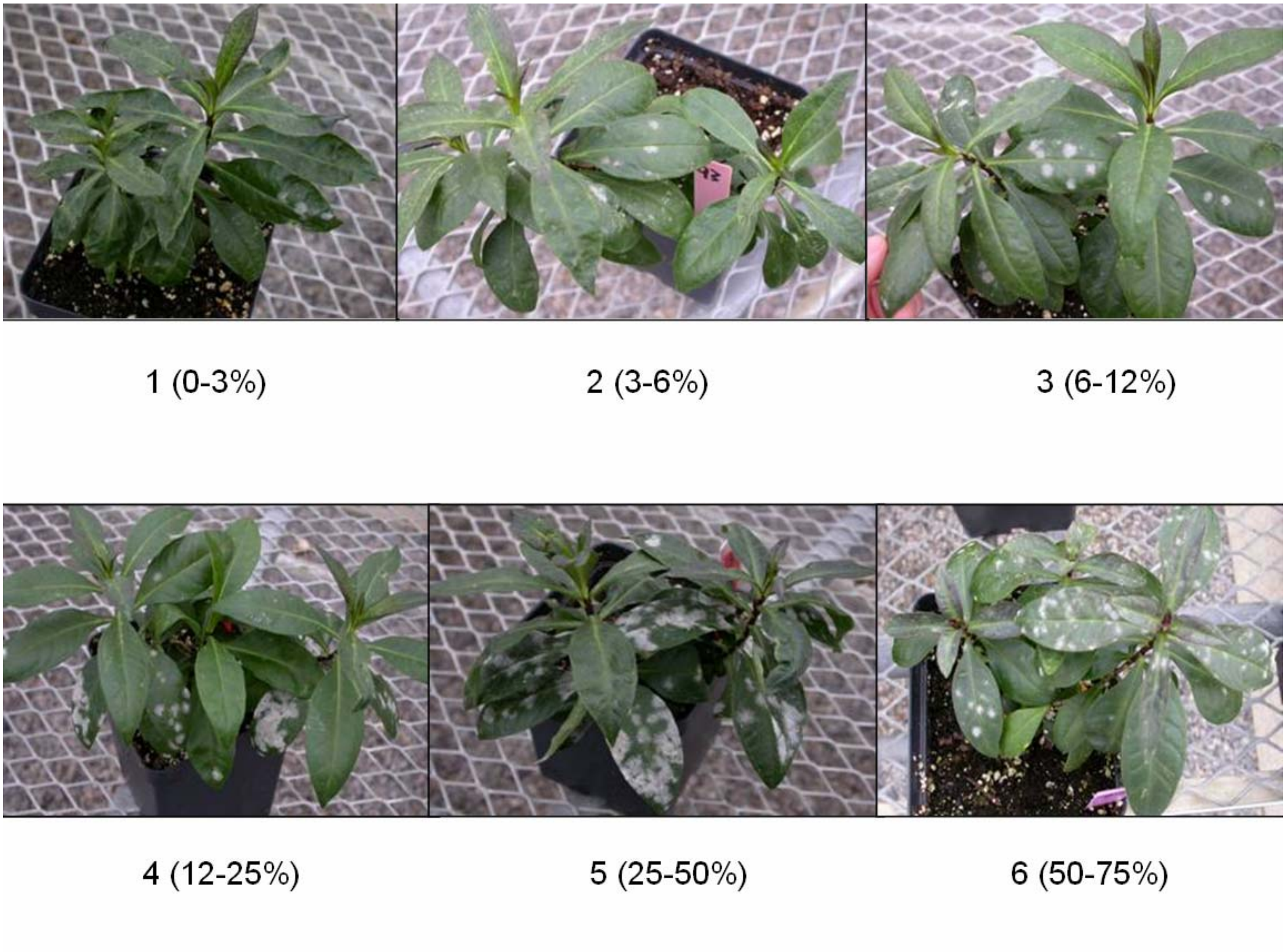
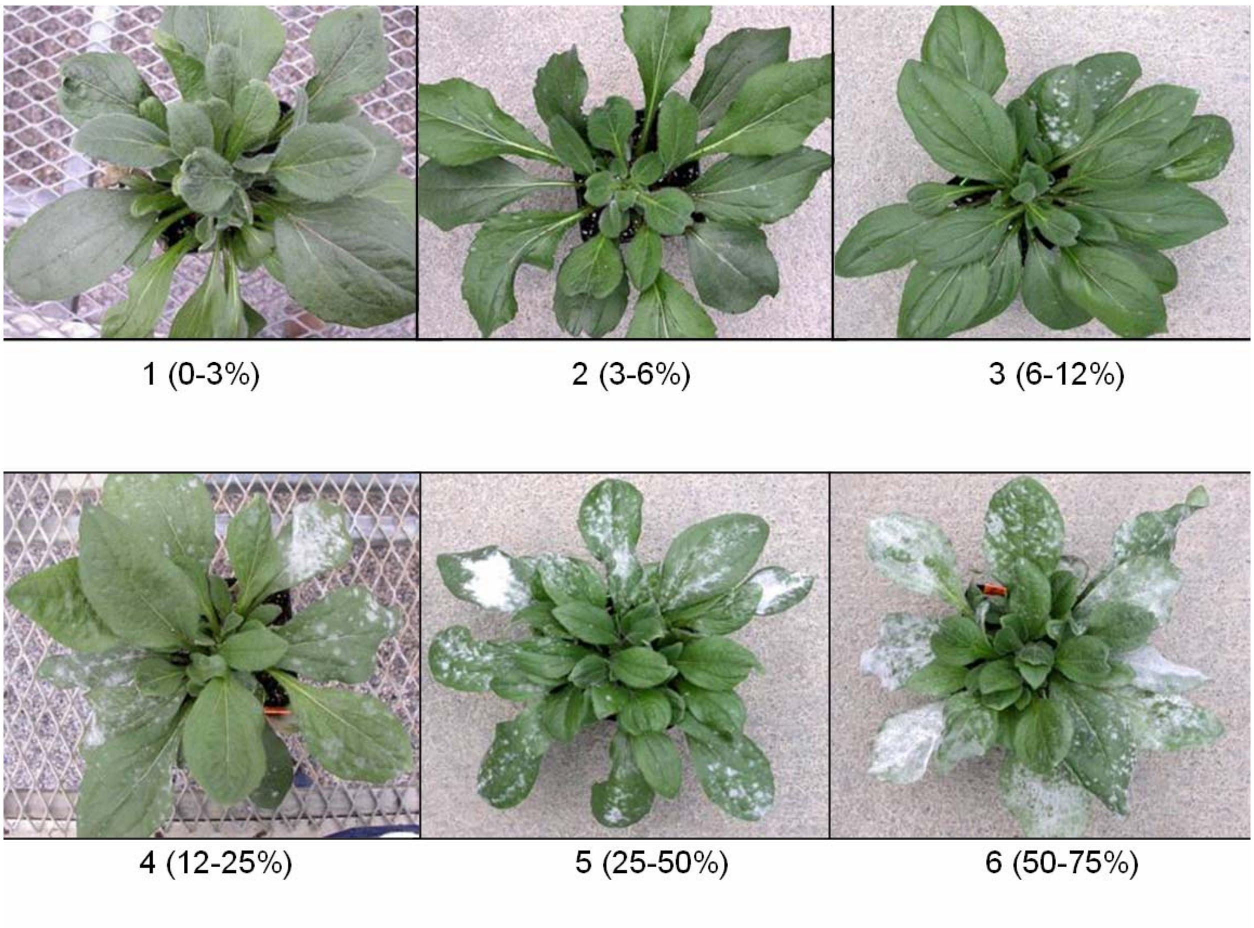


Figure 4.3. Disease severity ratings given to powdery mildew infected *Rudbeckia hirta* 'Indian Summer' plants using the Horsfall-Barratt Scale for assessing disease severity.



Chapter Five: Summary

Our initial objective was to provide a production plan for the greenhouse growth of *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer'. We looked into optimal fertilizer rates, irrigation rates, and media types. We determined that *P. paniculata* grows best when using 200 $mg \cdot L^{-1}$ N Cal Mag 15-5-15. This treatment produced plants with significantly greater average widths, quality ratings, and shoot dry weights in the *Phlox* experiment. *Phlox* was not responsive to irrigation rate, and grew best using Fafard 3B media, which resulted in plants with the greatest dry weights. For *Rudbeckia*, we determined the 300 $mg \cdot L^{-1}$ N treatment produced plants with the greatest height, average width, quality rating, and shoot dry weight. The highest irrigation rate produced the tallest plant with the highest quality rating and the greatest shoot dry weight. Scott's Perennial Mix produced the plants with the greatest dry weights in the *Rudbeckia* experiment, and tended to produce plants with greater heights, average widths, and quality ratings in comparison to the other treatments.

Our next objective was to look into possible rates of plant growth regulators (PGRs) to apply to both *Phlox* and *Rudbeckia* for height control. We determined that for *Phlox*, chlormequat chloride (4000 $mg \bullet L^{-1}$) and a tank mix of daminozide and chlormequat chloride (two and three applications of 5000/1500 and 7500/1500 $mg \bullet L^{-1}$) were effective in providing height control. For *Rudbeckia*, paclobutrazol (160 $mg \bullet L^{-1}$) and uniconazole (60 $mg \bullet L^{-1}$) could be used to reduce height.

Our third objective was to monitor the effects of powdery mildew on these crops in relation to the PGRs applied. We determined that, although certain chemicals were effective in reducing powdery mildew severity, none of the treatments resulted in completely disease-free plants. Therefore, we cannot recommend the use of these chemicals as a means powdery mildew control. But we can use the information we gained from these experiments to facilitate further research in the ornamentals area, looking possibly at other species of plants as well as other plant diseases.

Vita

Shannon N. Hill

EDUCATION

Master of Science, Horticulture, Fall 2004
Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, VA
Thesis: *Phlox paniculata* 'Blue Boy' and *Rudbeckia hirta* 'Indian Summer': cultural guidelines for greenhouse growth and powdery mildew control
Advisor: Joyce G. Latimer

Bachelor of Science, Horticulture, May 2002
Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, VA

EXPERIENCE

Graduate Research Assistant
Blacksburg, VA July 2002 – August 2004

- Experimental design and set-up
- Data collection
- Statistical analysis
- General plant care

Plant Disease Clinic, Virginia Tech
Blacksburg, VA February 1999 – Present

- Data entry
- Assisting in the diagnosing process
- Nematode assays
- Making media
- General laboratory work
- Compiling annual report

Insect ID Lab, Virginia Tech
Blacksburg, VA September 2001 – August 2003

- Data entry
- General laboratory work
- Insect pinning
- Compiling annual report

The Crow's Nest, Summer Internship
Blacksburg, VA May 2001 – August 2001

- Customer service
- Planting, weeding, and flower bed maintenance
- Constructing and installing trellises

The Tyler Rose
Salem, Virginia June 1999 – August 1999

- Planting, pinching back, and tagging chrysanthemums

AWARDS AND ACTIVITIES

Plant Growth Regulation Society of America (PGRSA): Graduate student travel award, $500 for 2004

Chi Delta Alpha (ΧΔΑ), Service Sorority

- Spring 2000: Pledge
- Fall 2000 – Spring 2002: Active member

Pi Alpha Xi (ΠΑΞ), Horticulture Honor Fraternity

- Fall 2001 – Spring 2002: Active member

Horticulture Club

- Fall 2000 – Spring 2002: Active member

Virginia Nursery and Landscape Association (VNLA): two $1,500 scholarships for 2000-2001 and 2001-2002

College of Agriculture and Life Sciences: $500 scholarship for 1998-1999