Performance of Selected Herbaceous Annual Ornamentals Grown at Decreasing Levels of Irrigation

D. Yvette Henson, Steven E. Newman, and David E. Hartley^{1,2}

Department of Horticulture and Landscape Architecture, Colorado State University, Fort Collins, CO 80523-1173

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Abstract. This study was conducted to evaluate the growth, visual quality, and stress response of 17 species of bedding plants and Kentucky bluegrass (*Poa pratensis* L.) grown outdoors for 10 weeks during the summer of 2003 at three locations in Colorado. Plants were irrigated at 100% of the reference evapotranspiration (ET₀) (amount required to maintain Kentucky bluegrass in an optimum condition) for 2 weeks followed by 8 weeks at five irrigation levels: 0%, 25%, 50%, 75%, and 100% ET₀. *Begonia carrieri* Hort. 'Vodka', *Lobelia erinus* L. 'Cobalt Blue', and *Viola* × *wittrockiana* Gams. 'Crown Gold' grew well with a minimum of 50% or more ET₀ based on Kentucky bluegrass. *Impatiens walleriana* Hook. fil. 'Tempo White' grew well only with 100% ET₀. *Antirrhinum majus* L. 'Sonnet Yellow', *Dianthus* L. 'First Love', *Lobularia maritima* (L.) Desv. 'Carpet White', and *Pelargonium* × *hortorum* L.H. Bailey performed well with 25% to 50% ET₀. The species *Catharanthus roseus* (L.) G. Don 'Peppermint Cooler', *Rudbeckia hirta* L. 'Indian Summer', *Senecio cineraria* D.C. 'Silver Dust', *Tagetes erecta* L. 'Inca Yellow' and *T. patula* L. 'Bonanza Gold', *Zinnia angustifolia* Kunth., and *Salvia farinacea* Benth. 'Rhea Blue', which are adapted to midsummer heat and low water, performed well with 0% to 25% ET₀. Species considered to be heat or drought tolerant—*Petunia* × *hybrida* hort. ex. E. Vilm. 'Merlin White' and *Glandularia* J.F. Gmel. 'Imagination'—required little or no irrigation. The bedding plant species evaluated in this study that required 25% or less ET₀ are well adapted for low-water landscape installations.

Water conservation is becoming an increasingly pertinent issue in Colorado and the intermountain Rocky Mountain west. Colorado has a semiarid to arid climate with recurrent drought periods (Doesken, 2004; Tweit, 2004) and limited water resources (Oad and DiSpigno, 1997). Add to this population growth (Ellefson and Winger, 2004; Oad et al., 1997; Tweit, 2004), which in turn increases the strain on water resources. There is a great deal of information reported in the literature quantifying the water requirements of food crops and turfgrass; however, data quantifying the irrigation requirements of ornamental plants required to maintain healthy growth and acceptable quality is minimal at present.

Past reports have classified ornamental plants as low, medium, and high water users based on anecdotal evidence. A California study with groundcovers reported that 50% of evapotranspiration (ET₀) (level of irrigation required to maintain Kentucky bluegrass in an optimum condition) was the minimum

amount of irrigation to maintain acceptable plant quality (Pittenger et al., 1990). Yet, there was considerable variability among species. A later study indicated that for *Vinca* L., *Gazania* Gaertn., and *Potentilla* L., there was no improvement in aesthetic appearance when irrigated at more than 30% ET₀. *Baccharis* L., *Drosanthemum* Schwant., and *Hedera* L. showed no improvement in appearance when grown above 20% ET₀ (Pittenger et al., 1992). Other California investigations concluded that irrigation less than or equal to 14% of ET₀ can be applied to established groundcovers and shrubs with no adverse effects on health and appearance (Sachs, 1991).

Previous work reported from Colorado, where 45 herbaceous perennial plants native to the western United States were subjected to irrigation and no irrigation, demonstrated no differences among irrigation treatments (Cox and Klett, 1984). Staats and Klett (1995) reported that for Kentucky bluegrass (*Poa pratensis* L. 'Challenger'), 50% bluegrass ET₀ was the optimum irrigation level, whereas *Cerastium tomentosum* L. required irrigation between 50% and 75% bluegrass ET₀ in one season and 25% ET₀ during the following season. *Potentilla tabernaemontani* Asch. required irrigation at 75% ET₀ and *Sedum acre* L. did well at 25% ET₀ (Staats and Klett, 1995). Taken together, these findings demonstrate substantial variation in water requirements for ornamental plants grown in Colorado.

This study was conducted to determine water requirements and quantify the growth, visual quality, and health of 17 popular species of bedding plants grown outdoors under Colorado conditions compared with Kentucky bluegrass (*Poa pratensis* L.). The objectives of this research were to provide information on minimum irrigation requirements for annual herbaceous ornamental plants to be used by landscape professionals.

Materials and Methods

The bedding plant species for this study were chosen based on their status as top-selling bedding plants in Colorado according to local greenhouse professionals (D. Gerace, Welby Gardens, Inc., Denver, Colo., pers. comm.). *Poa pratensis* L. (Kentucky bluegrass) was included in the study for comparison because the calculated reference evapotranspiration (ET₀) value was based on this species. The 17 herbaceous annual ornamental species tested included *Antirrhinum majus* L. 'Sonnet Yellow' (snapdragons); *Begonia carrieri* Hort. 'Vodka' [syn. *Begonia semperflorens* 'Vodka' (red-leaved wax begonias)]; *Catharanthus roseus* (L.) G. Don 'Peppermint Cooler' (Madagascar periwinkle or vinca); *Dianthus* L. 'First Love'; *Impatiens walleriana* Hook. fil. 'Tempo White' (impatiens); *Lobelia erinus* L. 'Cobalt Blue'; *Lobularia maritima* (L.) Desv. 'Carpet White' (sweet alyssum); zonal geraniums *Pelargonium* × *hortorum* L.H. Bailey 'Americana Red' (Fort Collins), *Pelargonium* × *hortorum* L.H. Bailey 'Kim Red' (Denver), and *Pelargonium* × *hortorum* L.H. Bailey 'Americana Pink' (Grand Junction); *Petunia* × *hybrida* hort. ex. E. Vilm. 'Merlin White'; *Rudbeckia hirta* L. 'Indian Summer' (black-eyed Susan); *Salvia farinacea* Benth. 'Rhea Blue' (mealy-cup sage or salvia); *Senecio cineraria* D.C. 'Silver Dust' (dusty miller); *Tagetes erecta* L. 'Inca Yellow' (African marigold); *Tagetes patula* L. 'Bonanza Gold' (French marigold); *Glandularia* 'Imagination' [*Glandularia* J.F. Gmel. 'Imagination' (syn. *Verbena* 'Imagination') is either a species of *Glandularia tenuisecta* (Briq.) Small (syn. *V. tenuisecta* Briq.), moss verbena or a hybrid between *Glandularia tenuisecta* and *Glandularia tenera* (Spreng.) Cabera (syn. *V. tenera* Spreng.), Latin American mock vervain. For clarification, this plant will be referred to as *Glandularia* in this manuscript.]; *Viola* × *wittrockiana* Gams. 'Crown Gold' (pansies); and narrow-leaf zinnias *Zinnia angustifolia* Kunth. 'Crystal White' (Fort Collins and Denver) and *Zinnia angustifolia* 'Crystal Orange' (Grand Junction). Cultivar differences among locations for *Pelargonium* and *Zinnia* were the result of issues with availability. Similar trends were observed for each of the cultivars among locations and the data were consequently pooled.

All herbaceous ornamental plants used in the field trials were commercially grown from F₁ hybrid seed or cuttings (Welby Gardens, Inc., Denver, Colo.) using a traditional sphagnum peat moss and vermiculite

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¹Former Graduate Research Assistant, Extension Specialist, and Associate Professor.

²To whom reprints requests should be addressed; e-mail steven.newman@colostate.edu.

substrate, and were transplanted to plastic 804 trays, 606 trays, or 10-cm pots (zonal geraniums). Initially plants were greenhouse grown and subsequently hardened by limiting water before transplanting into the trial beds.

The three locations used included a campus site, an urban site, and a site in western Colorado. The urban location was in Denver, Colo., at elevation 1553 m; latitude, 39.83°; longitude, -104.95°. The campus location was in Fort Collins, Colo., at elevation 1522 m; latitude, 40.57°; longitude, -105.09°. The western Colorado location was in Grand Junction, Colo. at elevation 1416 m; latitude, 39.04°; longitude, -108.54°.

Each location required some soil amendment. The Denver location was a clay soil and was amended with 0.018 m³ of sphagnum peat moss·m⁻². The Fort Collins location was a loam soil, which had been amended during previous years with various organic amendments. Grand Junction soils are typically very saline; therefore, the Grand Junction location was a raised bed and was filled with a sandy loam native topsoil. The raised bed was 1 m high, with 10-cm-thick cement walls and a bottom layer of gravel covered by landscape fabric. One application of a full-season, complete nutrient (7% N-0.874% P-4.98% K), and combined soluble and slow-release fertilizer (HARDY START; Welby Gardens) was applied at a rate of 122 g·m⁻² and lightly tilled into each plot before planting at each location.

Each bedding plant species was planted in a 1-m² square with nine plants spaced 25.4 cm on center. Kentucky bluegrass sod was planted in 61 × 76-cm blocks (Denver and Fort Collins) and 76 × 76-cm blocks (Grand Junction) by placing it on top of the drip tapes and building soil up around the edges. Planting was completed 28 May 2003 in Denver, 29 May 2003 in Fort Collins, and 17 July 2003 in Grand Junction. The Grand Junction location was planted late to accommodate for the travel distance and to schedule the peak bloom, because late summer and early fall temperatures would be more suitable for bedding plant performance.

The beds were mulched with 1.25 cm cedar bark in Denver and Fort Collins and 1.25 cm shredded wood from pallets in Grand Junction. All weeding was done by hand at all locations. Insecticides were used only if severe infestations of insects occurred. No dead heading of blooms was done except on zonal geraniums. Differences between mulch colors used at the Denver and Fort Collins locations compared with the Grand Junction location were negligible.

The irrigation treatments included five levels, determined as 0%, 25%, 50%, 75% and 100% of the reference evapotranspiration (ET₀) required for optimum Kentucky bluegrass growth. Daily weather data (temperature, solar radiation, wind speed, and relative humidity) were collected from local weather stations, which were used to calculate location-specific ET₀ using the Penman-Montieth equation (Qian et al., 1996).

Each irrigation zone (irrigation level based on percent ET₀) was operated by a separate solenoid valve. Flow meters were installed to measure the actual water volume of irrigation water applied to each zone. Water flow was then calibrated to ensure accuracy among treatments. Two lines of drip tape were installed 25.4 cm apart along the center of all experimental units from end to end of each whole plot. The drip tape was 1.6 cm, 8 mm polyethylene (Chapin Watermatics, Inc., Watertown, N.Y.) with emitters every 20.3 cm and had an output of 203 mL·min⁻¹·m⁻².

Irrigation was automatically applied to whole plots using a WeatherTRACK® ET Controller (HydroPoint Data Systems, Petaluma, Calif.). Daily weather data for the Denver location was collected from an on-site weather station from which ET₀ was determined. Daily weather data for the Fort Collins location was collected from a nearby Northern Colorado Water Conservancy weather station located in central Fort Collins from which ET₀ was determined. Daily weather data for the Grand Junction location used a network of local weather stations to obtain an "ET everywhere" value. HydroPoint Data Systems distributed these daily ET₀ values to each ET Controller via cellular technology. The ET controller automatically adjusted the irrigation output for each irrigation zone (%ET₀) accordingly. Each ET controller was programmed for each location's soil type, type of landscape plant material (flowers), depth of irrigation, slope and exposure, and time of day to begin irrigation. Temperature data from each location are included in Figs. 1 through 3.

Each zone was entered into the controller by subtracting out 75% for the 25% zone, 50% for the 50% zone, and 25% for the 75% zone. The 0% ET₀ zone received only natural precipitation (no irrigation). The 100% zone was 100% of the reference ET (ET₀) for Kentucky bluegrass (i.e., the ET required to grow Kentucky bluegrass to optimum—up to 3.28 cm water·m⁻²·week⁻¹). Irrigation applied to each zone as well as natural rainfall is included in Table 1. A rain sensor shutoff valve (Hunter Mini-Click, Cary, N.C.) was connected to the ET controller to initiate an automatic rain pause when 0.32 cm rain was detected. The daily data sent to the ET controller would initiate a rain pause for a calculated number of days after a rain event as well. All plots were irrigated to 100% ET₀ for 2 weeks after planting and were then subjected to the irrigation treatment levels for the following 8 weeks.

Percent cover, plant biomass, leaf temperature, and visual evaluations were collected to contrast the growth and health of each species at the different levels of irrigation at all three locations.

Percent cover using the point intercept method (Daubenmire, 1959) was measured every other week for 8 weeks at each location using a grid constructed from a 1-m² frame constructed from polyvinyl chloride pipe. An acceptable final percent cover was calculated

Fig. 1. Average daily temperature with maximum and minimum temperatures for Denver, Colo., collected during the first 2-week establishment period followed by the 8-week study period. The temperature data were collected from the National Oceanic & Atmospheric Administration weather station located at Denver International Airport, Commerce City, Colo.

Fig. 2. Average daily temperature with maximum and minimum temperatures for Fort Collins, Colo., collected during the first 2-week establishment period followed by the 8-week study period. The temperature data were collected from the Northern Colorado Water Conservancy District weather station located in central Fort Collins, Colo.

Fig. 3. Average daily temperature with maximum and minimum temperatures for Grand Junction, Colo., collected during the first 2-week establishment period followed by the 8-week study period. The temperature data were collected from the National Oceanic & Atmospheric Administration weather station located at Grand Junction Walker Field, Grand Junction, Colo.

for each species by taking its highest cover, dividing it by 93 (the highest average percent cover achieved by a plant species in the study), and then multiplying that by 75. This formula was used based on 75% being

Table 1. Rainfall and drip irrigation applied to each subplot as determined by evapotranspiration (ET₀) at each location for the 10-week duration of the study.

Location		Irrigation level (%ET ₀)				
		100	75	50	25	0
		(cm of irrigation) ^z				
Denver ^y	Applied irrigation	24.9	18.6	11.6	6.25	0
	Irrigation plus rainfall	36.0	29.7	22.7	17.4	11.1
Fort Collins ^x	Applied irrigation	25.7	19.0	14.2	5.89	0
	Irrigation plus rainfall	32.9	25.2	20.4	12.1	6.21
Grand Junction ^w	Applied irrigation	23.3	22.0	9.55	4.57	0
	Irrigation plus rainfall	26.1	24.8	12.4	7.39	2.82

^zApplied irrigation levels were calculated based on the volume of water applied, as determined by an inline recording device, and the area to which that volume was applied via the drip irrigation system.

^yRainfall data from the National Oceanic & Atmospheric Administration weather station located at Denver International Airport, Commerce City, Colo.

^xRainfall data from Northern Colorado Water Conservancy District weather station located in central Fort Collins, Colo.

^wRainfall data from the National Oceanic & Atmospheric Administration weather station located at Grand Junction Walker Field, Grand Junction, Colo.

Table 2. Plant quality evaluation of 17 bedding plant species and Kentucky bluegrass grown at five irrigation levels based on evapotranspiration for Kentucky bluegrass (ET₀) in Denver and Fort Collins, Colo.

Species	Irrigation level (% ET ₀)					ANOVA				
	100	75	50	25	0	Irrigation	Location	I × L	Linear	Quadratic
	(Rating)									
<i>Antirrhinum</i>	3.33	3.16	3.15	2.65	2.23	0.0019	0.0136	NS	0.0003	0.0211
<i>Begonia</i>	3.93	3.54	2.70	1.62	0.67	0.0004	NS	NS	0.0001	NS
<i>Catharanthus</i>	4.33	4.10	3.44	3.21	2.62	0.0001	NS	NS	0.0001	NS
<i>Dianthus</i>	4.11	3.78	3.24	2.43	1.98	0.0025	0.0001	NS	0.0003	NS
<i>Impatiens</i>	3.63	2.63	2.43	1.13	0.39	0.0121	0.0183	0.0201	0.0017	NS
<i>Lobelia</i>	3.89	3.40	2.77	2.04	1.08	0.0027	NS	NS	0.0004	NS
<i>Lobularia</i>	3.50	3.80	3.26	1.78	1.10	0.0057	0.0282	NS	0.0010	0.0380
<i>Pelargonium</i>	4.04	3.41	2.97	2.36	1.60	0.0018	NS	NS	0.0002	NS
<i>Petunia</i>	4.64	4.63	4.21	3.91	3.41	0.0016	0.0039	NS	0.0002	0.0477
<i>Poa</i>	4.73	4.15	3.38	1.74	0.43	0.0007	NS	NS	0.0001	0.0472
<i>Rudbeckia</i>	4.61	4.64	4.03	3.70	2.58	0.0002	NS	NS	0.0001	0.0018
<i>Salvia</i>	4.57	4.14	3.85	3.36	2.51	0.0008	NS	NS	0.0001	NS
<i>Senecio</i>	4.60	4.30	3.70	3.49	2.88	0.0042	0.0177	NS	0.0006	NS
<i>Tagetes erecta</i>	4.60	4.64	3.89	3.58	2.80	0.0001	NS	NS	0.0001	0.0024
<i>T. patula</i>	4.45	4.26	3.65	3.07	2.43	0.0002	NS	NS	0.0001	0.0307
<i>Glandularia</i>	3.85	3.93	3.67	3.27	3.15	NS	0.0018	0.0084	NS	NS
<i>Viola</i>	3.17	3.10	2.44	1.64	1.06	0.0133	NS	NS	0.0021	NS
<i>Zinnia</i>	4.62	4.42	4.04	3.18	2.58	0.0047	0.0437	NS	0.0007	NS

Evaluation was from 0 to 5, where 0 indicated dead or mostly dead plants; 2 indicated fair to moderate signs of stress, 3 indicated good plant growth with minimal signs of stress; 4 indicated very good plant growth with no signs of stress, insects, or disease; and 5 indicated excellent plant growth with no signs of stress, insects, or disease.

^{NS}Nonsignificant.

acceptable cover (Al-Kaisi and Broner, 2002).

Realizing that with a diverse collection of bedding plant species with differing growth habits, percent cover may not accurately assess plant growth when using only one plant spacing. To accommodate for that issue, the percent change in cover was also determined to compare plant growth among species. The first measurement of percent cover was used as a covariate for the next three subsequent measurements of percent cover to reduce variation among the experimental units. The difference between the final percent cover and the initial percent cover was analyzed as percent change.

Plant biomass was collected at the end of 8 weeks in Denver and Fort Collins only. No plant biomass was collected at Grand Junction. This was completed by cutting the four corner plants in each group at soil level and drying at 70 °C.

Plant temperatures were determined at all three locations with a hand-held IR thermometer (Omegascope, model 05530; Omega Engineering, Stamford, Conn.) (Hatfield, 1990). This was completed two or three times

every other week at each location between 11 AM and 1 PM Mountain Standard Time by aiming the IR thermometer at the center of each meter-square group of plants while maintaining a distance of 30 cm. The temperatures were recorded and the canopy temperature was subtracted from the air temperature [canopy temperature – air temperature (ΔT)] to obtain a measure of drought stress under decreasing levels of irrigation.

Plant visual evaluation was conducted during the All American Selections Annual Flower Trial Garden evaluations at the Denver and Fort Collins locations only at the beginning of Aug. The Grand Junction location was not evaluated. The evaluators were asked to rate each species on a scale of 0 to 5, where 0 indicated dead or mostly dead plants; 1 indicated poor or extensive wilting, curling, burning or discoloring, and insect or disease damage to plants; 2 indicated fair to moderate signs of stress, and insect or disease damage; 3 indicated good plant growth with minimal signs of stress, and insect or disease damage; 4 indicated very good plant growth with no signs of stress, insects, or disease; and 5 indicated excellent plant growth with no

signs of stress, insects, or disease. Visual plant ratings were averaged for each species within each treatment to determine the lowest irrigation level where each species still maintained acceptable visual quality. An evaluation score of 3 points or more at any level was used to determine the lowest irrigation level where growth and appearance were acceptable.

The experimental design was a split plot replicated at three locations. Each location had 500 m² (20 × 25 m) of planted area. This was divided into whole plot treatments, which included the five levels of irrigation. Within each of these irrigation whole plots were the subplots, which included the 18 species randomly placed. Each subplot treatment contained five 1-m² observations.

Effects for irrigation, location, and replications nested within location were determined by species (for each species separately) with analysis of variance using general linear models (PROC GLM, releases 8 and 9.1; SAS Inst., Cary, N.C.). A mixed model was used when irrigation was a fixed effect, location a random effect, and the five subsamples (replications of experimental units) nested within locations as a random

effect. The treatment (irrigation) effect was partitioned into linear and quadratic contrasts.

Results and Discussion

Eight weeks after the imposed irrigation treatment levels, a visual rating of three points indicated good plant growth with minimal signs of drought stress, and insect or disease damage. The plants were fairly uniform and vigorous in growth and flowering. Only *Petunia* and *Glandularia* maintained a plant quality of three points or more for the lowest irrigation level: 0% ET₀ (Table 2). *Glandularia* plant quality was unaffected by irrigation level. *Glandularia* 'Imagination' is either a species of *Glandularia tenuisecta* (syn. *V. tenuisecta*), moss verbena, or a hybrid between *Glandularia tenuisecta* and *Glandularia tenera* (syn. *V. tenera*), Latin American mock vervain.

G. tenuisecta is from open sunny habitats in South America and has become naturalized in the western and southern United States, whereas *Glandularia tenera* is from similar habitats in Brazil. Considering the native habitats, *Glandularia* would be assumed to be more drought resistant. Another characteristic of *Glandularia* that might have contributed to its drought resistance is small, finely dissected blue-green foliage (Daubenmire, 1974; Larcher, 2003), which is known to reduce evapotranspiration. Other similar species of this genus are widely planted in low-water use landscapes across the southwestern U.S. (Lockett et al., 2002).

Although *Petunia* quality was reduced to the greatest degree from 25% to 0% ET₀, as indicated by the quadratic trend (Table 2), it was still aesthetically acceptable. *Petunia* has many characteristics that make it an ideal candidate for a low-water use landscape,

primarily its ability to tolerate a broad range of temperatures. van Iersel (2003) reported that *Petunia* had the greatest daily carbon gain in response to short-term high temperatures when compared with geraniums and pansies. Both *Glandularia* and *Petunia* maintained a satisfactory plant quality of three points or more in spite of elevated canopy temperatures of more than 5 °C greater than the air temperature (Table 3).

Glandularia and *Petunia* grew well at all the irrigation levels, increasing in percent cover, change in percent cover, and plant biomass (Tables 4–6). Considering 75% coverage to be ideal, *Glandularia* performed best at 25% and greater ET₀, and *Petunia* at 75% and greater ET₀.

The genera *Catharanthus*, *Rudbeckia*, *Salvia*, *Senecio*, *Tagetes*, and *Zinnia* all had a rating of three points or more at 25% and greater ET₀ (Table 2). All these genera are

Table 3. Canopy–air temperature difference (ΔT°C) for 17 bedding plant species and Kentucky bluegrass grown at five irrigation levels based on evapotranspiration for Kentucky bluegrass (ET₀) in Denver, Fort Collins, and Grand Junction, Colo.

Species	Irrigation level (% ET ₀)					ANOVA				
	100	75	50	25	0	Irrigation	Location	I × L	Linear	Quadratic
	(ΔT °C)									
<i>Antirrhinum</i>	−0.57	0.44	1.80	4.10	5.45	0.0006	0.0001	0.0064	0.0001	NS
<i>Begonia</i>	4.23	5.15	6.68	10.18	12.49	0.0045	0.0001	0.0001	0.0004	NS
<i>Catharanthus</i>	0.07	1.06	2.34	4.90	6.13	0.0008	0.0001	0.0046	0.0001	NS
<i>Dianthus</i>	1.26	2.34	3.64	6.17	7.56	0.0007	0.0001	0.0006	0.0001	NS
<i>Impatiens</i>	1.28	2.27	4.87	7.81	10.1	0.0082	0.0001	0.0028	0.0006	NS
<i>Lobelia</i>	1.44	2.12	4.01	5.55	7.06	0.0020	0.0001	0.0021	0.0001	NS
<i>Lobularia</i>	−0.76	−0.38	0.61	3.01	7.08	0.0017	0.0001	0.0138	0.0002	0.0260
<i>Pelargonium</i>	−0.30	1.78	3.77	6.77	9.67	0.0001	0.0001	NS	0.0001	NS
<i>Petunia</i>	−1.38	−0.77	1.12	3.10	5.26	0.0036	0.0001	0.0005	0.0003	NS
<i>Poa</i>	1.37	2.59	5.57	9.99	16.7	0.0009	0.0001	0.0001	0.0001	NS
<i>Rudbeckia</i>	−1.26	0.013	0.097	2.62	5.17	0.0009	0.0001	0.0347	0.0001	NS
<i>Salvia</i>	−1.52	−0.53	1.39	3.11	5.06	0.0007	0.0001	0.0054	0.0001	NS
<i>Senecio</i>	−2.01	−0.96	0.18	2.23	3.08	0.0008	0.0001	0.0294	0.0001	NS
<i>Tagetes erecta</i>	−2.54	−1.33	0.065	2.51	3.99	0.0008	0.0001	0.0016	0.0001	NS
<i>T. patula</i>	−1.27	−0.40	0.95	2.75	4.76	0.0258	0.0001	0.0001	0.0022	NS
<i>Glandularia</i>	−0.94	−0.16	1.46	4.02	5.95	0.0009	0.0001	0.0001	0.0001	NS
<i>Viola</i>	1.45	2.75	4.99	7.42	9.75	0.0016	0.0001	0.0005	0.0001	NS
<i>Zinnia</i>	−2.67	−0.83	1.01	2.01	4.18	0.0008	0.0001	0.0090	0.0001	NS

NSNonsignificant.

Table 4. Percent cover of 17 bedding plant species grown at five irrigation levels based on evapotranspiration for Kentucky bluegrass (ET₀) in Denver, Fort Collins, and Grand Junction, Colo.

Species	Irrigation level (% ET ₀)					ANOVA				
	100	75	50	25	0	Irrigation	Location	I × L	Linear	Quadratic
	(% cover)									
<i>Antirrhinum</i>	47.9	46.0	40.6	31.8	27.0	0.0148	0.0001	0.0001	0.0014	NS
<i>Begonia</i>	25.9	23.0	17.9	9.58	6.62	0.0069	0.0006	0.0012	0.0028	NS
<i>Catharanthus</i>	48.7	47.9	36.8	24.4	19.6	0.0007	0.0001	0.0133	0.0001	NS
<i>Dianthus</i>	62.9	75.8	65.3	47.0	36.2	0.0464	0.0025	0.0011	0.0166	0.0484
<i>Impatiens</i>	44.0	35.1	27.6	9.71	2.57	0.0320	0.0001	0.0001	0.0029	NS
<i>Lobelia</i>	46.3	48.1	39.2	23.2	15.7	0.0260	0.0001	0.0001	0.0024	NS
<i>Lobularia</i>	63.0	64.4	52.7	42.0	26.9	0.0054	0.0002	0.0011	0.0013	0.0476
<i>Pelargonium</i>	67.1	66.6	65.3	38.4	28.9	0.0001	0.0001	0.0245	0.0001	0.0021
<i>Petunia</i>	78.1	75.1	73.8	62.9	59.1	0.0140	0.0001	NS	0.0018	NS
<i>Poa</i>	—	—	—	—	—	—	—	—	—	—
<i>Rudbeckia</i>	78.0	78.0	75.4	60.5	45.4	0.0014	0.0001	0.0460	0.0002	0.0109
<i>Salvia</i>	69.9	63.8	59.7	39.5	29.8	0.0008	0.0001	NS	0.0001	0.0456
<i>Senecio</i>	45.5	41.5	32.5	23.4	19.2	0.0057	NS	0.0240	0.0004	NS
<i>Tagetes erecta</i>	88.2	90.8	85.6	62.5	53.0	0.0101	0.0001	0.0004	0.0020	0.0600
<i>T. patula</i>	63.7	59.0	52.6	38.8	32.1	0.0007	0.0001	NS	0.0001	NS
<i>Glandularia</i>	91.9	92.6	89.8	77.1	72.1	0.0156	0.0020	NS	0.0023	NS
<i>Viola</i>	29.0	26.0	20.0	10.6	7.10	0.0549	0.0001	0.0001	0.0065	NS
<i>Zinnia</i>	86.1	84.7	76.0	59.1	48.8	0.0004	0.0001	NS	0.0001	0.0276

NSNonsignificant.

Table 5. Change in percent cover of 17 bedding plant species grown at five irrigation levels based on evapotranspiration for Kentucky bluegrass (ET₀) in Denver, Fort Collins, and Grand Junction, Colo.

Species	Irrigation level (% ET ₀)					ANOVA				
	100	75	50	25	0	Irrigation	Location	I × L	Linear	Quadratic
	(% change in cover)									
<i>Antirrhinum</i>	23.1	22.7	18.5	11.0	6.00	0.0342	0.0001	0.0001	0.0035	NS
<i>Begonia</i>	10.1	8.92	4.02	-2.54	-5.08	0.0144	0.0001	0.0003	0.0012	NS
<i>Catharanthus</i>	33.2	34.1	24.9	13.0	7.60	0.0008	0.0001	0.0037	0.0001	NS
<i>Dianthus</i>	23.8	34.0	30.5	14.1	7.79	NS	0.0038	0.0001	0.0347	NS
<i>Impatiens</i>	29.0	19.6	13.8	-3.4	-11.9	0.0396	0.0001	0.0001	0.0036	NS
<i>Lobelia</i>	27.0	27.0	19.1	6.55	-1.34	0.0313	0.0001	0.0001	0.0032	NS
<i>Lobularia</i>	22.3	25.6	21.8	17.8	-4.32	0.0035	NS	0.0432	0.0010	0.0073
<i>Pelargonium</i>	10.4	14.8	9.99	-1.91	-9.18	0.0020	NS	0.0331	0.0003	0.0419
<i>Petunia</i>	78.1	75.1	73.8	62.9	59.1	0.0140	0.0001	NS	0.0018	NS
<i>Poa</i>	—	—	—	—	—	—	—	—	—	—
<i>Rudbeckia</i>	35.7	35.1	36.5	24.2	9.25	0.0171	0.0001	0.0031	0.0032	0.0477
<i>Salvia</i>	41.6	38.2	36.8	17.8	7.76	0.013	0.0001	0.0153	0.0001	NS
<i>Senecio</i>	22.2	15.8	13.4	2.65	-0.65	0.0163	0.0003	NS	0.0014	NS
<i>Tagetes erecta</i>	25.2	26.6	32.4	18.9	2.37	NS	0.0001	0.0059	0.0309	0.0510
<i>T. patula</i>	29.2	24.4	27.1	14.6	6.11	NS	0.0001	0.0007	0.0102	NS
<i>Glandularia</i>	31.4	36.6	36.2	32.0	24.1	NS	0.0008	NS	NS	NS
<i>Viola</i>	8.18	8.17	1.84	-8.54	-8.70	0.0478	0.0001	0.0001	0.0057	NS
<i>Zinnia</i>	51.2	44.7	49.6	34.5	21.8	0.0011	0.0001	NS	0.0002	0.0302

NSNonsignificant.

Table 6. Plant biomass (in grams) of 17 bedding plant species grown at five irrigation levels based on evapotranspiration for Kentucky bluegrass (ET₀) in Denver and Fort Collins, Colo.

Species	Irrigation level (% ET ₀)					ANOVA				
	100	75	50	25	0	Irrigation	Location	I × L	Linear	Quadratic
	(g)									
<i>Antirrhinum</i>	40.4	37.7	35.8	29.0	24.7	NS	0.0001	0.0001	0.0384	NS
<i>Begonia</i>	12.1	10.4	7.69	3.24	2.63	0.0175	NS	NS	0.0026	NS
<i>Catharanthus</i>	22.7	20.2	19.8	10.7	7.19	0.0067	0.0013	NS	0.0011	NS
<i>Dianthus</i>	34.2	36.8	29.5	22.9	17.8	0.0118	0.0001	NS	0.0020	NS
<i>Impatiens</i>	18.1	11.9	11.4	3.86	1.57	0.0168	0.0353	NS	0.0025	NS
<i>Lobelia</i>	20.9	21.0	15.9	9.94	6.51	0.0025	NS	NS	0.0004	NS
<i>Lobularia</i>	39.1	45.8	41.8	26.2	19.5	NS	0.0001	0.0001	NS	NS
<i>Pelargonium</i>	38.2	33.4	29.8	20.1	15.8	0.0002	0.0001	0.0001	0.0001	NS
<i>Petunia</i>	73.3	75.9	68.7	54.4	55.6	NS	0.0001	NS	0.0319	NS
<i>Poa</i>	—	—	—	—	—	—	—	—	—	—
<i>Rudbeckia</i>	92.6	92.0	82.3	59.9	41.3	NS	0.0002	NS	0.0215	NS
<i>Salvia</i>	47.3	42.6	39.5	26.1	19.3	0.0271	0.0001	0.0141	0.0041	NS
<i>Senecio</i>	38.2	35.3	29.1	19.0	17.7	0.0274	0.0202	NS	0.0042	NS
<i>Tagetes erecta</i>	117.2	116.2	104.9	74.7	61.1	0.0023	NS	NS	0.0003	0.0528
<i>T. patula</i>	58.2	55.9	37.6	28.4	28.8	0.0106	0.0091	NS	0.0017	NS
<i>Glandularia</i>	80.0	72.8	55.0	38.3	39.9	0.0363	0.0001	NS	0.0059	NS
<i>Viola</i>	14.2	12.7	10.2	6.84	5.38	0.0287	0.0010	NS	0.0041	NS
<i>Zinnia</i>	80.8	80.8	79.5	52.6	48.5	0.0390	0.0001	0.0161	0.0082	NS

NSNonsignificant.

native to hot and dry climates, thus it would be expected that they perform well in our study. Of these, *Rudbeckia*, *T. erecta*, and *Zinnia* achieved a coverage of 75% or more at 50% ET₀ (Table 4) while increasing in canopy size (Tables 5 and 6).

Antirrhinum, *Dianthus*, and *Lobularia* required at least 50% ET₀ and *Begonia*, *Lobelia*, *Pelargonium*, and *Viola* required at least 75% ET₀ to achieve a quality rating of three points or more (Table 2). None of these genera achieved 75% coverage (Table 4) nor did they grow well at irrigation levels lower than 50% ET₀ (Tables 4–6). These genera were also under considerable drought stress at irrigation levels less than 50% ET₀, as shown by high ΔT values (Table 3). Many of these species are better adapted to cooler climates.

Antirrhinum grow best at cooler temperatures and, with recurrent wilting, flower quality declines (Rutland et al., 1987).

Wax-leaved begonias are considered to be drought resistant (Armitage, 2001), but under our conditions of high light, this trait was not observed. The Kentucky bluegrass included in the study required at least 50% ET₀ to maintain acceptable quality (Table 2).

Impatiens performed the poorest of all genera tested. It received a three points or more rating only when irrigated at 100% ET₀ (Table 2), but never achieved acceptable growth under our ambient conditions (Tables 4–6). This was anticipated, because this genus is typically planted in moderate to full shade in Colorado. Including *Impatiens* in this study was debated, yet these data support its potential success in the landscape when adequate irrigation is provided.

Many species adapted to lower irrigation rates had leaf temperatures near 0 °C or less at 100% ET₀ (Table 3). Typically leaf temperature increases as water stress increases (Hatfield, 1990; Smiciklas et al., 1989). Rose

and colleagues (1994) determined that, for greenhouse roses, the leaf-air temperature difference was inversely related to transpiration rate. At any point where ΔT is near 0 °C or less, plants are transpiring efficiently. Yet some species may maintain lower leaf temperatures through leaf color or adaptive leaf morphology by effectively reflecting solar radiation (Larcher, 2003). *Lobularia*, *Petunia*, *Rudbeckia*, *Salvia*, *Tagetes*, *Glandularia*, and *Zinnia* all had ΔT values near 0 °C or less even at 75% ET₀ (Table 3).

The majority of the species evaluated in this study grew well with a minimum of 50% or more ET₀ based on Kentucky bluegrass. Species considered to be heat or drought tolerant, *Petunia* and *Glandularia*, required little or no irrigation. The species included in this study, which are adapted to midsummer heat and low water, performed well with 25% or more ET₀, indicating that these species can adapt to low-water landscape installations.

This information will be beneficial for water providers to make recommendations about plant selection, planting design, and irrigation for plants in the Rocky Mountain west.

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