Floriculture

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Section Editor

Drench Applied Bonzi® Affects Growth and Flowering of Petunia and Impatiens Grown in Alternative Substrates.

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Significance to Industry: The results of this study indicate that there is possible concern that the efficacy of Bonzi® drench is affected by the use of the alternative substrates components of *WholeTree* or distilled cedar when blended with peat moss (50:50, v:v) and compared to a peatlite industry standard (75:25 peat:perlite, v:v). More research is needed to further investigate the effect of these alternative substrates on PGR substrate drenches with these and other crops.

Nature of Work: In the past several years, numerous studies have evaluated alternative substrate components for use in greenhouse production such as clean chip residual (2), whole tree (3), distilled cedar (6), and pine tree substrate (7). Some of these substrate components, such as whole tree and distilled cedar, are currently being used on a limited scale in commercial greenhouse production. Paclobutrazol is a plant growth regulator labeled for application as a substrate drench on greenhouse crops. Previous studies have shown that substrate components can negatively impact the efficacy of drench-applied paclobutrazol. A paclobutrazol drench application to chrysanthemum reduced plant height by 31% in a peat-based substrate, but only by 14% in a bark-based substrate (1). Million et al., (5) determined it took 14 times more paclobutrazol to achieve the same growth reduction of petunia in a 60% composted pine bark substrate (0% peatmoss) as in a 60% peatmoss substrate (0% composted pine bark). In contrast, Currey et al., (4) reported that effects of plant growth retardant (PGR) drenches were not affected by substrates containing parboiled rice hulls. The objective of this study was to evaluate the influence of alternative substrate components on the efficacy of drench-applied paclobutrazol in two bedding plants, petunia and impatiens.

This study was conducted at the Paterson Greenhouse Facility at Auburn University, Auburn, AL. Substrates evaluated were an industry standard peat:perlite (PL) mix (75:25, by vol), a pinebark:peat (PB) mix (50:50, by vol), a wholetree:peat (WT) mix (50:50, by vol), and a cedar:peat (DC) mix (50:50, by vol). Fresh loblolly pine (*Pinus taeda* L.) chips were obtained from a pine plantation in Macon County, AL by chipping

freshly cut trees (all above ground portions) and then milling the chips in a hammer mill to pass a 0.38 in. screen for the whole tree component. Distiller cedar was obtained from CedarSafe®, a company located in Huntsville, AL. Cedar logs (*Juniperus virginiana* L.) were debarked, shaved and further processed in a hammer mill to pass a 1.27 cm (0.5 in) screen. The milled cedar was then processed in a steam distiller removing a portion of the oil. All substrates had the following amendments added per cubic yard at mixing: 5 lb dolomitc lime, 1 lb MicroMax, 3 lb of slow release fertilizer (13-6-16, Harrell's, Lakeland, FL), and 4 oz AquaGro-L wetting agent. Containers (6 in azalea pot,) were filled with the substrates and three plugs (200 cell flat) of either petunia (*Petunia ×hybrida* 'Dreams Rose') or impatiens (*Impatiens walleriana* 'Extreme Violet') were planted in each container on February 22, 2013. Containers were placed in an un-shaded, twin-wall polycarbonate greenhouse on elevated benches and hand watered as needed.

Paclobutrazol (Bonzi®, Syngenta Crop Protection, Inc.) was applied as a substrate drench (4 oz per container) at 0, 1, or 2 ppm on petunia and at 0, 2, or 4 ppm on impatiens on March 12, 2013. Tap water was applied at the 0 ppm rate. A second PGR application at the same rates was made on March 29, 2013. Data collected on all plants on April 11, 2013 was average plant width ((widest width + width perpendicular to width)/2), counts of open flowers and buds showing color, shoot dry weight, a subjective root rating (0 (no visible roots) to 5 (roots visible over the entire substrate surface)), and substrate pH and electrical conductivity.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.2. The experimental design was a randomized complete block with eight blocks and a factorial treatment design of four substrates and three PRG rates. The two species were arranged as separate experiments. Linear and quadratic trends over PGR rates were tested using orthogonal polynomials. Differences among substrate least squares means were determined using Tukey's test ($\alpha = 0.05$). Probit analysis was used for root ratings with the multinomial probability distribution and a cumulative probit link.

Results and Discussion: Only the substrate type and PGR rate main effects were different for average plant widths and the substrate type main effect was different for flower and bud counts of petunia (Table 1). The highest average plant widths and flower and bud counts were for PL and DC followed by WT and the lowest for PB over all PGR rates. Average plant widths for plants in PB were 6% smaller and plants had 6 fewer flowers and buds that in PL. There was a linear decrease in average plant widths with increasing PGR rate over all substrates; plants receiving 2 ppm PGR were 9% shorter than those receiving no PGR. No differences in flower and bud counts were found for PGR rates.

Because substrate type and PGR rate independently affected average plant widths and PGR rate did not affect flower and bud counts, these responses in petunia provide no evidence that any of the alternative substrate components, including pine bark,

negatively impacted the efficacy of drench-applied paclobutrazol when compared to PL. The highest average plant widths and flower and bud counts were in PL and DC and the lowest in PB. Increasing PGR rate decreased average plant widths regardless of substrate type.

The substrate by PGR rate interaction was significant for shoot dry weight and root rating of petunia (Table 2). The highest or second highest shoot dry weights were found for PL and DC followed by WT and the lowest or next to lowest for PB at all PGR rates. Shoot dry weights for plants in PB were 33% smaller at 0 ppm, 32% smaller at 1 ppm, and 22% smaller at 2 ppm PGR than in PL. There was a linear decrease in shoot dry weights with increasing PGR rate for PB and DC, but no differences were found for PL and WT. Plants receiving 2 ppm PGR were 10% smaller than those receiving no PGR in PB and 4% smaller than those in DC. Root rating was highest in PL at the 0 ppm rate and lowest in WT, but there were no differences at the 1 ppm or 2 ppm rates. There was a linear decrease in root rating with increasing PGR rate in PL, but no differences were found in DC, PB, or WT.

Because the highest or second highest shoot dry weights in petunia were in PL and DC and the lowest in PB across all PGR rates and there was a linear decrease in shoot dry weights with increasing PGR in PB, shoot dry weight provides no evidence that any of the alternative substrate components, including pine bark, negatively impacted the efficacy of drench-applied paclobutrazol when compared to PL. The highest shoot dry weights were in PL and DC and the lowest in PB. Increasing PGR rate decreased shoot dry weights only in PB and DC.

Only the PGR rate main effect was different for flower and bud counts and the substrate and PGR rate main effects were different for shoot dry weight of impatiens (Table 3). Flower and bud counts decreased linearly with increasing PGR rate over all substrates with plants receiving 4 ppm PGR having 12 more flowers and buds than those receiving no PGR. The highest shoot dry weights were for PL followed by WT and DC and the lowest for PB over all PGR rates. Shoot dry weights for plants in PB were 21% less than those in PL. Shoot dry weights decreased linearly with increasing PGR rate over all substrates; plants receiving 4 ppm PGR were 21% smaller than plants receiving no PGR.

Because substrate type and PGR rate independently affected shoot dry weights and substrate type did not affect flower and bud counts, these responses in impatiens provide no evidence that any of the alternative substrate components, including pine bark, negatively impacted the efficacy of drench-applied paclobutrazol when compared to PL. The highest and second highest shoot dry weights were in PL and DC and the lowest in PB. Increasing PGR rate decreased shoot dry weights and flower and bud counts regardless of substrate type.

The substrate by paclobutrazol rate interaction was significant for average plant width and root rating of impatiens (Table 4). Average plant width was highest in PL, WT, and

DC, and lowest in PB at 0 ppm PGR, but there were no differences in substrates at 2 ppm PGR. However, at 4 ppm PGR, average plant width was highest in PB and PL and lowest in DC and WT. At 0 ppm PGR, plants in PB were 8% smaller than those in PL, but at 4 ppm PGR, plants in PB were 5% larger than those in PL. There were linear decreases in average plant width with increasing PGR rate for all substrates; plants receiving 4 ppm PGR were 26%, 25%, 15%, and 24% smaller than those receiving no PGR in PL, WT, PB, and DC, respectively. Root ratings at 0 ppm PGR were highest in PL and lowest in WT, PB, and DC while root ratings at 2 ppm PGR were highest in PL and WT and lowest in PB and DC, but there were no differences among substrates at 4 ppm PGR. A linear decrease and a quadratic change in root ratings were found in PL and PB, respectively, but no trends were found in WT or DC.

Average plant width of impatiens in PB was higher in value than in PL at 4 ppm PGR indicating that the efficacy of drench-applied paclobutrazol was negatively impacted by pine bark at the highest PGR rate. However, because there was no difference in average plant width at 4 ppm PGR between PL and DC and WT, efficacy of drench-applied paclobutrazol was not impacted by these alternative substrate components.

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Table 1. Effects of Bonzi® drenches and alternative substrates on petunia growth.[z]

Substrate	Average plant width (cm)[y]	Flower and bud count
75P:25PL[x]	37.5ab[w]	23a
50P:50WT	36.4bc	20b
50P:50PB	35.3c	17c
50P:50DC	38.3a	23a
Drench rate (ppm)		
0	38.6	21
1	36.7	21
2	35.3	21
Trends[v]	L***	NS

[z]Only the substrate type and Bonzi® rate main effects were significant at α = 0.05.
[y]Average plant width = (widest width + width perpendicular to widest) / 2.
[x]75P:25PL = 75% peat:25% perlite, 50P:50WT = 50% peat:50% whole tree, 50P:50PB = 50% peat:50% pine bark, 50P:50DC = 50% peat:50% distilled cedar.
[w]Least squares means comparisons (lower case letters in column) using Tukey's test at α = 0.05.
[v]Significant linear (L) trend using orthogonal polynomials at α = 0.001 (***), NS = not significant.

Table 2. Effects of Bonzi® drenches and alternative substrates on petunia growth.[z]

	Shoot dry weight (g) Drench Rate (ppm)			
Substrate	0	1	2	Trends[y]
75P:25PL[x]	12.32a	11.42a	9.55a	NS
50P:50WT	10.67b	9.55b	8.30b	NS
50P:50PB	8.23c	7.80c	7.43b	L***
50P:50DC	10.87b	10.68a	10.48a	L***
	Root rating[v] Drench Rate (ppm)			
Substrate	0	1	2	Trends
75P:25PL[x]	5a[u]	4ns	3ns	L***
50P:50WT	2c	3	3	NS
50P:50PB	3b	3	3	NS
50P:50DC	3b	3	4	NS

[z]The substrate by Bonzi® rate interaction was significant at α = 0.05.
[y]Significant linear (L) trends using orthogonal polynomials at α = 0.001 (***), NS = not significant.
[x]75P:25PL = 75% peat:25% perlite, 50P:50WT = 50% peat:50% whole tree, 50P:50PB = 50% peat:50% pine bark, 50P:50DC = 50% peat:50% distilled cedar.
[w]Least squares means comparisons (lower case letters in column) using Tukey's test at α = 0.05.
[v]Root balls were rated 0 (no visible roots) to 5 (roots visible over the entire substrate surface). Data are medians.
[u]Comparisons among medians (lower case letters in columns) using paired contrasts at α = 0.05.

Table 3. Effects of Bonzi® drenches and alternative substrates on impatiens growth.[z]

Substrate	Flower and bud count	Shoot dry weight (g)
75P:25PL[y]	112ns[x]	7.7a
50P:50WT	110	6.3bc
50P:50PB	108	6.1c
50P:50DC	110	6.8b
Drench rate (ppm)		
0	115	7.6
2	111	6.6
4	103	6.0
Trends[w]	L***	L***

[z]Only the substrate type and Bonzi® rate main effects were significant at α = 0.05.

[y]75P:25PL = 75% peat:25% perlite, 50P:50WT = 50% peat:50% whole tree, 50P:50PB = 50% peat:50% pine bark, 50P:50DC = 50% peat:50% distilled cedar.

[x]Least squares means comparisons (lower case letters in column) using Tukey's test at α = 0.05, ns = not significant.

[w]Significant linear (L) trends using orthogonal polynomials at α = 0.001 (***).

Table 4. Effects of Bonzi® drenches and alternative substrates on impatien growth.[z]

	Average plant width (cm)[y]			
	Drench rate (ppm)			
Substrate	0	2	4	Trends[x]
75P:25PL[w]	33.3a[v]	27.0ns	24.8ab	L***
50P:50WT	32.4a	26.9	24.4b	L***
50P:50PB	30.6b	28.0	26.0a	L***
50P:50DC	32.4a	28.3	24.5b	L***
	Root rating[u]			
	Drench rate (ppm)			
Substrate	0	2	4	Trends
75P:25PL	4.0a	3.0a	2.0ns	L***
50P:50WT	2.5b	2.0a	2.0	NS
50P:50PB	3.0b	1.0b	2.0	Q**
50P:50DC	2.5b	1.5b	1.5	NS

[z]The substrate by Bonzi® rate interaction was significant at α = 0.05.

[y]Average plant width = (widest width + width perpendicular to widest) / 2.

[x]Not significant (NS) or significant linear (L) or quadratic (Q) trends using orthogonal polynomials at α = 0.01 (**) or 0.001 (***).

[w]75P:25PL = 75% peat:25% perlite, 50P:50WT = 50% peat:50% whole tree, 50P:50PB = 50% peat:50% pine bark, 50P:50DC = 50% peat:50% distilled cedar.

[v]Least squares means comparisons (lower case letters in column) using Tukey's test at α = 0.05, ns=not significant.

[u]Root balls were rated 0 (no visible roots) to 5 (roots visible over the entire substrate surface). Data are medians.

Measuring Disease Severity of *Pythium spp.* and *Rhizoctonia solani* in Substrates Containing Pine Wood Chips

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Significance to Industry: This study demonstrates how the mini-Horhizotron can be utilized in plant pathology, and investigates the disease severity of *Pythium ultimum*, *Pythium aphanidermatum*, and *Rhizoctonia solani* on bedding plants grown in peat based substrates containing varying percentages of pine wood chips, and an industry standard potting mix. Horhizotrons, when used in addition to other disease assessment techniques, can help provide a more well-rounded and accurate assessment of root disease severity. The ability to view the rhizosphere and the accuracy with which root length can be measured suggests that the mini-Horhizotron could have broad applications in plant pathology research. The results from these experiments show that disease severity of these pathogens was equal and often less prevalent than in a traditional potting mix, which offers additional evidence of the viability of pine wood chips to be used as a replacement to perlite in substrates for greenhouse crop production.

Nature of Work: When alternative substrates are developed for container production it is important that all aspects of root development are considered, including response to soil borne pathogens. In the south eastern United States loblolly pine (*Pinus taeda* L.) has been identified as a readily available and inexpensive alternative for commonly used substrate components (3). Perlite is the most commonly used aggregate in greenhouse substrates, but it is often the most expensive, and concerns have been raised about health risks and sustainability issues (3). Recent research has shown that pine wood chips (PWC) are a suitable alternative to perlite in peat based substrates (3), but there is no information regarding disease severity of common soil borne pathogens on greenhouse plants that are grown in peat substrates amended with PWC.

Pythium spp. are some of the most common and persistent pathogens in greenhouse production, and almost all greenhouse crops are susceptible to one or more species of pythium. *Pythium aphanidermatum* and *P. ultimum* are two species that are especially common as pathogens of potted plants (1). *P. aphanidermatum* in particular is an economically important, aggressive species of pythium that causes damping off, root rot, stem rots, and blights. It has a wide host range, including many annuals and

bedding plants, and favors warm temperatures and wet soils, making it an issue in greenhouse production (4). Common symptoms are yellowing foliage, stunted plant growth, and wilt (1). *Rhizoctonia solani* is an aggressive pathogen with a wide host range that causes several diseases, including damping off, stem and leaf blights, and root, stem, and crown rots. When the fungus grows over the plant foliage, it is referred to as web blight. Rhizoctonia root rot occurs on most flowering potted plants and can cause considerable economic losses (1).

Mini-Horhizotron Study. The mini-Horhizotron (developed at North Carolina State University in 2013), is a smaller version of the Horhizotron™ (5) and is a more appropriate size for smaller bedding plants and annuals. It has three concave walls (quadrants) constructed out of transparent acrylic sheets, allowing the rhizosphere to be viewed. Each quadrant has two measureable faces, giving a sum of six quadrant faces per mini-Horhizotron. Shade panels were constructed out of PVC that fit tightly against the acrylic walls to block light (2). Each mini-Horhizotron holds about the same volume of media as a 6 inch pot. The mini-Horhizotron allows for the observation and measuring of root disease and dieback over time without disturbing the root system or the container media. It allows root rot to be measured more accurately than subjective root ratings, and less severe root symptoms can be observed easily. Aggravating disease factors, such as potting media conditions and insect larvae, can also be viewed.

The mini-Horhizotron study was implemented at the Marye Ann Fox Teaching Laboratories Greenhouse at North Carolina State University. Three different substrates were used: Fafard 4P (containing 45% sphagnum peat moss, processed pine bark, perlite, vermiculite, wetting agent, starter nutrients and dolomitic limestone), a substrate containing 80% peat moss and 20% PWC, and a third substrate containing 70% peat moss and 30% PWC. Substrates containing PWC had the following amendments added per cubic yard at mixing: 7.5 pounds 200 mesh dolomitic limestone. There were six pathogen treatments compared in this study: Trt. 1) 4P-U (uninoculated), Trt. 2) 30PWC-U, Trt. 3) 20PWC-U, Trt. 4) 4P-I (inoculated), Trt. 5) 30PWC-I, Trt. 6) 20PWC-I. Mini-Horhizotrons were filled with each individual substrate and one plug of *Antirrhinum majus* 'Snapshot Red' (bedding snapdragon) was planted in each. The mini-Horhizotrons were arranged in a complete randomized block design with three substrate replicates per treatment, yielding a total of 18 mini-Horhizotrons. The plants were watered as needed with 200 ppm nitrogen derived from a 20-10-20 water soluble fertilizer and allowed to grow until root systems were well developed and had reached the end of the quadrants in the mini-Horhizotrons. On 23 April, 2013 treatments 4, 5, and 6 were inoculated with *Pythium aphanidermatum* from colonized rice grains. The inoculum was created by placing 25 g of long grain white rice in a beaker with 25 mL of water and autoclaving twice over the course of two days, which took place on 14 April 2013 and 15 April, 2013. The autoclaved rice grains were then inoculated on 16 April, 2013 with four colonized agar discs of *P. aphanidermatum*. Six grains of inoculum were inserted two inches below the substrate surface of each mini-Horhizotron. The root systems of all plants were traced by hand using a blue marker onto transparencies at the time of inoculation, and again one month later at the termination of the study.

Transparencies were cut to match the size of each quadrant, and were held in place by binder clips while roots were being traced. Only healthy, white roots were traced; roots showing any sign of disease (off color, water soaked, no root hairs, cortex sloughing off, etc.) were not included for measurement. The traced roots were photographed and the images were converted to black and white using a high contrast red filter in Adobe Photoshop CS5, and were then uploaded to Cornell University's RootReader 2D software where they were measured for total root length. The digital images were set to a resolution of 182.9 pixels/cm., with an error criterion of 9.1 pixels. At termination shoots were visually inspected for disease symptoms and rated on a scale of 1 to 5 with 5 = healthy, 4 = slightly stunted, 3 = chlorosis/moderate stunting/delayed flowering, 2 = wilting/severe stunting, and 1 = dead. Shoots were removed at the substrate surface and weighed to determine fresh weight, and a bloom count was taken. Data were analyzed using Tukeys Studentized Range Test ($p \leq 0.05$) (SAS Institute version 9.1, Cary, NC). On 24 May, 2013 root samples from each plant were plated onto PARP media (a pythium selective media) to confirm the presence of *P. aphanidermatum* in the inoculated treatments. On 25 May, 2013 *P. aphanidermatum* was observed growing from all of the substrate treatments, including the uninoculated controls. As a result, the uninoculated treatments for each substrate were not included in the means, therefore disease occurrence and severity was just compared among substrates.

Disease survey. The disease survey was implemented at the Marye Ann Fox Teaching Laboratories Greenhouse at North Carolina State University on 9 May 2013, using the same substrates as the mini-Horhizotron study, with the same amendments added to the substrates containing PWC. There were nine pathogen treatments compared in this study: Trt. 1) 4P-U (uninoculated), Trt. 2) 30PWC-U, Trt. 3) 20PWC-U, Trt. 4) 4P-P(Pythium), Trt. 5) 30PWC-P, Trt. 6) 20PWC-P , Trt. 7) 4P-R (Rhizoctonia), Trt. 8) 30PWC-R, Trt. 9) 20PWC-R. Plastic pots (5 inch diameter) were filled with the substrates and one plug of vinca (*Catharanthus roseus)*, marigold (*Tagetes patula)*, wax begonia (*Begonia semperflorens-cultorum)*, or impatiens (*Impatiens walleriana)* was planted. Containers were arranged in a randomized split block with six replicates per species, and four species per treatment. Plants were fertilized the same as in the mini-Horhizotron study, and on 22 May 2013 treatments 4 – 6 were inoculated with *Pythium ultimum* and treatments 7 – 9 were inoculated with *Rhizoctonia solani.* The inoculum for each species was created on 19 May 2013 using the same techniques as outlined in the mini-Horhizotron study, and seven rice grains were inserted one inch below the substrate surface in each pot. Data collected for this study included the date when symptoms were first observed, and visual ratings of the shoots and roots. Shoots were visually inspected for disease symptoms and rated on a scale of 1 to 5 with 5 = healthy, 4 = slightly stunted/few cankers or leaf blight, 3 = chlorosis/moderate stunting/delayed flowering/moderate stem and crown rot or leaf blight, 2 = wilting/severe stunting/severe stem and crown rot or leaf blight, and 1 = dead. Roots were visually inspected for root rot and rated on a scale of 1 to 5 with 5 = healthy white roots / no disease recovered, 4 = 25% root rot or seemingly healthy roots + disease recovered, 3 = 50% root rot, 2 = 75% root rot, and 1 = brown/dead roots. Data were analyzed using Tukeys Studentized Range Test ($p \leq 0.05$) (SAS Institute version 9.1, Cary, NC).

Results and Discussion:

Mini-Horhizotron study: Results from data taken at termination indicated that the root systems and shoots of snapdragons grown in the substrates containing 20% and 30% PWC were less effected by *Pythium aphanidermatum* infection than those grown in Fafard 4P (Table 1 and Figure 1). Plants grown in the 80:20 peat/PWC substrate had the highest total root length at the end of the experiment (Figure 1), and plant health ratings were significantly higher than Fafard 4P (Table 1). The peat/PWC plants displayed no wilting. Snapdragons grown in 80:20 peat/PWC displayed minimal stunting as a result of infection, and the mean fresh weight of those plants was 32g heavier than those grown in Fafard 4P (Table 1). The mean bloom count for the 80:20 peat/PWC substrate was 20 blooms, 70:30 peat/PWC was 5 blooms, and Fafard 4P had zero blooms (Table 1).

Disease survey: Results from the disease survey indicated that disease severity in substrates containing pine wood chips was equal to Fafard 4P, except in the case of vinca root ratings for both *P. ultimum* and *R. solani* treatments, impatiens shoot ratings for *R. solani* treatments, and impatiens root ratings for *P. ultimum* treatments, where disease severity was less than Fafard 4P (Tables 2 and 3). The plants grown in peat/PWC substrates exhibited symptoms at later dates than Fafard 4P (Figure 2). The Rhizoctonia treatments for all of the substrates exhibited web blight, leaf blight, crown rot, stem rot and/or root rot. Impatiens seemed particularly susceptible to Rhizoctonia infection and the impatiens and begonias had stem and crown rot more so than root rot, with numerous cankers observed and some loss of shoots from stem rot. Web and leaf blights seemed to be most prevalent on the marigolds, and root rot was most prevalent on the vinca, with some leaf blight also observed. Ratings were significantly higher for vinca root health in the 70:30 peat/PWC substrate than the Fafard 4P, and shoot health was significantly higher on the impatiens grown in the 80:20 peat/PWC substrate. (Table 2) The impatiens grown in the 80:20 peat/PWC displayed the least amount of wilting caused by disease infection.

Pythium symptoms were not as obvious as the Rhizoctonia. Shoot symptoms observed were mild to moderate stunting, and stem cankers near the substrate level. Substrates containing peat/PWC were shown to have less disease severity on the root systems of vinca and impatiens than Fafard 4P, with the 80:20 peat/PWC having the highest mean rating for those species (Table 3).

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Table 1. Comparison of fresh weights, plant health ratings, and bloom counts of bedding snapdragons grown in three different substrates that were infected with *Pythium aphanidermatum*.

Substrates	Fresh Weight (g)	Plant Health Rating[v]	Bloom Count
80:20 P/PWC[z]	50.7a[w]	4.2a	20.0a
70:30 P/PWC[y]	39.0a	3.8ab	5.0a
4P[x]	18.7b	2.8b	0.0a

[z] Substrate containing 80% peat moss and 20% pine wood chips.
[y] Substrate containing 70% peat moss and 30% pine wood chips.
[x] Fafard 4P.
[w] Tukeys Studentized Range Test ($p \leq 0.05$). Means with same letter in column = no significant difference.
[v] Plant Health Rating on a scale of 1 to 5 with 5 = healthy, 4 = slightly stunted, 3 = chlorosis/moderate stunting/delayed flowering, 2 = wilting/severe stunting, and 1 = dead.

Table 2. Root and shoot health ratings of annuals grown in three different substrates that were infected with *Rhizoctonia solani*.

	Vinca		Impatiens		Begonia		Marigold	
Substrate	Root[w]	Shoot[v]	Root	Shoot	Root	Shoot	Root	Shoot
80:20 P/PWC[z]	2.9ab[u]	3.3a	2.1a	3.3a	2.7a	3.4a	3.3a	3.1a
70:30 P/PWC[y]	3.7a	4.1a	1.8a	2.3b	2.3a	3.1a	3.3a	3.3a
4P[x]	2.7b	3.3a	1.8a	2.2b	2.6a	2.6a	3.5a	2.9a

[z] Substrate containing 80% peat moss and 20% pine wood chips.
[y] Substrate containing 70% peat moss and 30% pine wood chips.
[x]Fafard 4P.
[w]Root health rated on a scale of 1 to 5 with 5 = healthy white roots / no disease recovered, 4 = 25% root rot or seemingly healthy roots + disease recovered, 3 = 50% root rot, 2 = 75% root rot, and 1 = brown/dead roots.
[v]Shoot health rated on a scale of 1 to 5 with 5 = healthy, 4 = slightly stunted/few cankers or leaf blight, 3 = chlorosis/moderate stunting/delayed flowering/moderate stem and crown rot or leaf blight, 2 = wilting/severe stunting/severe stem and crown rot or leaf blight, and 1 = dead.
[u]Tukeys Studentized Range Test ($p \leq 0.05$). Means with same letter in column = no significant difference.

Table 3. Root and shoot health ratings of annuals grown in three different substrates that were infected with *Pythium ultimum.*

	Vinca		Impatiens		Begonia		Marigold	
Substrate	**Root[w]**	**Shoot[v]**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**
80:20 P/PWC [z]	3.4a[u]	4.3a	3.0a	4.0a	2.9a	3.5a	3.4a	3.8a
70:30 P/PWC [y]	3.3a	4.0a	2.7ab	3.6a	3.2a	3.9a	3.1a	3.8a
4P[x]	2.5b	3.6a	2.3b	3.3a	2.9a	3.5a	2.9a	3.5a

[z] Substrate containing 80% peat moss and 20% pine wood chips.
[y] Substrate containing 70% peat moss and 30% pine wood chips.
[x]Fafard 4P.
[w]Root health rated on a scale of 1 to 5 with 5 = healthy white roots / no disease recovered, 4 = 25% root rot or seemingly healthy roots + disease recovered, 3 = 50% root rot, 2 = 75% root rot, and 1 = brown/dead roots.
[v]Shoot health rated on a scale of 1 to 5 with 5 = healthy, 4 = slightly stunted, 3 = chlorosis/moderate stunting/delayed flowering, 2 = wilting/severe stunting, and 1 = dead.
[u]Tukeys Studentized Range Test ($p \leq 0.05$). Means with same letter in column = no significant difference.

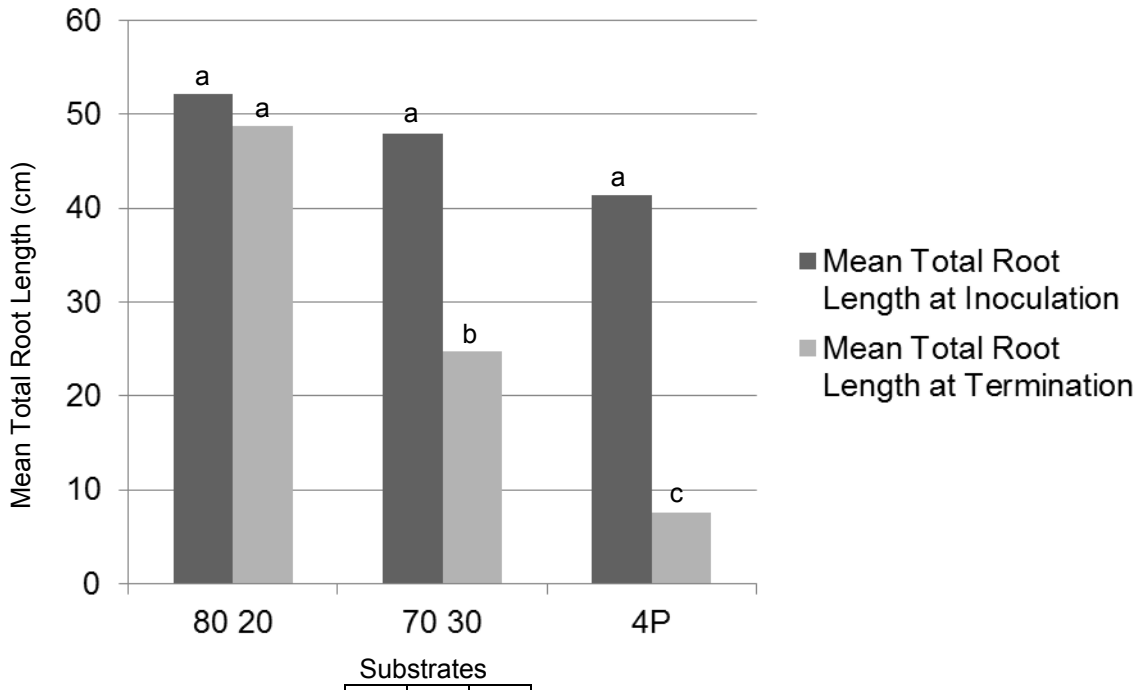

Figure 1. Comparison of mean total root lengths of snapdragons grown in mini-Horhizotrons containing 80% peat moss and 20% pine wood chips, 70% peat moss and 30% pine wood chips, and Fafard 4P at the time of inoculation with *Pythium aphanidermatum*, and at the termination of the experiment.

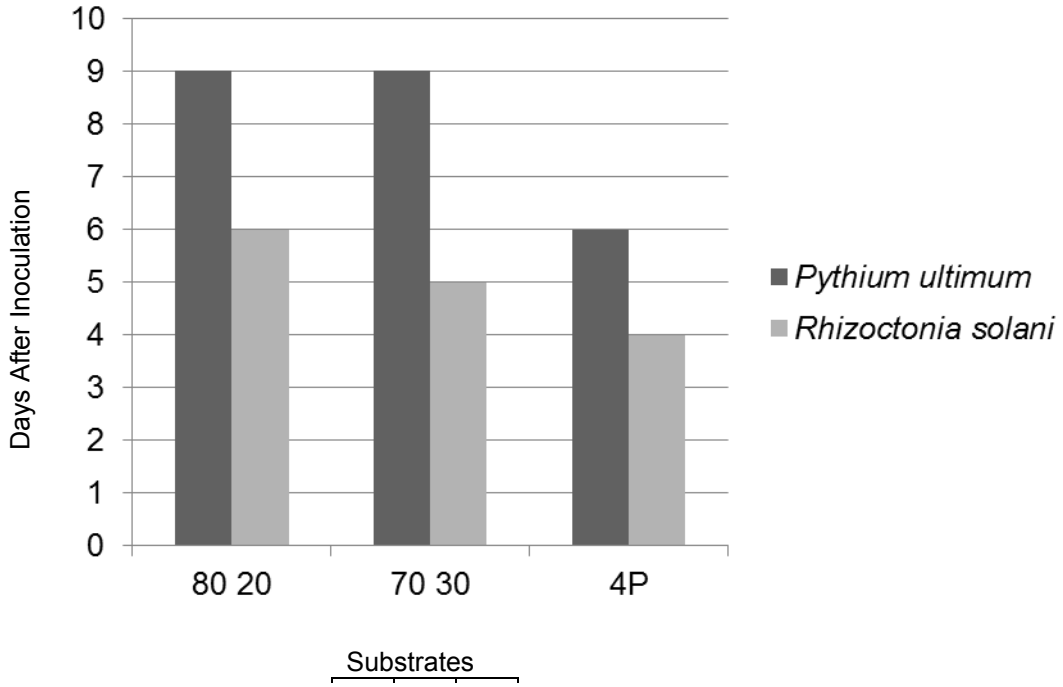

Figure 2. The number of days after inoculation with *Rhizoctonia solani* and *Pythium ultimum* when symptoms were visible on bedding annuals grown in substrates containing 80% peat moss and 20% pine wood chips, 70% peat moss and 30% pine wood chips, and Fafard 4P.

Measuring Substrate Water Potential Changes During Plant Wilt

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Index Words: dewpoint potentiameter, permanent wilt

Significance to Industry: A better understanding of horticultural substrate water potential can help growers efficiently irrigate their plants during production. Studying plants undergoing drought stress and quantifying both substrate water potential and permanent wilting point can provide information on plant irrigation needs, possibly leading to less frequent irrigation, saving the grower money. Further, understanding that horticultural substrates differ in plant unavailable water (which influences the time it takes for plants to wilt after an irrigation event) may help growers choose substrates that can extend time untill permanent wilting and effectively lengthen the postharvest life of container plants once in a post production retail environment. Plants used in this study were allowed to wilt past the normally accepted range of permanent wilting point of -1.0 MPa to -2.0 MPa and lower, yet completely recovered after rewatering. This study indicates a possible need to extend the permanent wilting point range as well as the need to investigate plant available water related to horticultural substrates.

Nature of Work: Within the past few decades there has been an increase in containerized plant production, leading to an increased interest in watering efficiency (6). There has also been increased interest in plant available and unavailable water within horticultural substrates and their relationship to permanent wilt (2, 5). Plant available water is the water present in the substrate that is readily available for plant use; unavailable water is present in the substrate yet is unable to be taken up by plants (7). It is important to know if plant available and unavailable water varies among commonly used substrates and if these hydrophysical properties can be better understood or modified to enhance the performance of certain substrates for plant production. Permanent wilting point (PWP) is a term used to describe the point in which substrate water potential is too low for plants to recover (8). Research on PWP can help uncover information on plant, water and substrate relationships, and may help growers water more efficiently.

The 15 Bar pressure plates (producing a suction of -1.5 MPa) have been used to determine plant unavailable water in mineral soils for decades. This technique/apparatus was adopted by horticultural scientists and also used to measure water properties of soilless substrates. Recent research has discovered that the 15 Bar apparatus will often produce inaccurate measurements when used on soilless

substrates (3, 4). The reason for the inaccurate measurements is thought to be due to a loss in hydraulic conductivity between the pressure plate and the substrate particles which are much larger and more porous than mineral soils (2). Recently, the WP4C dewpoint potentiameter (Decagon, Pullman, WA) has been shown to more accurately measure water potential of highly porous soilless container substrates (1). Soil/substrate materials are placed in small round sample cups and enclosed inside the chamber of the dewpoint potentiameter in order for water potentials to be determined. While inside the dewpoint potentiameter there is a small mirror above the sample with a small space in between. The mirror is heated and cooled until the precise point in which condensation forms on the mirror, this is referred to as the chilled-mirror technique. The dewpoint potentiameter is then able to determine the relative humidity above the sample and subsequently the water potential of the sample in the chamber. The objective of this experiment was to measure the substrate water potential changes during increasing stages of plant wilt of plants grown in a commercial substrate.

The experiment was implemented on April 12, 2013 at a greenhouse located at North Carolina State University, Raleigh, NC. The substrate used in this experiment was Fafard® 4P Mix (Sun Gro Horticulture, Agawam, MA). Thirty-six containers were filled with similar volumes of the 4P substrate and, 18 replications each of vinca (*Catharanthus roseus* 'Cooler Deep Orchid'*)* and marigold (*Tagetes patula* 'Janie Deep Orange') plugs were transplanted into 5-inch containers (ITML Horticultural Products, Middlefield, OH). Plants were placed on a greenhouse bench and arranged in a randomized complete block design. Plants were hand watered as needed with 200 ppm N derived from 20-10-20 Peat-Lite Special (The Scotts Co. Marysville, OH) fertilizer. Four weeks after transplanting, plants were placed in a large plastic container in order to fully saturate the substrate in all containers before allowing plants to dry down. Tap water was then incrementally added to the large container to gradually saturate the substrate from below until the water level reached just below the brim of the containers. Once the containers were submerged (water could be seen glistening on top of the substrate surface of all containers) they were allowed to saturate for 10 minutes, then slowly removed from the tub and placed on a greenhouse bench to freely drain. Plants were then allowed to dry under normal greenhouse environmental conditions and no irrigation was supplied so that plants would naturally wilt. Wilting stages were visually determined as follows, 1) stage one initial flagging; 2) stage two leaves resting towards the stem of the plant and; 3) stage three complete reduction of leaf surface area as leaves lost turgidity. As plants reached each of the three wilting stages the plants were prepared for substrate sampling. Substrate samples were collected by removing the wilted plants from their containers and extracting a 1 cm deep column of substrate down the entire profile (top to bottom) of the root ball. Three replications of each plant species at each wilting stage were collected. After substrate samples were collected the plants were immediately rewatered to see if they would recover from each respective wilt stage. Sampling steps were repeated for each additional wilting stage. Substrate samples were placed in 3.7 cm i.d. x 1.1 cm tall stainless steel sample cups (Decagon, Pullman, WA). The cups containing the samples were immediately sealed and wrapped with Parafilm M® (American Can Co., Greenwich, CT). Samples were

then placed in the dewpoint potentiameter to determine water potential of the individual samples. Data were analyzed using Duncan's Multiple Range test (version 9.2, SAS Institute, Cary, NC).

Results and Discussion: Figure 1 illustrates the changes in substrate water potential at increasing stages of wilt for marigolds. Stage one occurred at -0.11 MPa. Stage two wilting occurred at -0.33 MPa which is far below the proposed range for PWP of -1.0 to -2.0 (2) but had moved well beyond this range by stage three at -2.2 MPa. Figure 2 shows the changes in water potential at increasing stages of wilt for vinca. Stage one and stage two wilt occurred at -0.08 and -0.80 MPa respectively. Stage three wilt was at -5.11 MPa far above the PWP range. All plants recovered within 24 hours after rewatering. These data suggest that plant wilt for these species, even when severe, does not mean the plant has reached its permanent wilting point. The permanent wilting point for plants (at least these species tested) appears to be well below the commonly referenced range of -1.0 to -2.0 MPa. Vinca went to substantially lower tensions before wilting (and recovering) compared to marigold which may be attributed to their noted heat and drought tolerance as landscape annuals. These data also reaffirm previous works (2) that the dewpoint potentiameter is capable of measuring substrate water potentials at very low tensions. Further research needs to be conducted on the water potential of plants as wilting occurs between species and substrates. Other parameters should also be further studied to better understand changes in horticultural substrate water potentials including physiological differences in plant species, drought tolerance, root architecture, exposure to heat stress, etc. as these may explain variation in expected readings.

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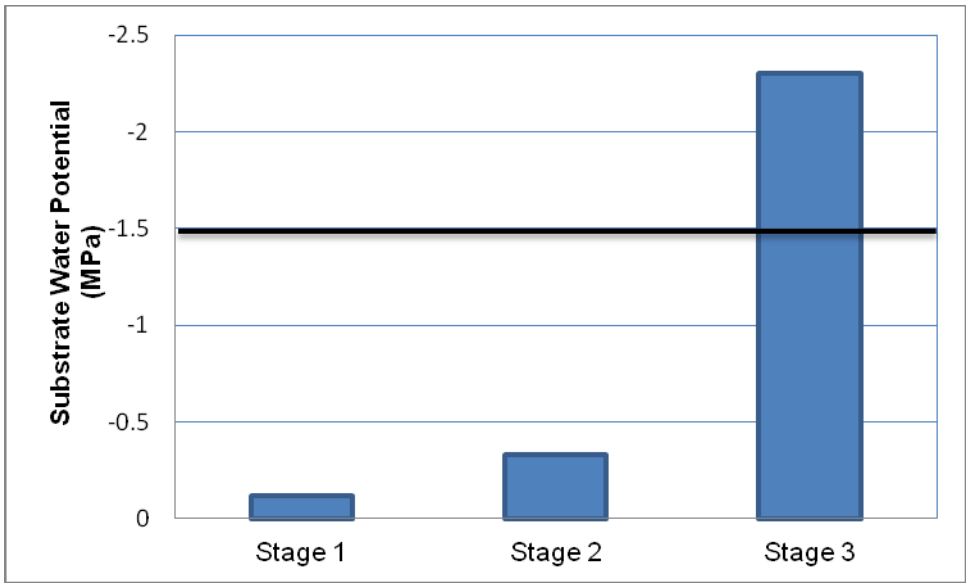

Fig.1 Substrate water potential of Fafard 4P with marigolds allowed to dry to three increasing stages of wilt. Stage one: initial flagging, stage two leaves resting towards the stem of the plant, and stage three complete reduction of leaf surfaces area as leaves lost turgidity. The bold line indicates -1.5 MPa the accepted permanent wilting point for most plants.

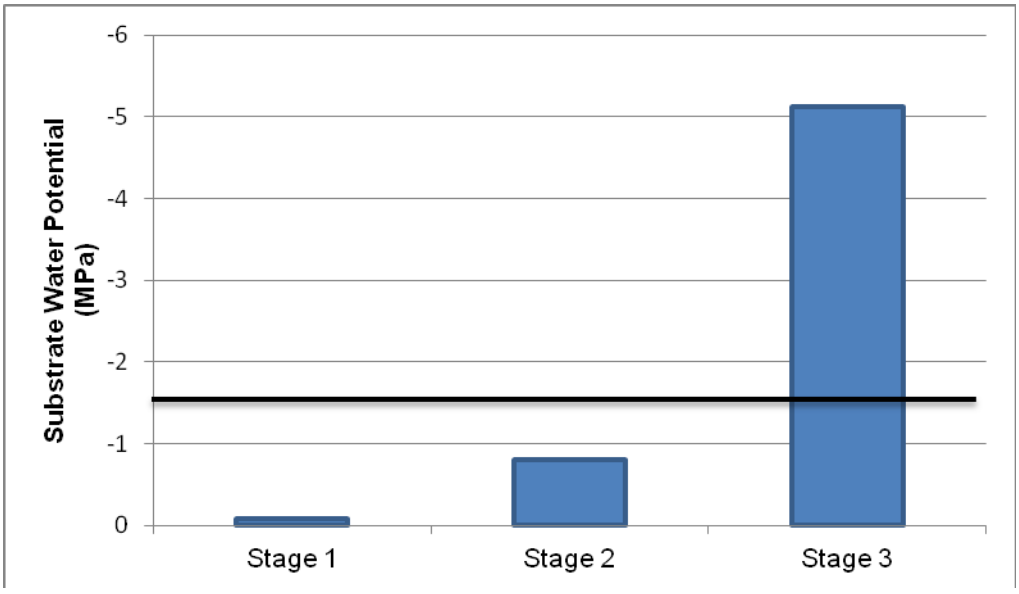

Fig. 2 Substrate water potential of Fafard 4P with vinca allowed to dry to three increasing stages of wilt. Stage one: initial flagging, stage two leaves resting towards the stem of the plant, and stage three complete reduction of leaf surfaces area as leaves lost turgidity. The bold line indicates -1.5 MPa the accepted permanent wilting point for most plants.

Effects of Nitrogen Rates on Plant Growth and Flowering Performance in Reblooming Iris

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Index Words: specialty cut flower, *Iris germanica* 'Immortality'

Significance to Industry: At present, U.S. cut flower market is mainly supplied by imported cut flowers. Newly developed specialty cut flowers have been proven to be profitable. For its fragrance, showy display with multi-colors, *Iris germanica* has great potential to serve as a specialty cut flower crop. In 2012 iris stalks accounted for $14.2 million of the 342 million cut flower whole sale reported of the 15 state's total (6). However, with a short season of availability as a cut flower, scheduled year round production is needed to make iris a viable specialty cut flower. Research has been conducted to make reliable reblooming of reblooming iris cultivars possible, but there is currently no effective method of regulating reblooming (1, 3, 4, 5). Recent research results showed that increasing fertilizer rate can improve inflorescence and stalk length (2). But limited research has been conducted concerning nitrogen (N) fertilizer guidelines for reblooming iris. Efficient N fertilizer management can increase N use efficiency, reduce N runoff, and decrease the potential for environmental contamination (7). The objective of this research is to investigate the optimal N fertigation rate for promoting reblooming of 'Immortality' iris.

Nature of Work: Iris has great potential to serve as a specialty cut flower crop. Based on the short season of availability of iris, scheduled year round blooming is needed to make iris a viable specialty cut flower. The reblooming iris, also called rebloomer or remontant, can produce more than one crop of bloom stalks in a single growing season. 'Immortality' is a reliable reblooming iris cultivar which was used in this study. *Iris germanica* 'Immotality' belongs to the Tall Bearded iris class and is often called German iris. It flowers in early spring, March and April, and again from late July into October or even later in warmer climates.

This experiment was initiated in spring 2012 using 'Immortality'. This study focused on the effects of five N rates (0, 5, 10, 15 or 20 mM) on plant growth and reblooming performance. There were 5 replications in each N treatment with 16 subsamples in a randomized complete block design. Rhizomes of iris 'Immortality' were dug up from the field at North Farm, Mississippi State University on March 14, 2012. Plants were selected for uniformity and transplanted into 1-galon (9 inch diameter× 6 inch height) pots filled with Fafard mix #2 with no starter fertilizer (1 plant/pot). Plants were grown

outdoors under natural conditions in Mississippi State, Mississippi and were drip-irrigated as needed throughout the growing season.

Plants were fertigated twice per week from April to September 2012. During each fertigation, plants in each group were fertigated (400ml each pot) with one of five nitrogen (N) concentrations (0, 5, 10, 15 or 20mM N from NH_4NO_3, Sigma Aldrich, St. Louis, MO) plus N-free fertilizer (1.06 mg mL^{-1}, Cornell No N Formula 0-6-27, Greencare Fertilizers, Kankakee, IL). The number and length of flower stalks and plant height were collected from mid-summer to late fall. Five plants in each treatment were destructively harvested in December 2012. At harvest, data taken included plant height and number of fans. Leaves and rhizome were washed with double distilled water. All the samples were divided into 3 parts, leaves, roots, and rhizomes and dried in 60ºC forced-air oven. Samples were grounded for total nitrogen analysis (Analyzed in Mississippi State University Extension Service Soil Testing Laboratory).

Result and Discussion: 2012 growth and blooming: Results showed that increasing N rate can improve plant height and reblooming flower yield. The 20 mM N rate significantly increased the second blooming compared to the other rates. Plants received 0 and 5 N rates did not produce any second time bloom in later summer and fall (Table 1). Higher N rates produced earlier first bloom and extended the growth period of new fans which has the potential to produce more reblooming flowers. Higher N fertigation rates significantly increased the length of flower stems in spring blooming.

2013 growth and blooming: In early spring 2013, the plant height and number of new fans significantly increased with increasing N rate (Table 2). Higher fertigation rates had positive influence on the yield of blooming in spring 2013.

2012 N concentrations and contents: The N concentrations in different tissues are significantly different. The average concentration in leaves is higher than that in rhizomes and roots (Table 3). Rhizome tissue has the highest N content and highest dry weight (Table 4). N concentrations in root and rhizome tissue are significantly improved by increasing N rate. However, the N concentrations of leaf tissues under various N treatment were similar.

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Table 1. Influence of nitrogen (N) fertigation rate on the number and length of blooming stalks of iris 'Immortality'.

	2012, 1st blooming		2012, 2nd blooming		2013, 1st blooming	
Nitrogen rate (mM)	Number of stems (Stems/plant)	Stem length (cm)	Number of stems (Stems/plant)	Stem length (cm)	Number of stems (Stems/plant)	Stem length (cm)
0	0.03c[z]	34.0b	0b	-	0.0b	-
5	0.75b	37.4b	0b	-	0.4ab	62.0a
10	0.95ab	39.0ab	0.06b	49.0a	0.4ab	49.1a
15	1.21ab	40.4ab	0.11b	46.0a	0.4ab	55.2a
20	1.25a	45.1a	0.34a	45.7a	1.4a	56.2a

[z] Means denoted by the same letter within a column are not significantly different ($LSD_{0.05}$)

Table 2. Effects of nitrogen (N) fertigation rate on plant height and the number of fans of iris 'Immortality'.

Nitrogen treatment (mM)	Plant height (Dec., 2012)	Number of fans (Dec., 2012)	Plant height (March, 2013)	Number of fans (March, 2013)	Plant height (April, 2013)	Number of fans (April, 2013)
0	13.6d[z]	3b	10.2c	7c	32.4d	8c
5	22.3c	8a	17.5b	10bc	46.2c	11bc
10	28.3bc	6ab	19.9b	13ab	51.7bc	14b
15	31.7ab	6ab	21.5b	9bc	54.8b	8c
20	37.8a	5b	30.4a	17a	62.5a	19a

[z] Means denoted by the same letter within a column are not significantly different ($LSD_{0.05}$)

Table 3. Effects of nitrogen (N) fertigation rate on plant dry weight (DW) of iris 'Immortality'. Plants were harvested in December 2012.

Nitrogen treatment (mM)	Leaf DW (g)	Root DW (g)	Rhizome DW (g)	Total DW (g/plant)
0	3.4c [z]	3.0c	18.2bc	24.6c
5	13.0b	15.8a	28.7abc	54.4ab
10	19.2ab	15.3a	32.1a	66.5a
15	20.1a	11.6b	17.1c	48.7b
20	23.0a	13.4ab	29.2ab	65.5ab

[z] Means denoted by the same letter within a column are not significantly different ($LSD_{0.05}$)

Table 4. Effects of nitrogen (N) fertigation rate on N concentration and content of iris 'Immortality'. Plants were harvested in December 2012.

Nitrogen treatment (mM)	Leaf N Concentration (%)	Leaf N Content (g/plant)	Root N Concentration (%)	Root N Content (g/plant)	Rhizome N Concentration (%)	Rhizome N Content (g/plant)	Total N Content (g/plant)
0	2.6a	0.09c	0.7b	0.06b	1.3c	0.30c	0.35c
5	2.7a	0.37b	0.7b	0.09a	2.3b	0.57ab	1.08b
10	2.8a	0.52ab	0.8b	0.13a	3.4a	1.07a	1.69a
15	2.8a	0.53a	1.1a	0.14a	3.4a	0.80bc	1.23ab
20	2.8a	0.67a	1.1a	0.16a	3.2ab	0.92ab	1.72a

[z] Means denoted by the same letter within a column are not significantly different ($LSD_{0.05}$)