Use of Antitranspirants to Reduce Water Stress on Herbaceous and Woody Ornamentals[1]

Bruce L. Dunn[2], Janet C. Cole[3], and Mark E. Payton[4]
Department of Horticulture and Landscape Architecture
Oklahoma State University, Stillwater, OK 74078-6027

Abstract

Experiments were conducted to evaluate potential means for reducing moisture stress in nine herbaceous and woody ornamental species. In Expt. 1 (2009), a water only control treatment and the antitranspirant Stasis™ at two different rates were applied as a drench application before inducing drought stress in the greenhouse by withholding water for two weeks. No significant differences in visual ratings in relation to plant quality were detected among treatments 5 days after application for any species. At 10 days after treatment, visual ratings were better for *Veronica* at the lower Stasis™ rate, *Hibiscus* at the low and higher Stasis™ rate, and *Weigela* at lower and higher Stasis™ rate compared to no Stasis™. At 15 days after treatment, visual ratings were worse for *Coreopsis*, *Rudbeckia*, and *Salvia* at both low and high Stasis™ rates; but, were better for *Hibiscus* and *Weigela* at the lower and higher Stasis™ rates compared to the no Stasis™ treatment. In Expt. 2 (2010), the antitranspirants Stasis™ and Root-Zone were evaluated along with a no antitranspirant and well-watered control treatments at single rates. No significant differences in visual ratings existed among treatments five days after application for any species. At 10 days after treatment, visual ratings were higher for *Coreopsis*, *Forsythia*, *Nandina*, and *Weigela* with Stasis™ or Root-Zone compared to no antitranspirant application. Visual ratings for *Rudbeckia* and *Salvia* with Stasis™, and *Euonymus* with Root-Zone were also better than the stress treatment at 10 days after treatment. At 15 days after treatment, visual ratings were higher for *Coreopsis* and *Salvia* with Stasis™ compared to the stress treatment. *Rudbeckia*, *Euonymus*, and *Weigela* with Stasis™ or Root-Zone and *Nandina* with Root-Zone all had better visual ratings than the stress treatment. Evapotranspiration was not reduced for any Stasis™ or Root-Zone treatment for any species in either experiment compared to control stress treatments.

Index words: ABA, shelf life extension, Stasis™, Root-Zone, wilt, transpiration, plant quality.

Species used in this study: burning bush (*Euonymus alatus* Thunb., Siebold); heavenly bamboo (*Nandina domestica* Thunb.); weigela (*Weigela florida* Bunge, A. DC); 'Lynwood Gold' showy forsythia (*Forsythia* × *intermedia* Vahl 'Lynwood Gold'); Rose of Sharon (*Hibiscus syriacus* L.); woodland sage (*Salvia nemorosa* L.); orange coneflower (*Rudbeckia fulgida* Aiton); whorled tickseed (*Coreopsis verticillata* L.); speedwell (*Veronica* L. sp.).

Significance to the Nursery Industry

Exposure of potted plants to high temperatures during shipping often results in severe water stress, leading to reduced plant quality with less market appeal. Applying an antitranspirant is one tool growers may use to reduce plant transpiration and consequently water stress. Drench applications of Stasis™ or Root-Zone did not significantly lower plant evapotranspiration rates. Plant quality ratings were similar five days after treatment using either Stasis™ or Root-Zone compared to untreated controls for all species in this study; however, 10 and 15 days after treatment Stasis™ or Root-Zone improved quality ratings compared to controls for some species.

Introduction

During shipping and display at retail outlets water stress can rapidly develop in container-grown plants (6). This stress is due to a lack of available moisture in the media for root uptake and water loss from transpiration in the leaves. Controlling transpiration through stomatal closure is one way to limit the severity of water stress. The plant hormone abscisic acid (ABA) has many known functions during plant growth and development including mediating a root-to-shoot stress signal through the xylem during drought conditions to elicit stomatal closure (3, 9). Exogenous application of ABA on several annual bedding plants extended their marketability under simulating shipping and retail circumstances and water stressed conditions (2). Antitranspirants, made with synthetic ABA or chemicals that elicit an ABA response, are readily available and can be applied to plants as a foliar spray, sprench (spray to drench), or substrate drench to restrict transpiration by slowing moisture loss from plants (6). Although ABA is naturally synthesized by plants, synthetic formulations of ABA can be absorbed by leaves and roots (3, 10), leading to a quicker and preventative response. Sharma et al. (11) compared the effects of ABA and its synthetic analogs, 8'-methylene ABA methyl ester (PBI 365) and 8'-acetylene ABA methyl ester (PBI 429) on tomato (*Lycopersicon esculentum* Mill.), snapdragon (*Antirrhinum majus* L.), and nasturtium (*Tropelaum majus* L.) seedlings using root-dip treatments and showed ABA analogs are better than natural ABA in effectiveness and persistence. Effective formulations are those that prevent excessive water loss without reducing CO_2 uptake, resulting in reduced photosynthetic activity (5).

Antitranspirants to manage plant water stress have received attention since the 1960s. Recent breakthroughs in synthetic ABA production have reduced costs resulting in a potentially cost-effective choice for growers (1, 8). Results of antitranspirant use have been highly variable (4), and commercial use of ABA products is hindered by a lack of knowledge about species-specific application rates, as the

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[2]Assistant Professor. To whom reprint requests should be addressed. bruce.dunn@okstate.edu.

[3]Regents Professor. janet.cole@okstate.edu.

[4]Professor, Statistics Department, Oklahoma State University, Stillwater, OK 74078. mark.payton@okstate.edu.

effectiveness varies with concentration, mode of application, plant species, and developmental stage (2, 11, 13). The objective of this study was to determine the effectiveness of two drench antitranspirants (Stasis™ and Root-Zone) not reported previously in the literature on selected herbaceous and woody ornamentals.

Materials and Methods

Experiment 1 (2009). The experiment was initiated on August 5, 2009, at the Oklahoma State University Horticulture Research Greenhouses in Stillwater, OK. Thirty plants per species of five woody ornamentals including *Euonymus alatus* (Thunb.) Siebold, *Nandina domestica* Thunb., *Weigela florida* (Bunge) A. DC, *Forsythia × intermedia* Vahl 'Lynwood Gold', and *Hibiscus syriacus* L. and four herbaceous ornamentals including *Salvia nemorosa* L., *Rudbeckia fulgida* Aiton, *Coreopsis verticillata* L. and *Veronica* L. sp. were utilized. Plants were obtained from Greenleaf Nursery Co., Park Hill, OK, as either 5.1 cm (2 in) plug liners for the herbaceous material or in #1 containers for all woody plant material except *Euonymus*, which was in a #2 container. Liners were transplanted to 11.4 cm (4.5 in) plastic pots (ITML Horticultural products, Middlefield, OH) 6 weeks before the start of the experiment, using Metro Mix 702 media (SunGro Horticulture Distribution Inc., Bellevue, WA). Woody plants remained in original containers. All plants were watered in the morning on the first day only and treatments were applied in the afternoon on the first day only of the experiment. Ten plants were utilized per treatment, and all treatments were applied as a drench. Treatments were 1) control, plants received either 44.4 ml (1.5 oz) of water for the herbaceous species or 147.9 ml (5 oz) for the woody species, 2) 103.5 ml (3.5 oz) of Stasis™ (Natural Industries, Houston, TX) was added to 3.78 liters (1 gal) of water then applying 44.4 ml (1.5 oz) of solution per pot for herbaceous species or adding 177.4 ml (6 oz) of Stasis™ per 3.78 liters (1 gal) of water then applying 147.9 ml (5 oz) to the woody species, 3) 207 ml (7 oz) of Stasis™ with 3.78 liters (1 gal) of water then applying 44.4 ml (1.5 oz) solution to the herbaceous species or mixing 354.8 ml (12 oz) Stasis™ per 3.78 liters (1 gal) of water then applying 147.9 ml (5 oz) solution per woody species. Treatments were based on label rates of 2 to 5 parts Stasis™ to 100 parts water for herbaceous plants and 5 to 10 parts Stasis to 100 parts water for woody plants. Greenhouse temperatures averaged 38C (100F) during the day and 21C (70F) at night with relative humidity of 52%. Maximum photosynthetic photon flux (PPF) was 1400 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Data collection. Data were collected every 5 days starting after noon on day 1 and continuing for 20 days. Plant ratings were used to determine plant quality: 1 = dead, 2 = severe wilting with yellowing and browning of leaves, 3 = wilting with yellow and green leaves, 4 = slight wilting with green leaves rolled downward, 5 = no symptoms of water stress. Each plant was rated individually and independent of previous rating. Evapotranspiration was estimated by subtracting pot weight using an ES Series Digital Scale (Ohaus Corporation, Pine Brook, NJ) on day 5 from day 1, day 10 from day 5, day 15 from day 10, day 20 from day 15, and day 20 from day 1.

Experiment 2 (2010). The experiment was initiated on July 21, 2010, at the Oklahoma State University Horticulture Research Greenhouses in Stillwater, OK. Plants were obtained from Greenleaf Nursery Co., Park Hill, OK, as either 5.1 cm (2 in) plug liners for the herbaceous material or in #1 containers for all woody plant material. Liners were transplanted to 11.4 cm (4.5 in) plastic pots (ITML Horticultural products, Middlefield, OH) 2 months before the start of the experiment, while the woody plants remained in original containers. Nine plants per treatment were used. Treatments included: 1) irrigated daily through a drip system from Day 1 through Day 15 until saturated, 2) treatment was irrigated until saturated on Day 1, then water withheld thereafter, 3) 89 ml (3 oz) of Stasis™ was added to 3.78 liters (1 gal) of water then 135 ml (4.6 oz) of solution was applied to each pot for herbaceous species or 266 ml (9 oz) of Stasis™ per 3.78 liters (1 gal) of water then 680 ml (23 oz) solution was applied to the woody species, 4) Root-Zone (GSI Horticulture, Bend, OR) was applied at the same concentrations and application rates as Stasis™ for the herbaceous and woody plants. Treatments were based on label rates of Stasis™ as indicated above and Root-Zone label rates starting at 2 oz of Root-Zone per gallon of water for herbaceous plants and 6 oz for woody plants. For treatments three and four on the first day only, plants were watered in the morning and solutions were applied in the afternoon in amounts that saturated the media.

Data collection. Data were collected started after noon every 5 days starting on day 1 and continuing for 15 days. Leaf temperature was measured using a MicroRay HVAC non-contact infrared thermometer with laser pointer (Eurotron E Instruments group LLC., Langhome, PA) during the afternoon. The infrared thermometer was held ~ 91 cm (36 in) from the top of the plant and pointed at the center of the plant canopy. A LI-1600 Steady State Porometer (LI-COR, Inc., Lincoln, NE) was utilized to collect stomatal resistance in leaves, except for *Coreopsis* as the leaves were too narrow to fit into the aperture of the porometer and treatments at 15 days after treatment where the majority of plants were already dead. Soil moisture content was determined using a POGO Portable Soil Sensor (Stevens® Water Monitoring Systems, Inc. Portland, OR), which provides soil moisture measurements in units of water fraction by volume (wfv) as a percentage of water in the soil. Calibration was based on the loam soil setting with full soil saturation considered to be between 0.3 and 0.45 wfv. Plants were also rated as described for Expt. 1. Evapotranspiration was estimated by subtracting pot weight using an ES Series Digital Scale on day 5 from day 1, day 10 from day 5, day 15 from day 10, and day 15 from day 1. Negative evapotranspiration values on well-watered treatment plants reflect a heavier weight at the end than at the beginning due to sampling time following irrigations. Greenhouse summer temperatures averaged from 27C (80F) during the day to 21C (70F) at night with relative humidity of 55%. Maximum photosynthetic photon flux (PPF) was 1300 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Statistics. The experimental design was completely randomized by herbaceous or woody species in year one and completely randomized regardless of species in year two. The experimental unit was a pot with a single plant with 10 reps in year one and 9 reps in year two per species per treatment. Statistical analyses were conducted with SAS Version 9.2 (SAS Institute, Cary, NC). Analysis of variance procedures (PROC MIXED) were conducted for each species to assess the effect of treatment with repeated measures (date). An autoregressive period 1 covariance structure was used to model across time and within experimental unit variation. The simple effects of treatments for given levels of species and time were assessed (SLICE option in an LSMEANS statement), and when significant, pairwise t tests were conducted. Significance was determined at $P \leq 0.05$. Only data with significant differences are discussed.

Results and Discussion

Coreopsis. In 2009, plants not treated with Stasis™ and low rate Stasis™ had a higher visual rating than plants receiving the higher rate Stasis™ 15 days after treatment (Table 1). In 2010, by 10 days after treatment, the stressed plants had a lower visual rating than well-watered plants or those receiving Stasis™ or Root-Zone (Table 2). At this same

Table 1. Effect of no Stasis™ or Stasis™ applied at low or high label rates on visual ratings of several herbaceous and woody perennial species placed under drought stress in 2009. n = 10.

Genus[z]	Treatment[y]	Number of days after treatment	Visual rating[x]
	Herbaceous perennials		
Coreopsis	No Stasis™	5	4.2a[w]
	Low Stasis™	5	4.3a
	High Stasis™	5	4.7a
	No Stasis™	10	3.6a
	Low Stasis™	10	3.8a
	High Stasis™	10	4.0a
	No Stasis™	15	3.4b
	Low Stasis™	15	2.3a
	High Stasis™	15	2.1a
	No Stasis™	20	1.2a
	Low Stasis™	20	1.8a
	High Stasis™	20	1.7a
Rudbeckia	No Stasis™	5	4.6a
	Low Stasis™	5	4.4a
	High Stasis™	5	4.6a
	No Stasis™	10	3.1a
	Low Stasis™	10	3.2a
	High Stasis™	10	3.3a
	No Stasis™	15	3.4b
	Low Stasis™	15	2.7a
	High Stasis™	15	2.7a
	No Stasis™	20	1.1a
	Low Stasis™	20	1.0a
	High Stasis™	20	1.0a
Salvia	No Stasis™	5	4.6a
	Low Stasis™	5	4.6a
	High Stasis™	5	4.4a
	No Stasis™	10	3.5a
	Low Stasis™	10	3.6a
	High Stasis™	10	3.8a
	No Stasis™	15	3.7b
	Low Stasis™	15	2.7a
	High Stasis™	15	2.2a
	No Stasis™	20	1.0a
	Low Stasis™	20	1.0a
	High Stasis™	20	1.0a
Veronica	No Stasis™	5	4.6a
	Low Stasis™	5	4.6a
	High Stasis™	5	4.6a

Table 1 Continued...

Table 1. Continued.

Genus[z]	Treatment[y]	Number of days after treatment	Visual rating[x]
Veronica	No Stasis™	10	3.5a
	Low Stasis™	10	4.3b
	High Stasis™	10	3.8ab
	No Stasis™	15	3.1a
	Low Stasis™	15	2.5a
	High Stasis™	15	2.7a
	No Stasis™	20	1.0a
	Low Stasis™	20	1.0a
	High Stasis™	20	1.0a
	Woody perennials		
Hibiscus	No Stasis™	5	4.1a
	Low Stasis™	5	4.9a
	High Stasis™	5	4.3a
	No Stasis™	10	2.7a
	Low Stasis™	10	3.7b
	High Stasis™	10	3.4b
	No Stasis™	15	1.7a
	Low Stasis™	15	2.7b
	High Stasis™	15	2.9b
	No Stasis™	20	1.0a
	Low Stasis™	20	1.6a
	High Stasis™	20	1.6a
Weigela	No Stasis™	5	4.6a
	Low Stasis™	5	4.6a
	High Stasis™	5	4.4a
	No Stasis™	10	2.7a
	Low Stasis™	10	3.8b
	High Stasis™	10	3.4b
	No Stasis™	15	1.7a
	Low Stasis™	15	2.6b
	High Stasis™	15	2.9b
	No Stasis™	20	1.0a
	Low Stasis™	20	1.4a
	High Stasis™	20	1.6a

[z]Only species with significant differences are listed.

[y]Stasis™ label rates are 2 to 5 parts Stasis™ to 100 parts water for herbaceous plants and 5 to 10 parts Stasis™ to 100 parts water for woody plants. The low Stasis™ treatment was at 103.5 ml·liter^{-1} (3.5 oz·gal^{-1}) for herbaceous perennials and 177.4 ml·liter^{-1} (6 oz·gal^{-1}) for woody perennials. The high Stasis™ treatment was twice the low Stasis™ treatment rate.

[x]Rating scale was from 1 to 5 with 1 being a dead plant and 5 being a plant with no symptoms of water stress.

[w]Means within columns for each rating date followed by the same letter are not significantly different based on protected LSD, $P < 0.05$.

Table 2. Visual rating, leaf temperature, stomatal resistance, and substrate moisture of several herbaceous and woody perennial species that were drought stressed, well watered (not stressed), or treated with Stasis™ or Root-Zone in 2010. n = 9.

Genus	Treatment[z]	Number of days after treatment	Visual rating[y]	Leaf temperature (C)	Stomatal resistance (sec·cm^{-1})[x]	Substrate moisture (%)
			Herbaceous perennials			
Coreopsis	Well-Watered	5	5.0a[w]	31.5a	—	0.387a
	Stressed	5	5.0a	32.2a	—	0.291b
	Stasis™	5	5.0a	32.4a	—	0.394a
	Root-Zone	5	5.0a	36.5a	—	0.376a
	Well-Watered	10	4.9a	32.6a	—	0.392a
	Stressed	10	3.8b	41.3a	—	0.057b
	Stasis™	10	4.8a	39.8a	—	0.088b
	Root-Zone	10	4.6a	37.4a	—	0.078b
	Well-Watered	15	5.0a	36.3b	—	0.346a
	Stressed	15	2.2c	43.8a	—	0.003b
	Stasis™	15	3.2b	49.0a	—	0.001b
	Root-Zone	15	2.8bc	46.5a	—	0.000b
Rudbeckia	Well-Watered	5	5.0a	33.7a	31.5a	0.406a
	Stressed	5	5.0a	34.7a	9.9b	0.358b
	Stasis™	5	5.0a	35.1a	6.3b	0.401a
	Root-Zone	5	5.0a	37.4a	4.2b	0.403a
	Well-Watered	10	4.9a	32.9a	4.0a	0.405a
	Stressed	10	3.3c	39.9a	8.8a	0.068 d
	Stasis™	10	4.0b	38.2a	7.8a	0.133c
	Root-Zone	10	3.4c	37.4a	6.2a	0.184b
	Well-Watered	15	4.9a	37.7b	4.7b	0.392a
	Stressed	15	1.3c	42.0ab	—	0.000b
	Stasis™	15	2.4b	45.6a	—	0.005b
	Root-Zone	15	2.8b	39.2b	17.4a	0.014b
Salvia	Well-Watered	5	5.0a	28.6a	7.2a	0.387a
	Stressed	5	5.0a	31.5a	4.2a	0.173b
	Stasis™	5	5.0a	29.4a	3.2a	0.377a
	Root-Zone	5	5.0a	34.5a	2.5a	0.364a
	Well-Watered	10	5.0a	31.5c	0.8b	0.366a
	Stressed	10	1.7c	49.8b	14.1ab	0.000b
	Stasis™	10	3.7b	40.9b	19.3a	0.008b
	Root-Zone	10	1.9c	39.9b	8.7b	0.003b
	Well-Watered	15	5.0a	37.7c	2.5	0.334a
	Stressed	15	1.0c	53.3a	—	0.000b
	Stasis™	15	1.6b	48.2ab	—	0.000b
	Root-Zone	15	1.1bc	46.8b	—	0.000b
Veronica	Well-Watered	5	5.0a	28.9a	17.7a	0.399a
	Stressed	5	5.0a	32.5a	5.1b	0.245b
	Stasis™	5	5.0a	31.0a	4.2b	0.371a
	Root-Zone	5	5.0a	35.6a	3.7b	0.385a
	Well-Watered	10	5.0a	31.5b	1.3a	0.399a
	Stressed	10	1.8b	44.5a	0.0a	0.000b
	Stasis™	10	1.8b	39.8a	10.2a	0.004b
	Root-Zone	10	2.0b	43.2a	6.1a	0.006b
	Well-Watered	15	5.0a	37.0b	5.7	0.350a
	Stressed	15	1.1b	45.1a	—	0.000b
	Stasis™	15	1.2b	50.1a	—	0.000b
	Root-Zone	15	1.4b	39.5b	—	0.000b
			Woody perennials			
Forsythia	Well-Watered	5	5.0a	31.3b	21.4ab	0.195a
	Stressed	5	5.0a	34.0b	41.5a	0.096b
	Stasis™	5	5.0a	35.8a	8.0b	0.155a
	Root-Zone	5	5.0a	39.1a	5.2b	0.161a

Table 2 Continued next page …

Table 2. Continued.

Genus	Treatment[z]	Number of days after treatment	Visual rating[y]	Leaf temperature (C)	Stomatal resistance (sec·cm^{-1})[x]	Substrate moisture (%)
Forsythia	Well-Watered	10	5.0a	36.3a	6.1a	0.167a
	Stressed	10	3.6c	35.5a	14.2a	0.011b
	Stasis™	10	4.0b	38.8a	9.5a	0.021b
	Root-Zone	10	3.9b	35.8a	7.8a	0.011b
	Well-Watered	15	5.0a	37.0a	3.9a	0.090a
	Stressed	15	3.1b	34.8b	14.6a	0.000b
	Stasis™	15	3.3b	41.8a	28.9a	0.000b
	Root-Zone	15	3.3b	34.5b	14.9a	0.000b
Hibiscus	Well-Watered	5	5.0a	30.4c	12.1a	0.224a
	Stressed	5	5.0a	35.6ab	28.6a	0.102c
	Stasis™	5	5.0a	32.2bc	5.6a	0.156b
	Root-Zone	5	5.0a	36.7a	5.3a	0.192a
	Well-Watered	10	5.0a	34.2a	1.1a	0.175a
	Stressed	10	2.0b	37.4a	8.8a	0.002b
	Stasis™	10	2.1b	36.3a	9.8a	0.005b
	Root-Zone	10	2.1b	39.6a	7.3a	0.017b
	Well-Watered	15	4.8a	34.9b	2.8	0.121a
	Stressed	15	1.1b	34.3b	—	0.000b
	Stasis™	15	1.1b	40.0a	—	0.000b
	Root-Zone	15	1.2b	33.8b	—	0.000b
Euonymus	Well-Watered	5	5.0a	35.5a	16.8a	0.086a
	Stressed	5	5.0a	35.1a	18.7a	0.032b
	Stasis™	5	5.0a	36.9a	8.0b	0.065a
	Root-Zone	5	5.0a	38.1a	6.4b	0.092a
	Well-Watered	10	5.0a	36.8a	2.2a	0.074a
	Stressed	10	3.7b	39.1a	14.1a	0.000b
	Stasis™	10	4.1b	37.0a	8.1a	0.003b
	Root-Zone	10	4.8a	38.1a	9.1a	0.003b
	Well-Watered	15	4.9a	39.1ab	7.0a	0.048a
	Stressed	15	1.8c	36.1bc	—	0.000b
	Stasis™	15	2.9b	40.3a	10.1a	0.000b
	Root-Zone	15	3.3b	33.8c	19.0a	0.000b
Nandina	Well-Watered	5	5.0a	33.2a	23.2a	0.193a
	Stressed	5	5.0a	35.2a	22.7a	0.085b
	Stasis™	5	5.0a	32.7a	6.6a	0.208a
	Root-Zone	5	5.0a	37.0a	6.8a	0.228a
	Well-Watered	10	5.0a	36.4a	15.0a	0.209a
	Stressed	10	4.1b	38.2a	25.8a	0.000b
	Stasis™	10	4.7a	38.0a	10.5a	0.023b
	Root-Zone	10	4.7a	37.2a	32.1a	0.024b
	Well-Watered	15	5.0a	39.1a	9.4a	0.149a
	Stressed	15	3.4c	35.8ab	2.2a	0.000b
	Stasis™	15	3.8bc	38.5a	2.9a	0.000b
	Root-Zone	15	4.0b	33.5b	16.1a	0.002b
Weigela	Well-Watered	5	5.0a	33.7a	25.4a	0.192a
	Stressed	5	5.0a	34.8a	11.0b	0.078b
	Stasis™	5	5.0a	35.3a	7.4b	0.209a
	Root-Zone	5	5.0a	39.1a	5.6b	0.195a
	Well-Watered	10	4.9a	36.1a	1.0a	0.179a
	Stressed	10	2.3c	37.8a	15.0a	0.000b
	Stasis™	10	3.2b	39.5a	11.4a	0.002b
	Root-Zone	10	3.6b	40.0a	9.5a	0.004b
	Well-Watered	15	4.8a	38.5ab	11.6a	0.064a
	Stressed	15	1.4c	35.7b	—	0.000b
	Stasis™	15	2.2b	41.8a	7.6a	0.000b
	Root-Zone	15	2.6b	36.5b	—	0.000b

Table 2 Continued next page …

Table 2. Continued.

[z]Well-Watered plants were drip irrigated daily with tap water throughout the study. Stressed plants were watered to container capacity on the first day and received no more water throughout the study. Stasis™ and Root-Zone were applied to herbaceous perennials at 135 mL·liter^{-1} (4.5 oz·gal^{-1}) and to woody perennials at 266 mL·liter^{-1} (9 oz·gal^{-1})). Stasis™ label rates are 74–185 mL·liter^{-1} (2.5–6.25 oz·gal^{-1}) Stasis™ for herbaceous plants and 185–296 mL·liter^{-1} (6.25–10 oz·gal^{-1}) for woody plants, while Root-Zone label rates suggest starting at 59 mL·liter^{-1} (2 oz·gal^{-1}) of water for herbaceous plants and 177 mL·liter^{-1} (6 oz·gal^{-1}) for woody plants.

[y]Rating scale was from 1 to 5 with 1 being a dead plant and 5 being a plant with no symptoms of water stress.

[x]Except for *Coreopsis*, as the leaves were too narrow to fit into the aperture of the porometer, data not reported is due to the majority of plants within treatment being dead.

[w]Means within columns for each rating date followed by the same letter are not significantly different based on protected LSD, $P < 0.05$.

time, the well-watered plants had higher substrate moisture content than those in the stressed, Stasis™ or Root-Zone treatments. At 15 days after treatment, well-watered plants had the highest visual rating. Plants in the stressed treatment had the lowest visual rating while plants treated with Stasis™ or Root-Zone had visual ratings intermediate between well-watered and stressed plants. Leaf temperature was lowest and substrate moisture was highest in well-watered plants 15 days after treatment, and leaf temperature did not differ among stressed, Stasis™ treated, or Root-Zone treated plants. Evapotranspiraton between 5 and 10 days after treatment was lowest for well-watered plants, intermediate for stressed plants, and highest for plants treated with Stasis™ or Root-Zone in 2010 (Table 3).

Rudbeckia. Plants not receiving Stasis™ had a greater visual rating 15 days after treatment than plants receiving either rate of Stasis™ in 2009 (Table 1). Evapotranspiration from 5 to 10 days after treatment was greater in plants receiving either Stasis™ treatment (Table 4). In 2010, at 5 days after treatment, the well-watered plants had a greater stomatal resistance than plants in any other treatment (Table 2). Stressed plants had lower substrate moisture five days after treatment than the well-watered plants or those receiving either Stasis™ or Root-Zone. At 10 days after treatment, the well-watered plants had the highest visual rating, Stasis™ treated plants had an intermediate visual rating, while stressed plants and those receiving Root-Zone had the lowest visual rating. Substrate moisture differed among all treatments 10 days after treatment with well-watered plants having the highest followed by Root-Zone treated plants, then Stasis™ treated plants and stressed plants. By 15 days after treatment, well-watered plants had the highest visual ratings, and there were no differences among the stressed, Stasis™ and Root-Zone treated plants. Stasis™ treated plants had a higher leaf temperature than well-watered or Root-Zone treated plants, but no higher leaf temperature than stressed plants, and there were no differences among plants in the remaining treatments. Well-watered plants had higher stomatal resistances than other plants treated 5 days after treatment but had lower stomatal resistance than Root-Zone treated plants 15 days after treatment. Substrate water content was highest in the well-watered treatment and did not differ among the stressed, Stasis™ treated, or Root-Zone treated plants 15 days after treatment. Evapotranspiration between 5 and 10 days after treatment was lowest for well-watered plants (Table 3). Stasis™ treated plants had a higher evapotranspiration rate than stressed plants, but transpiration of Root-Zone treated plants did not differ from that of stressed or Stasis™ treated plants.

Salvia. Visual rating of plants not receiving Stasis™ was greater 15 days after treatment than that of plants receiving either Stasis™ treatment in 2009 (Table 1). Evapotranspiration of plants receiving the higher Stasis™ rate was greater than plants receiving no Stasis™, but plants receiving the lower Stasis™ rate did not differ in evapotranspiration from plants receiving no Stasis™ or the higher Stasis™ rate (Table 4). In 2010, substrate moisture in the well-watered plants was similar to that of plants treated with Stasis™ or Root-Zone, but the stressed substrate moisture of stressed plants was lower than all other treatments 5 days after treatment (Table 4). By 10 days after treatment, substrate moisture content in the stressed, Stasis™ and Root-Zone treated plants was lower than that of the well-watered plants. Visual ratings of plants in the well-watered treatment were higher than those of any other treatment 10 days after treatment while visual ratings of plants receiving Stasis™ were intermediate, and visual ratings of plants in the stressed treatment and those receiving Root-Zone did not differ and were lower than those of other treatments. Leaf temperature was lowest for the well-watered treatment and higher but did not differ among the stressed, Stasis™ or Root-Zone treated plants. Stomatal resistance was greatest for plants in the Stasis™ treatment but did not differ among the other treatments. Evapotranspiration was lowest in well-watered plants, highest in Stasis™ treated plants, and intermediate in stressed plants (Table 3).

Veronica. In 2009, Visual rating of plants receiving the lower Stasis™ rate was greater than that of plants not receiving a Stasis™ treatment, but plants receiving the higher Stasis™ treatment did not differ in visual rating from plants receiving no Stasis™ or the lower treatment at 10 days after treatment (Table 1). Evapotranspiration between 5 and 10 days after treatment was lowest in the non-Stasis™ treated plants and greater but not different in either Stasis™ treatments (Table 4). In 2010, by 5 days after treatment, stomatal resistance was greatest in the well-watered plants and did not differ among the stressed, Stasis™ or Root-Zone treated plants (Table 2). Substrate moisture at 5 days after treatment was lowest in the stressed treatment and greatest but did not differ among the well-watered plants, Stasis™ and Root-Zone treated plants. At 10 days after treatment, visual rating and substrate moisture were highest for well-watered plants and lowest and did not differ among stressed, Stasis™ and Root- Zone treated plants. Leaf temperature was lowest in well-watered plants and greater but not different among stressed, Stasis™ and Root-Zone treated plants. Similar results occurred 15 days after treatment in which visual ratings and substrate moisture were greatest for well-watered plants and lower but did not differ for stressed, Stasis™ and

Table 3. **Evapotranspiration (g) of several herbaceous and woody perennial species between 5 and 10 days after Stasis™ or Root-Zone treatment (DAT) in 2010. n = 9.**

Genus[z]	Treatment[y]	Evapotranspiration (g) 5 to 10 DAT[x]
	Herbaceous perennials	
Coreopsis	Well-Watered	–21.1a[w]
	Stressed	35.6b
	Stasis™	60.0c
	Root-Zone	65.6c
Rudbeckia	Well-Watered	–15.6a
	Stressed	43.3b
	Stasis™	73.3c
	Root-Zone	66.7bc
Salvia	Well-Watered	–41.1a
	Stressed	10.0b
	Stasis™	26.7c
	Root-Zone	20.0bc
	Woody perennials	
Forsythia	Well-Watered	–25.3a
	Stressed	108.9b
	Stasis™	146.7c
	Root-Zone	261.1c
Hibiscus	Well-Watered	–207.8a
	Stressed	96.7b
	Stasis™	114.4b
	Root-Zone	115.6b
Euonymus	Well-Watered	–145.6a
	Stressed	122.2b
	Stasis™	166.7bc
	Root-Zone	191.1c
Nandina	Well-Watered	–157.8a
	Stressed	70.0b
	Stasis™	104.4bc
	Root-Zone	141.1c
Weigela	Well-Watered	–84.4a
	Stressed	73.3b
	Stasis™	123.3b
	Root-Zone	158.9b

[z]Evapotranspiration date and species with significant differences are listed. Significant differences found among other evapotranspiration dates are discussed in text.

[y]Well-Watered plants were drip irrigated daily with tap water throughout the study. Stressed plants were watered to container capacity on the first day and received no more water throughout the study. Stasis™ and Root-Zone were applied to herbaceous perennials at 89 mL·liter^{-1} (3 oz·gal^{-1}) and to woody perennials at 266 mL·liter^{-1} (9 oz·gal^{-1}).

[x]Evapotranspiration was estimated by subtracting pot weight using an ES Series Digital Scale on day 10 from day 5, and negative values on well-watered treatment plants reflect a heavier weight at the end than at the beginning due to sampling time following irrigations.

[w]Means followed by the same letter are not significantly different at $P <$ 0.05.

Root-Zone treated plants. At 15 days after treatment, leaf temperature was greatest and did not differ for the stressed and Stasis™ treated plants and lower but did not differ for the well-watered and Root-Zone treated plants.

Forsythia. No differences in visual ratings occurred in 2009 (data not presented). In 2010, at 5 days after treatment, plants in the well-watered and stressed treatment had lower leaf temperatures than those treated with Stasis™ or Root-Zone (Table 2). Stomatal resistance was greatest for stressed plants and lowest for plants receiving Stasis™ or Root-Zone, but well-watered plants did not differ in stomatal resistance from those of any other treatment at 5 days after treatment. Substrate moisture content of stressed plants was lower than that of any other treatment and the other treatments did not differ in substrate moisture at 5 days after treatment. At 10 days after treatment, visual ratings were highest on well-watered plants, lowest on stressed plants, and intermediate but did not differ on Stasis™ or Root-Zone treated plants. By 15 days after treatment, well watered plants had the highest visual ratings, but stressed plants and those treated with Stasis™ or Root-Zone did not differ. Substrate moisture was greatest on well-watered plants and lower and did not differ among stressed, Stasis™ and Root-Zone treated plants 10 and 15 days after treatment. At 15 days after treatment, leaf temperature was highest on well-watered plants and those receiving Stasis™, and lowest on stressed plants and Root-Zone treated plants. Evapotranspiration of well-watered plants was lowest between 5 and 10 days after treatment while that of stressed plants was intermediate and evapotranspiration of Stasis™ and Root-Zone treated plants was highest and did not differ (Table 3).

Hibiscus. In 2009, at 10 and 15 days after treatment, the plants receiving either rate of Stasis™ had a higher visual rating than those not receiving Stasis™ (Table 1). In 2010, at 5 days after treatment, leaf temperature was greatest on plants receiving Root-Zone and lowest on well-watered plants (Table 2). Leaf temperature of stressed plants was greater than that of well-watered plants but did not differ from Stasis™ or Root-Zone treated plants, and Stasis™ treated plants had a lower leaf temperature than those treated with Root-Zone, but did not differ in leaf temperature from well-watered or stressed plants. Substrate moisture 5 days after treatment

Table 4. **Evapotranspiration (g) of several herbaceous and woody perennial species between 5 and 10 days after no Stasis™ treatment (DAT) or Stasis™ treatment at low or high label rate in 2009. n = 10.**

Genus[z]	Treatment[y]	Evapotranspiration (g) 5 to 10 DAT[x]
Rudbeckia	No Stasis™	73.9a[w]
	Low Stasis™[y]	134.0b
	High Stasis™[y]	127.6b
Salvia	No Stasis™	107.6a
	Low Stasis™	132.9ab
	High Stasis™	155.3b
Veronica	No Stasis™	69.2a
	Low Stasis™	93.1b
	High Stasis™	97.7b

[z]Only species and evapotranspiration dates with significant differences are listed.

[y]Low Stasis™ treatment was the label rate of 20 mL·liter^{-1} (3.5 oz·gal^{-1}) for herbaceous perennials and 60 mL·liter^{-1} (9 oz·gal^{-1}) for woody perennials. The high Stasis™ treatment was twice the low Stasis™ treatment rate.

[x]Evapotranspiration was estimated by subtracting pot weight using an ES Series Digital Scale on day 10 from day 5, and negative values on well-watered treatment plants reflect a heavier weight at the end than at the beginning due to sampling time following irrigations.

[w]Means followed by the same letter are not significantly different at $P <$ 0.05.

was greatest and did not differ between the well-watered treatment and Root-Zone treatment. Substrate moisture was lowest in the stressed treatment and intermediate in the Stasis™ treatment. At 10 and 15 days after treatment, the well-watered plants had the highest visual rating and substrate moisture content while plants in the stressed, Stasis™ and Root-Zone treatments did not differ but were lower than well-watered plants in visual rating and in substrate moisture. At 15 days after treatment leaf temperature was greatest in plants receiving Stasis™ but lower and did not differ among the other treatments. Evapotranspiration was lowest in the well-watered plants between five and 10 days after treatment (Table 3), intermediate in the stressed treatment and lowest in the Stasis™ and Root-Zone treatments.

Euonymus. No differences among treatments occurred for visual ratings in 2009 (data not presented). In 2010, stomatal resistance was greatest in the well-watered and stressed treatment and lowest in plants receiving Stasis™ or Root-Zone five days after treatment (Table 2). Substrate moisture was lowest in stressed plants and did not differ among the other treatments 5 days after treatment. At 10 days after treatment, visual ratings were greatest for well-watered plants and plants receiving Root-Zone, and lower for stressed plants and those receiving Stasis™. Substrate moisture was greater in well-watered plants than in plants in any other treatment 10 days after treatment. By 15 days after treatment, visual rating was highest in well-watered plants, intermediate in Stasis™ and Root-Zone treated plants, and lowest in stressed plants. Leaf temperature was greater in Stasis™ treated plants than in Root-Zone treated plants 15 days after treatment. Well-watered plants had a higher leaf temperature than Root-Zone treated plants but leaf temperatures of well-watered plants did not differ from those of stressed plants or Stasis™ treated plants. Stressed plants had lower leaf temperatures than Stasis™ treated plants, but leaf temperatures of stressed plants did not differ from those of well-watered or Root-Zone treated plants. Substrate moisture did not differ among stressed, Stasis™ treated, and Root-Zone treated plants, but substrate moisture for plants in all of these treatments was lower than for well-watered plants 15 days after treatment. Evapotranspiration was lowest for well-watered plants intermediate for stressed plants, and highest for Root-Zone treated plants between 5 and 10 days after treatment. Stasis™ treated plants did not differ in evapotranspiration from stressed or Root-Zone treated plants during this time period (Table 3).

Nandina. No differences among treatments occurred for visual ratings in 2009 (data not presented). In 2010, 5 days after treatment, substrate moisture did not differ among well-watered, Stasis™ or Root-Zone treated plants, but all of these treatments had higher substrate moisture contents than the stressed treatment (Table 2). Similarly, at 10 days after treatment, visual ratings of plants in well-watered, Stasis™, and Root-Zone treatments did not differ, but plants in each of these treatments had higher visual ratings than plants in the stressed treatment. At 10 and 15 days after treatment, substrate moisture content was greater in the well-watered treatment than in any other treatment. Fifteen days after treatment, the well-watered plants had the highest visual ratings while stressed plants had the lowest and Root-Zone treated plants were intermediate. Visual ratings of Stasis™ treated plants were lower than well-watered plants, but similar to those of stressed plants and Root-Zone treated plants. Leaf temperatures of well-watered plants and Stasis™ treated plants were greater than those of Root-Zone treated plants, but leaf temperature of stressed plants did not differ from those of any other treatment 15 days after treatment. Evapotranspiration was lowest for well-watered plants, intermediate for stressed plants, and highest for Root-Zone treated plants between 5 and 10 days after treatment (Table 3). Evapotranspiration of Stasis™ treated plants did not differ from stressed or Root-Zone treated plants.

Weigela. In 2009, visual rating was lower for the plants not receiving Stasis™ than for plants receiving either rate of Stasis 10 and 15 days after treatment (Table 1). In 2010, stomatal resistance was greater on well-watered plants than on stressed, Stasis™ or Root- Zone treated plants 5 days after treatment (Table 2). Substrate moisture was greatest on well-watered plants, Stasis™ and Root-Zone treated plants but lower on stressed plants 5 days after treatment. At 10 and 15 days after treatment, visual ratings were highest for well-watered plants, lowest for stressed plants, and intermediate for Stasis™ and Root-Zone treated plants. Substrate moisture was greatest for well-watered and lowest for the stressed, Stasis™, and Root-Zone treatments 10 and 15 days after treatment. Leaf temperature was greatest for plants receiving Stasis™, and lowest for stressed and Root-Zone treated plants 15 days after treatment. Well-watered plants did not differ in leaf temperature from those of any other treatment at this time. Evapotranspiration was lower for well-watered plants than for all other treatments between 5 and 10 days after treatment (Table 3). Evapotranspiration did not differ among stressed, Stasis™, and Root-Zone treatments during this time period.

In summary, this study indicated that Stasis™ or Root-Zone effectiveness is species dependent. This study is supported by other studies where species-dependent responses existed among bedding plants and exogenous ABA treatments (1, 2, 6, 13). The species-dependent responses over the two years may be due to one or a combination of factors including different application rates in both experiments, retention and accumulation of the chemical in the roots, efficiency of chemical transfer from the roots to the xylem, the exchange of chemical between the xylem in the shoot, pH of the leaf symplastic reservoir, regulation of any ABA conjugates, and the sensitivity of the guard cells to the ABA (12).

No significant differences in visual ratings were reported among species at 5 DAT including the stressed or no Stasis™ treatments indicating plants still had sufficient available water. As for visual ratings at 10 DAT and 15 DAT, Stasis™ treated plants at 3 oz·gal^{-1} were better for the herbaceous perennials *Coreopsis*, *Rudbeckia*, and *Salvia*. Stasis™ at 6 oz·gal^{-1} had significantly higher visual ratings for *Hibiscus*, whereas, 9 oz·gal^{-1} was most effective for *Forsythia*, *Euonymus*, and *Nandina*. Stasis™ rates of 6, 9, or 12 oz·gal^{-1} all showed significantly higher visual ratings for *Weigela* than no water or stressed treatments. Root-Zone treated plants had significantly higher visual ratings than the stress treatment for *Coreopsis*, *Rudbeckia*, *Forsythia*, *Euonymus*, *Nandina*, and *Weigela* either 10 DAT, 15 DAT, or both depending on the species. Based on visual ratings, effective treatment period for Stasis™ and Root-Zone would be between 5 and 10 DAT for *Coreopsis*, *Rudbeckia*, *Forsythia*, *Euonyomus*, *Nandina*, and *Weigela*, and only 5 DAT for *Salvia*, *Veronica*, and *Hibiscus*. Although drought stress recovery was not investigated, beyond the effective range, plants would not likely recover and would be undesirable from the severe wilting and browning of leaves.

No significant differences in increased stomatal resistance, except for *Rudbeckia* at 15 DAT, were seen throughout either study indicating that Stasis™ and Root-Zone may affect plant drought response through means other than stomatal closing. Lower transpiration rates can also occur by decreasing total leaf area and growth or stomatal density on leaves (11). The unexpectedly high stomatal resistance values for *Rudbeckia*, *Veronica*, and *Weigela* under well watered conditions 5 days after treatment initiation may have been due to the sampling time at which stomata were closed to maintain the ratio of intercellular to atmospheric CO_2 (15) or may have been an indication of excess soil moisture stress as was reported in grapes (7). Soil moisture content was not significantly different among chemical treatments to the well watered treatment at 5 DAT, but was not significantly different to the stress treatment starting 10 DAT indicating a breakdown of the chemicals effectiveness to retain moisture in the plant.

It should be noted that if plants are watered after chemical application then the chemicals are no longer effective and growers may not see any affect. Growers should evaluate the effectiveness of these antitranspirants under their own production practices to evaluate if such chemical applications justify product and labor costs. Success of another drench antitranspirant, s-ABA (ConTego™; Valent BioSciences), has been reported to effectively reduce water loss and extend shelf life of impatiens, seed geranium, petunia, marigold, salvia, and pansy (12). Variables that may have affected results include greenhouse temperatures, plant media, plant species, and the amount, rate, and timing of chemical applied.

Literature Cited

1. Barrett, J. and C. Campbell. 2006. S-ABA: Developing a new tool for the big grower. Big Grower 1 (November):26–29.

2. Blanchard, M.G., L.A. Newton, E.S. Runkle, and D. Woolard. 2007. Exogenous applications of abscisic acid improved the postharvest drought tolerance of several annual bedding plants. Acta Hort. 755:127–132.

3. Davies, W., G. Kudoyarova, and W. Hartung. 2005. Long-distance ABA signaling and its relation to other signaling pathways in the detection of soil drying and the mediation of the plant's response to drought. J. Plant Growth Regulat. 24:285–295.

4. Evans, R.G. and E.J. Sadler. 2008. Methods and technologies to improve efficiency of water use. Water Resources Research. 44:W00E04, doi:10.1029/2007WR006200.

5. Goreta, S., D.I. Leskovar, and J.L. Jifon. 2007. Gas exchange, water status, and growth of pepper seedlings exposed to transient water deficit stress are differentially altered by antitranspirants. J. Amer. Soc. Hort. Sci. 132:603–610.

6. Hummel, R.L. 1990. Water relations of container-grown woody and herbaceous plants following antitranspirant sprays. HortScience 25:772–775

7. Montague, T., E. Hellman, and M. Krawitzky. 2008. Comparison of greenhouse grown, containerized grapevine stomatal conductance measurements using two differing porometers. Proc. of the 2nd Annu. Natl. Viticult. Res. Conf. 2:58–59.

8. Petracek, P.D., D. Woolard, R. Menendez, and P. Warrior. 2005. Challenges for the commercial development of s-abscisic acid (ABA). Proc. 2005 Annual Conf. Plant Growth Regulat. Soc. Amer. 7–9. November 20, 2011. http://www.pgrsa.org/2005_Proceedings/papers/003.pdf

9. Pei, Z.M. and K. Kuchitsu. 2005. Early ABA signaling events in guard cells. J. Plant Growth Regulat. 24:296–307.

10. Sharma, N., S.R. Abrams, and D.R. Waterer. 2005. Uptake, movement, activity, and persistence of an abscisic acid analog (8' acetylene ABA methyl ester) in marigold and tomato. J. Plant Growth Regulat. 24:28–35.

11. Sharma, N., S.R. Abrams, and D.R. Waterer. 2006. Evaluation of abscisic acid analogs as holding agents in bedding plant seedlings. HortTechnology 16:71–76.

12. Waterland, N.L., C.A. Campbell, J.J. Finer, and M.L. Jones. 2010. Abscisic acid application enhances drought stress tolerance in bedding plants. HortScience 45:409–413.

13. Waterland, N.L., J.J. Finer, and M.L. Jones. 2010. Benzyladenine and gibberellic acid application prevents abscisic acid-induced leaf chlorosis in pansy and viola. HortScience 45:925–933.

14. Wilkinson, S. and J. Davies. 2002. ABA-based chemical signaling: the co-ordination of responses to stress in plants. Plant, Cell Environ. 25:195–210.

15. Wong, S.C., I.R. Cowan, and G.D. Farquhar. 1979. Stomatal conductance correlates with photosynthetic capacity. Nature 282:424–426.