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# Greenhouse and Subsequent Landscape Growth Responses of Petunia and Pansy to Container Size, Copper-Coated Containers, and Extended Production Times

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## ABSTRACT

**Pansy (*Viola* x *wittrockiana* 'Happy Face White Blotch') and petunia (*Petunia* x *hybrida* 'Ultra Plum', 'Primetime Pink', and/or 'Primetime White') were grown in $Cu(OH)_2$-treated or non-treated plastic containers with six media compartments of 61, 101, or 158 $cm^3$ volume for zero, seven, or fourteen days past first flower. Two thirds of the plants in each treatment combination were transplanted from the greenhouse into outdoor ground beds to determine subsequent landscape performance. Other studies investigated seedling growth of both species in factorial combinations of $Cu(OH)_2$-treated and non-treated plugs (1.5 $cm^3$) and treated or non-treated 158 $cm^3$ cell packs during greenhouse production. Additional greenhouse studies were conducted on petunia to compare cultivar-dependent responses to Cu-treated containers and to determine water consumption. Larger pack sizes resulted in consistently larger, more floriferous, and greater quality-rated plants across plant taxa and Cu-treatments, but required more water during production than smaller pack sizes. Responses to Cu-treated containers were dependent on species/cultivar, container size, and/or production stage. Enhanced vegetative growth, flowering, or quality ratings in response to Cu-treated containers, both post-production and following transplanting to the landscape, were more evident with larger pack size and when production times were extended past optimum shipping times. Some pansy and petunia seedlings were chlorotic when grown in Cu-treated plug trays, but usually recovered when transplanted to larger cell packs.**

## RESUMEN

**Se cultivaron plantas de pensamiento (*Viola* x *wittrockiana* cultivar 'Happy Face White Blotch') y de petunia ( *Petunia* x *hybrida* cultivares 'Ultra Plum', 'Primetime Pink' y/o 'Primetime White') en macetas de plástico tratadas o no tratadas con $Cu(OH)_2$ conteniendo compartimientos con volumen de 61, 101, o 158 $cm^3$ por cero, siete o catorce días después de la primera floración. Dos tercios de las plantas en cada combinación de tratamiento fueron transplantadas del invernadero a camas en el suelo en exterior para determinar su subsecuente desempeño en jardín. En otros estudios, se investigó el crecimiento de ambas especies en combinaciones factoriales de orificios (1.5 $cm^3$) tratados y no tratados con $Cu(OH)_2$ y de paquetes de celdillas de 158 $cm^3$ tratadas y no tratadas durante la producción en invernadero. Se condujeron estudios de invernadero adicionales en petunia para comparar las respuestas dependientes del cultivar a los contenedores tratados con Cu y para determinar el consumo de agua. El uso de compartimientos de mayor volumen produjo plantas que fueron de mayor tamaño, más floreadoras, y de mayor calidad en los diferentes taxones de plantas y tratamientos con Cu, pero requirió más agua durante la producción que el uso de compartimientos de menor volumen. Las respuestas a las macetas tratadas con Cu fueron dependientes de la especie/cultivar, el tamaño de la maceta, y/o el estado de producción. El aumento en el crecimiento vegetativo, la floración, o los grados de calidad ocurridos en respuesta a los contenedores tratados con Cu, tanto en postproducción como después del transplante al jardín exterior, fueron más evidentes cuando se usaron compartimientos de mayor volumen y cuando los tiempos de producción se extendieron más allá de los tiempos óptimos para embarque. Algunas de las plántulas de petunias y de los pensamientos presentaron clorosis cuando crecieron en las charolas con orificios tratados con Cu, pero usualmente se recuperaron cuando se transplantaron a los paquetes de celdillas más grandes.**

It is well documented that Cu-containing latex compounds applied to the interior surfaces of containers reduce root deformation at the container wall:medium interface and increase the fibrosity (branching) of roots during the production of various woody plants (Arnold and Struve, 1989a; Arnold and Young, 1991; Beeson and Newton, 1992). Copper-treated containers have also been reported to increase the vegetative growth or flowering of some woody species during container production (Arnold, 1992; Arnold and Struve, 1989a and b; Ticknor, 1989). Reductions in post-transplant stress symptoms and improved growth have been demonstrated for woody species, but the effects appear to be

**Table 1.** Interactions between cell volume (pack size) and cultivar on the vegetative growth and flowering of 'Primetime Pink' and 'Primetime White' petunia after 28 days in greenhouse production.[z]

| Cultivar | Cell size | Shoot dry mass | Total plant dry mass | Flower and floral buds per plant |
|---|---|---|---|---|
| | ($cm^3$) | (g) | (g) | (number) |
| 'Primetime Pink' | 158 | 1.68 a[y] | 1.79 a | 23.4 a |
| | 101 | 1.44 b | 1.55 b | 20.7 b |
| | 61 | 1.06 c | 1.13 c | 17.4 c |
| 'Primetime White' | 158 | 1.31 a | 1.38 a | 16.3 ab |
| | 101 | 1.22 a | 1.29 a | 17.7 a |
| | 61 | 0.94 b | 1.00 b | 14.7 b |
| Significance: | | | | |
| Cultivar | | **[x] | ** | ** |
| Cell size | | ** | ** | ** |
| Cultivar x cell size | | ** | ** | ** |

[z]Data were pooled across $Cu(OH)_2$-treatments.

[y]Means within a column and cultivar followed by the same letter are not significantly different at $P \leq 0.05$, using least squares means procedure.

[x]** and * indicate statistically significant effects at $P \leq 0.01$ and $P \leq 0.05$, respectively.

species dependent (Arnold, 1996; Arnold and Struve, 1989b; Struve, 1993).

Few studies have documented the effects of copper-treated containers on the growth and quality of annual bedding plants and other herbaceous materials (Arnold et al., 1993; Case and Arnold, 1992; Latimer and Baden, 1993). Results from a study by Arnold et al. (1993) showed that *Celosia cristata* L. 'Castle Pink' and *Impatiens wallerana* Hook. 'Super Elfin Red' grown in $Cu(OH)_2$-treated containers had heavier shoots or increased flower production as compared to plants grown in non-treated containers during greenhouse production. Ruter (1995) reported that Cu-treated containers increased vegetative growth of *Plumbago auriculata* Lam., but not *Coreopsis verticillata* L. A recent study demonstrated that applying $Cu(OH)_2$ to small propagation containers of several perennials significantly improved their flowering after being transplanted into baskets (Svenson and Johnston, 1995).

It appears that bedding plants are subject to root binding (Latimer, 1991), as is seen with other vigorously rooted perennial and woody plants. This may be a hindrance to rapid establishment in the landscape. This becomes a bigger concern when plants are grown in smaller containers and need to be held in the greenhouse for several days past optimum transplant stage. Bedding plants are ideally shipped at or just prior to opening of the first flower to allow maximum postharvest shelf-life. Delayed shipment can result in plants that have outgrown the capacity of the potting medium present in a given container, resulting in a subsequent decline in plant vigor and appearance. Utilizing copper compounds for controlling root growth of bedding plants may improve their performance during the production phase as well as their performance after transplanting into landscape beds. Some species of woody plants have shown improved water uptake or reduced water stress when grown in Cu-treated containers (Vartak, 1993) or transplanted from Cu-treated containers to the field (Arnold, 1996) compared to those in or from non-treated containers.

Pansies are an important cool season bedding plant crop and greenhouse crop in warm temperate and subtropical regions. Petunias are a popular spring to summer transition season color plant in the same regions. Reducing adverse effects of extended production schedules and/or improving establishment of these species could benefit producers, landscapers, and consumers.

The objectives of this study were to determine: 1) effects of $Cu(OH)_2$-treated cell packs on growth and water consumption of petunia during greenhouse production, 2) effects of $Cu(OH)_2$-treated (formulated as Spin Out) plug trays on subsequent growth and flowering of pansy and petunia in cell packs, and 3) the interactions among cell pack size, $Cu(OH)_2$ treatment, and production holding time on pansy and petunia greenhouse performance and subsequent growth in the landscape.

## MATERIALS AND METHODS

*Cultivar responses and water consumption.* Two petunia cultivars (*Petunia* x *hybrida* Hort. Vilm.-Andr. 'Primetime White' and 'Primetime Pink') were seeded on 2 Aug. 1993 into non-treated plug trays (molded plastic propagation trays with 1.5 $cm^3$ inverted cone-shaped pockets, TLC Polyform Inc., Morrow, Ga.) containing Fafard germination substrate (Conrad Fafard Inc., Agawam, Md.). Plants were grown in a polyethylene greenhouse at day/night temperature setpoints of 25/18°C and fertigated with an 15N-2.2P-12.4K (15-5-15) fertilizer at 100 $mg \cdot L^{-1}$ N. Recorded temperatures (Model 08369-70 Oakton mini-drum hygrothermograph, Cole-Parmer Instrument Co., Vernon Hills, Ill.) indicated a maximum high of 31°C and low of 13°C.

On 15 Sept., plants were transplanted into treated, spray painted on interior surfaces with $Cu(OH)_2$ at 100 $g \cdot L^{-1}$ of latex carrier (7% wt.:vol., formulated as Spin Out, Griffin Corp., Houston, Texas), or non-treated 61 $cm^3$, 101 $cm^3$, and 158 $cm^3$ six-cell packs (molded plastic tray inserts, Kord Products Inc, Bramalea, Ont., Canada) containing Fafard # 2 medium. After

**Table 2.** Effects of interactions between plug and pack $Cu(OH)_2$ treatments on 'Happy Face White Blotch' Pansy grown in $Cu(OH)_2$-treated or non-treated plug trays and transplanted to treated or non-treated 158 $cm^3$ cell packs. Plants were harvested at green stage (average of one or fewer flowers per plant).

| $Cu(OH)_2$ treatment | | Height | Root dry | Plant |
|---|---|---|---|---|
| Plugs | Packs | | mass | index |
| | | (cm) | (g) | ($cm^3$) |
| - Cu | - Cu | 13.5 a[z] | 1.16 a | 3025 a |
| | + Cu | 12.0 bc | 0.95 b | 2354 bc |
| + Cu | - Cu | 11.3 c | 0.77 c | 2068 c |
| | + Cu | 12.3 b | 0.88 bc | 2649 ab |

[z]Means within a column followed by the same letter are not significantly different at $P \leq 0.05$, using least squares means procedure.

**Table 3.** Effects of factorial combinations of growing petunias in $Cu(OH)_2$-treated or non-treated plug trays and transplanted to treated or non-treated 158 $cm^3$ cell packs during greenhouse production.

| $Cu(OH)_2$ treatment | | Flower | Open | Total flowers & | Root dry | Total plant |
|---|---|---|---|---|---|---|
| Plug | Pack | buds | flowers | floral buds | mass | dry mass |
| | | (number) | (number) | (number) | (g) | (g) |
| - Cu | - Cu | 1.5 a[z] | 1.0 a | 2.5 a | 0.08 c | 1.07 bc |
| | + Cu | 1.1 b | 0.8 ab | 1.9 b | 0.10 b | 1.18 b |
| + Cu | - Cu | 0.9 b | 0.5 b | 1.5 b | 0.09 bc | 1.05 c |
| | + Cu | 1.1 b | 0.7 b | 1.8 b | 0.14 a | 1.35 a |

[z]Means within a column followed by the same letter are not significantly different at $P \leq 0.05$, using least squares means procedure.

**Table 4.** Main effects of extended production past green stage on pansies during greenhouse production.[z]

| Days from green stage | Open flowers | Total flowers & floral buds | Shoot dry mass | Root dry mass | Total plant dry mass |
|---|---|---|---|---|---|
| | (number) | (number) | (g) | (g) | (g) |
| 0 | 0.4 c[y] | 1.8 b | 0.55 c | 0.08 b | 0.63 c |
| 7 | 0.9 b | 2.2 b | 0.80 b | 0.11 b | 0.91 b |
| 14 | 2.2 a | 3.8 a | 0.99 a | 0.16 a | 1.15 a |

[z]Data were pooled across pack sizes and $Cu(OH)_2$-treatments.

[y]Means within a column followed by the same letter are not significantly different at $P \leq 0.05$, using least squares means procedure.

potting, plants were irrigated as needed with the same type and concentration of fertilizer described above. Packs were placed on 0.3 m spacings in a randomized complete block design with three blocks and one pack (six plants) per block per treatment combination.

To determine overall water consumption for plants grown in the different Cu-treated and non-treated packs, irrigation inputs and outputs (amount leached) for the 'Primetime Pink' petunia were monitored. Beginning immediately after transplanting and subsequently as plants required irrigation (determined by weight when lifting cell packs and visual inspection of the media), each Cu-treated and non-treated 61, 101, and 158 $cm^3$ six-pack received 150, 200, and 250 ml of irrigation solution, respectively. Volume of solution leached through the packs was recorded and subtracted from solution applied to determine overall water consumption. On 13 Oct., plants were harvested and measured for root and shoot fresh and dry mass.

*Plug experiments*. Factorial experiments were conducted to test the effects of Cu- treated and non-treated plug trays and containers on the greenhouse performance of a typical fall- and spring-planted bedding plant species. Pansy (*Viola* x *wittrockiana* Gams. 'Happy Face White Blotch') was seeded on 26 Aug. 1994 into $Cu(OH)_2$-treated or non- treated 1.5 $cm^3$ cell plug trays containing Fafard germination substrate (Conrad Farfard, Inc., Agawam, Md.). Plants were grown in a polyethylene greenhouse with temperature setpoints of 25/18°C (day/night), recorded maximum high of 32°C and low of 10°C, and fertilized periodically with a 15N-2.2P-12.4K fertilizer at 100 $mg \cdot L^{-1}$ N. On 18 Oct., all plants were transplanted into treated or non-treated 158 $cm^3$ six-packs containing Fafard # 2 medium and grown for six weeks under similar greenhouse and fertilization regimes. Packs were placed on 0.3 m spacings in a randomized complete block design with five blocks and one pack (six plants) per block per treatment combination.

At six weeks of greenhouse production (at first flower or green stage), plants were harvested and evaluated for leaf number, height, average width (mean of widest and narrowest

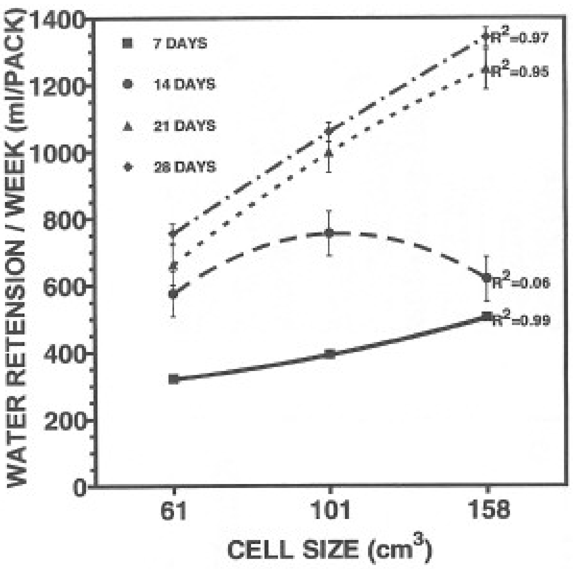


**Fig. 1.** Effects of significant ($P \leq 0.05$) interactions among pack size and production time on weekly water consumption of petunia plants grown for 7 (■ = mean ± standard errors, lines are second order polynomial regression equations), 14 (●), 21 (▲), or 28 (◆) days in 61, 101, or 158 $cm^3$ cell packs during greenhouse production. Data were pooled across $Cu(OH)_2$-treatments. Regression equations were significant at $P \leq 0.05$ for days 7, 21, and 28, but not day 14.

spread perpendicular to height), number of flower buds and open flowers, root fresh and dry mass, shoot fresh and dry mass, and overall visual quality. Quality ratings were determined independently by two evaluators. A consensus rating was determined when ratings differed for individual plants. Quality ratings were assigned as follows: 0 = dead; 1 = alive but of very poor quality; 2 = below minimum acceptable quality, evidence of poor vigor, little flowering, or foliage not medium to dark green; 3 = acceptable overall quality and appearance, growth form, size and flowering typical of the species and development stage; 4 = above average overall quality and appearance for the species and developmental stage; 5 = superior plant in overall quality and appearance, dense and symmetrical growth form, dark green foliage, abundant flowering. A growth index was calculated as height x widest width x narrowest width.

For spring studies, petunia (*Petunia* x *hybrida* Hort. Vilm.-Andr. 'Ultra Plum') was seeded on 7 Feb. 1995, transplanted on 14 Mar., and harvested on 20 Apr. Plants were grown and treated similarly as for the fall pansy experiments above. Maximum recorded high and low temperatures in the greenhouse were 28°C and 10°C, respectively.

*Production timing experiments*. Experiments were conducted to determine the interaction between cell pack size, $Cu(OH)_2$ treatment, and production holding time on pansy and petunia performance in the greenhouse and landscape. 'Happy Face White Blotch' pansy was seeded on 27 Aug. 1994 into non-treated plug trays (1.5 $cm^3$ / cell) containing Fafard germination substrate and grown in a polyethylene greenhouse as described in the previous experiment. On 19 Oct., plants were transplanted into either Cu-treated ($Cu(OH)_2$ at 100 $g{\cdot}L^{-1}$) or non-treated 61 $cm^3$, 101 $cm^3$, or 158 $cm^3$ cell packs (six cells•$pack^{-1}$) containing Fafard # 2 medium and grown for either six, seven, or eight weeks, corresponding to first flower or green stage and seven or 14 days past green stage, respectively. Packs were placed on 0.3 m spacings in a randomized complete block design with three blocks and one pack (six plants) per block per treatment combination. After either six, seven, or eight weeks of growth (0, 7, or 14 days past green stage), two plants were randomly harvested from each pack and evaluated as those in the previous experiment.

The remaining plants from packs of all sizes were planted in landscape beds (three randomized complete blocks with four plants•$block^{-1}$ of each treatment combination) after each greenhouse harvest. Landscape beds contained Luftkin clay loam soil amended with 0.17 $m^3$ peat moss per 10.6 $m^2$ and Osmocote 14N-6.1P-11.6K (Scotts Co., Marysville, Ohio) at a rate of 9.8 $g{\cdot}m^{-2}$ N. Weeds were removed manually, overhead irrigation was provided as needed. Plants were evaluated periodically throughout the growing season for total open flowers and overall quality. On 22 Apr., final evaluations were taken, plants harvested, and fresh and dry mass recorded.

For corresponding spring studies, 'Ultra Plum' petunia was seeded on 6 Feb. 1994 into plug flats and transplanted on 13 Mar. into similarly treated or non-treated cell packs. For this study, plants were grown for either four (first flower stage), five, or six weeks, corresponding to first flower or green stage and seven or 14 days past green stage, respectively, before being harvested or planted into the landscape. Production guidelines were followed and data analyzed similarly as in the fall production timing study. Landscape trials were harvested on 11 May and evaluated as previously described.

Trends of tissue mass data as indicated by fresh masses were similar to that of dry masses, thus only dry mass data are presented. Data for each species were analyzed separately in each experiment. Data for significant interactions ($P \leq 0.05$) are presented for each experiment. If higher order interactions were not significant, data were pooled across non-significant effects and lower order interactions or main effects and then presented if they were significant ($P \leq 0.05$). Least squares means and polynomial regression analyses procedures were used to elucidate treatment differences for significant main effects and interactions not involved in significant high order interactions.

## RESULTS AND DISCUSSION

*Cultivar responses and water consumption*. Regardless of Cu treatment, shoot mass, total plant mass and total number of flowers and floral buds tended to increase with increased cell size (Table 1). 'Primetime Pink' petunia tended be more responsive to larger cell sizes than 'Primetime White' petunia (Table 1). Across cultivars, Cu-treated packs statistically increased ($P \leq 0.05$) root (0.09 vs. 0.08 g) and total plant (1.43 vs. 1.29 g) dry mass and the number of total flowers and buds present (19 vs. 17) for petunias. Shoot dry mass of 'Primetime White' petunia was significantly ($P \leq 0.05$) increased by Cu-treated packs (1.26 vs. 1.06 g), while

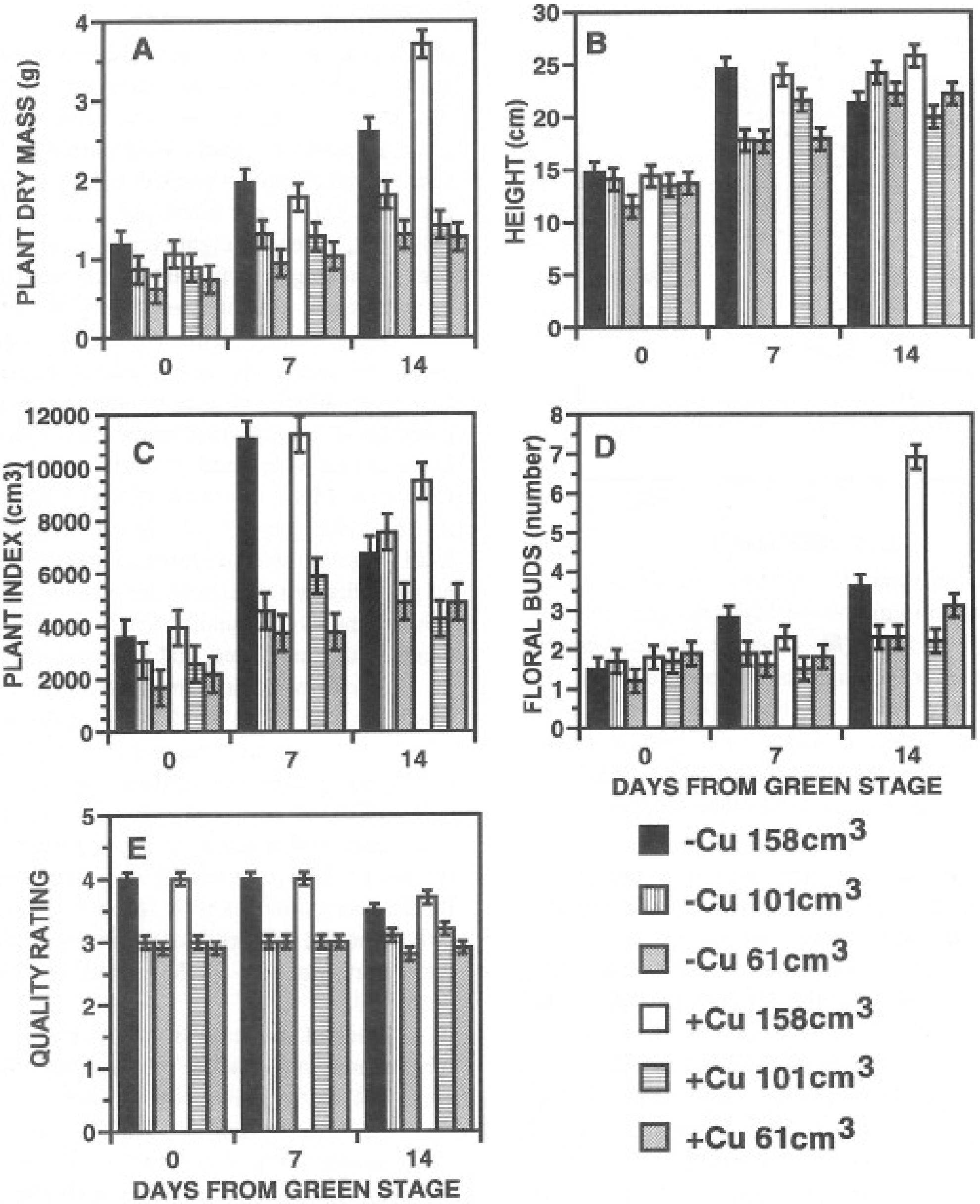


**Fig. 2.** Effects of significant ($P \leq 0.05$) pack size x $Cu(OH)_2$-treatment x production time interactions on total dry mass (A), plant height (B), plant index (C), number of flower buds (D), and quality rating (E) of petunia at zero, seven, and fourteen days from green stage grown in 158, 101, or 61 $cm^3$ cell pack containers that were sprayed on interior surfaces with $Cu(OH)_2$ at $100 g \cdot L^{-1}$ latex carrier, or not treated. Each point represents the mean (± standard error) of ten plants.

'Primetime Pink' was not statistically different (1.43 vs. 1.36 g), documenting differential responses among cultivars of the same species. Numerous studies have documented differential growth responses to Cu-treated containers among woody species (Arnold and Struve, 1993; Beeson and Newton, 1992) and herbaceous species (Arnold et al., 1993; Case and Arnold, 1992; Latimer and Baden, 1993; Ruter, 1995; Svenson and Johnston, 1995), but not among cultivars of the same herbaceous species.

Mean weekly water consumption increased over time with rootballs in larger pack sizes retaining more irrigation water (Fig. 1), probably due to greater evapotranspiration demands of plants in larger pack sizes due to greater shoot and total plant mass (Table 1) and greater exposed media surface (12.3, 19.3, and 22.5 $cm^2$ for 61, 101, and 158 $cm^3$ cells, respectively). No differences in water consumption could be attributed to use of Cu-treated containers (data not presented).

*Plug experiments*. Copper-treated plugs or packs tended to suppress the height, root mass, and growth index of pansy (Table 2) and slightly decreased flowering of petunia (Table 3). However, Cu-treated plugs slightly increased flowering of pansies (0.5 vs. 0.2 flowers, $P \leq 0.05$) across pack treatments. A significant ($P \leq 0.05$) interaction was present for flowering and some vegetative growth parameters of petunias grown in combinations of treated and non-treated plugs and packs. The combination of planting petunias in Cu-treated plugs and Cu-treated packs resulted in the most vegetative growth, but fewer flowers than those that were never grown in Cu-treated plugs or packs (Table 3). Copper-treated plugs increased ($P \leq 0.05$) the growth index (5017 vs. 4500 $cm^3$) of petunia across plug/pack combinations. Petunia shoot mass was increased with Cu-treated 158 $cm^3$ cell packs compared to non-treated 158 $cm^3$ cell packs (1.15 vs. 0.98 g). Previous studies showed that flowering responses to Cu-treated containers were concentration dependent for *Impatiens wallerana* Hook. (Arnold et al., 1993) and cultivar dependent with *Forsythia* x *intermedia* Zab. (Ticknor, 1989). A foliar chlorosis developed on $Cu(OH)_2$-treated plugs of both species. The chlorosis frequently decreased or disappeared following transplanting of the plugs to packs. Analysis of potting medium samples showed an increase in soluble salts and pH that may have resulted in the observed response.

*Production timing experiments.* Copper-treated packs had no significant effect on growth or flowering of pansy during the extended greenhouse production timing experiment (data not presented). In general, effects of Cu-treated packs were most evident on petunia the longer plants were held in the greenhouse past first flower stage. Petunia in Cu-treated 158 $cm^3$ cell packs had greater total mass (Fig. 2A), height (Fig. 2B), plant index (Fig. 2C), and number of flower buds (Fig. 2D) than those in non-treated 158 $cm^3$ cell packs when held for 14 days past first flower. However, growth parameters were more dependent upon pack size at first flower and at seven days past first flower than on Cu treatments. Copper-treated pack effects on petunia grown in 101 and 61 $cm^3$ cell packs were of a lesser magnitude and less consistent in response (Fig. 2). The interaction between Cu-treatment and pack size over production time was statistically significant ($P \leq 0.05$) for visual quality ratings of petunias, however, differences in quality ratings were likely not of commercial significance (Fig. 2 E). A container size by Cu-treatment interaction was reported for growth of several coniferous species in small containers (Burdett and Martin, 1982; Struve, 1993).

Across pack sizes and holding times, Cu-treated packs slightly reduced the root to shoot dry mass ratio of petunias (0.18 vs. 0.13, $P \leq 0.05$). Similar reductions in root to shoot ratios have been reported for several herbaceous (Arnold et al., 1993) and woody (Arnold and Struve, 1989a, b; Beeson and Newton, 1992) species. Regardless of Cu treatments, petunias grown in 158 $cm^3$ cell packs had greater vegetative growth (Fig. 2, 3A) and produced more flower buds (Fig. 2D), open flowers (Fig. 3C), and total flowers and buds (Fig. 3B). Petunias grown in 101 $cm^3$ cell packs and had only slightly greater vegetative growth (Fig. 2, 3A) and flowering (Fig. 3B, C) than those grown in 61 $cm^3$ cell packs.

While vegetative growth and flower production of pansies continued to increase with longer production times (Table 4), overall market-ability declined as stems elongated resulting in a less dense plant, especially on the 61 and 101 $cm^3$ cell packs. A general chlorosis occasionally occurred on some of the plants of both species in smaller pack sizes. The chlorosis was more common and severe on the $Cu(OH)_2$-treated 61 $cm^3$ cell packs, but chlorotic plants generally recovered following planting to landscape bed.

*Production timing, field performance.* Prolonged holding of petunias during greenhouse production had inconsistent

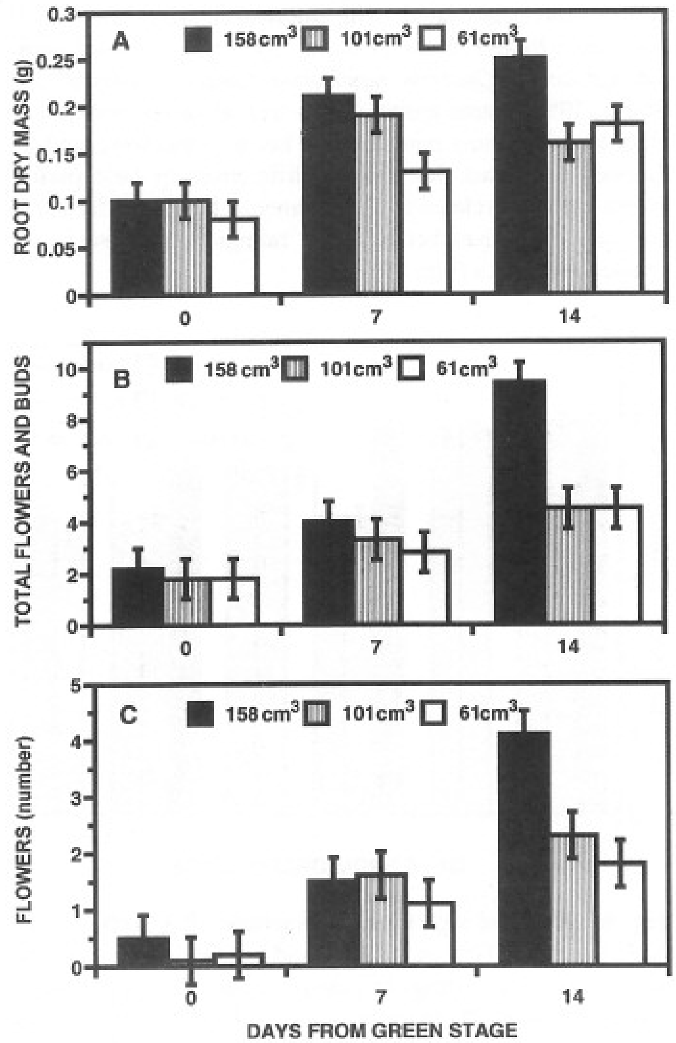


**Fig. 3.** Effects of significant ($P \leq 0.05$) interactions among pack size and production time on root dry mass (A), total flowers and floral buds (B), and number of open flowers (C) of petunia at zero, seven, or fourteen days from green stage grown in 158 (solid), 101 (vertical hash marks), or 61 $cm^3$ (horizontal hash marks) cell pack containers. Each point represents the mean (± standard error) of 20 plants, data for $Cu(OH)_2$-treatments were pooled for each pack size.

effects on flower counts and dry masses regardless of pack size or Cu treatment (data not presented). However, prolonged holding during production did have an impact on quality ratings of petunias at the end of the field trials. Visual ratings were greater for all pack sizes and Cu treatment combi nations if planted to the landscape at first flower (Fig. 4). If petunias were planted seven days later, those in non-treated 158 $cm^3$ cell packs performed better than those in Cu-treated 158 $cm^3$ cell packs, but plants in Cu-treated 101 and 61 $cm^3$ cell packs performed better than those from non-treated 101 or 61 $cm^3$ cell packs (Fig. 4). This might be attributed to the more fibrous root systems observed on Cu-treated packs, as the more fibrous root system may be better able to utilize available water and nutrients within the limited root volume of small packs. A spatially more uniformly distributed root system was associated with increased water uptake in *Photinia* x *fraseri* Dress. (Vartak, 1993) and increased nutrient uptake in *Quercus acutissima* Carruth. (Arnold and Struve, 1993) plants grown in Cu- treated versus non-treated black plastic nursery containers. When petunias were held for fourteen days past first flower, differences in field performance were not related to Cu treatments, but plants from 158 $cm^3$ cell packs had better visual ratings than those in the smaller pack sizes (Fig. 4).

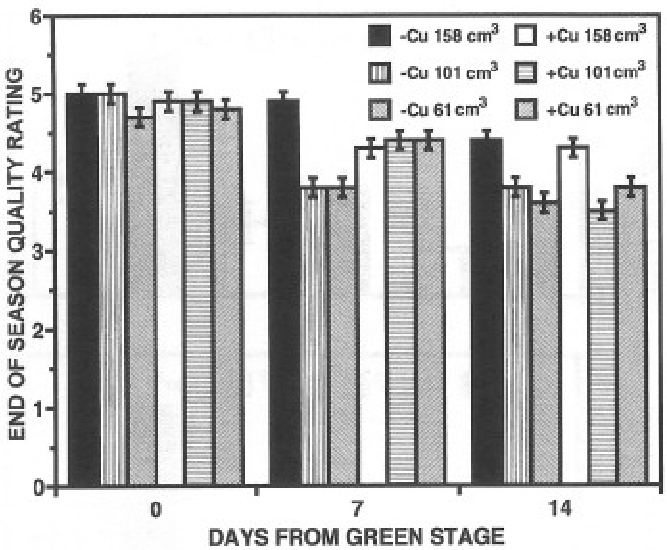


**Fig. 4.** Effects of significant interactions ($P \leq 0.05$) among pack size, $Cu(OH)_2$- treatments, and production time on end of season quality ratings of petunia in the landscape following transplanting from greenhouse production at 0, 7, or 14 days from green stage from 158, 101, or 61 $cm^3$ cell containers painted on interior surfaces with $Cu(OH)_2$ at 100 $g{\cdot}L^{-1}$ latex carrier, or not treated. Each point represents the mean (± standard error) of 12 plants.

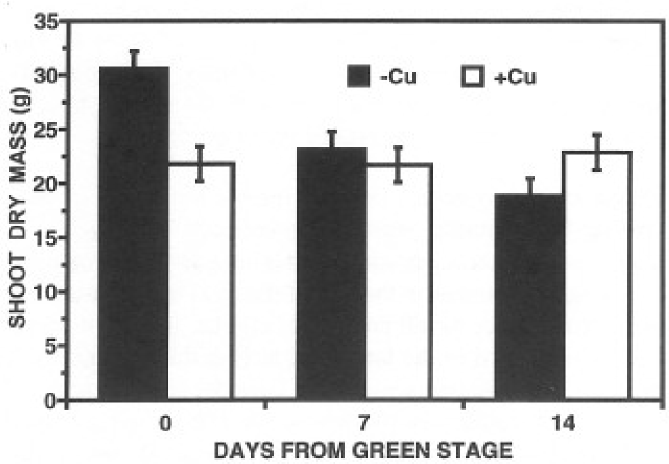


**Fig. 5.** Effects of significant ($P \leq 0.05$) interactions among, $Cu(OH)_2$-treatments and production time on shoot dry mass of pansy grown for 0, 7, or 14 days past green stage in containers sprayed with $Cu(OH)_2$ at 100 $g{\cdot}L^{-1}$ latex carrier (open columns = mean (± standard error) of 36 plants) or not treated (solid columns) and then transplanted to the landscape.

An interaction between Cu treatments, across pack sizes, and extension of the production time past first flower was evident for pansy. If pansies were planted to the landscape at first flower, those from non-treated packs had the greatest shoot dry weight at the end of the field trials (Fig. 5). However, Cu-treated and non-treated packs had similar shoot dry masses at the end of the field trials if held in production for seven days past first flower. When the holding time was extended to four teen days past first flower, plants from Cu-treated packs had greater shoot dry mass (Fig. 5). Conversely, extended production time had little adverse effect on landscape shoot dry masses of pansies grown in $Cu(OH)_2$-treated cell packs, while initially greater landscape shoot dry masses of pansies grown in non-treated cell packs declined steadily with extended production time (Fig. 5).

Two generalizations were illustrated with these studies. First, use of larger pack sizes allowed bedding plants to be held past peak sales/shipping stage with less substantial reductions in quality and subsequent landscape performance than did smaller pack sizes. Despite the use of identical age seedlings from the same size plugs, those seedlings grown in larger packs consistently resulted in superior plants both during greenhouse production and throughout the growing sea son in the landscape. These results suggest that landscapers and consumers would likely benefit from purchasing bedding plants in larger pack sizes, but growers would need premium prices to justify the additional bench space and materials required for the larger plants. Second, responses of petunia and pansy grown in $Cu(OH)_2$-treated packs versus non-treated containers were species, cultivar, pack size, and/or production stage dependent. Results indicate that some measures of postharvest quality and subsequent landscape performance can be enhanced by the use of Cu-treated containers during production of petunia and pansy, but the cost effectiveness of these improvements must be determined by individual growers for their conditions, production regimes, plant taxa, and target market.

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