Evaluating a Line Source Irrigation System for Determining Water Requirements of Herbaceous Perennials[1]

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Abstract

We investigated wind effects on the water distribution pattern of a line source irrigation system experimental design that creates a decreasing linear moisture gradient and the growth of twelve perennial wildflower species. Species were randomly assigned to rows perpendicular to a main line of spray irrigation heads, parallel to the decreasing irrigation rates, and irrigated at 110% of evapotranspiration at the heads. At low wind speed (0.44 m/s, 1.4 ft/s), application rates decreased linearly from 50 mm/hr (2 in/hr) for positions closest to the irrigation line to zero at 4 m (12 ft) from the irrigation line. Application rates at positions farthest from the irrigation line were affected by wind speeds as low as 1 m/s (3.3 ft/s). At high wind speeds (3.8 m/s, 12.5 ft/s), application rates at all positions averaged the same across all positions but with extremely high variability. We detected a water stress response in several species known to be drought sensitive. A line source irrigation design offers a potential way to efficiently assess the response of a large number of perennial species to varying irrigation rates by creating a linear moisture gradient, but only when applied under low wind speeds.

Index words: landscape irrigation, line source irrigation, herbaceous perennials, water conservation.

Species used in this study: golden columbine (*Aquilegia chrysantha* Gray.); sundrops (*Calylophus hartweggi* Benth.); purple coneflower (*Echinacea purpurea* L. Moench); buckwheat (*Eriogonum jamesii* Benth.); blanket flower (*Gaillardia aristata* Pursh.); whirling butterflies (*Gaura lindheimeri* Englem & Gray.); sticky geranium (*Geranium viscosissimum* Fisch. & Mey.); blue flax (*Linum perenne* L.); evening primrose (*Oenothera macrocarpa* Nutt.); pine leaf penstemon (*Penstemon pinifolius* Greene); 'Red Rocks' penstemon (*Penstemon* x *mexicali*), and globe mallow (*Sphaeralcea grossularifolia* [Hook. & Arn.) Rydb.]

Significance to the Nursery Industry

Water shortages throughout the United States have increased interest in using water conserving plant species in the landscape. However, there have been limited studies conducted to evaluate drought tolerance of ornamental species, especially herbaceous perennial species. A line source irrigation experimental design can potentially quantify and compare the irrigation needs, as well as assess drought response, of a large number of herbaceous perennial species in order to identify those more suitable for low water use landscapes. However, the influence of wind speed, rooting volume, and plant canopy size need to be considered when designing and interpreting results.

Introduction

Municipal water shortages throughout the United States have created a demand for water conserving urban landscapes. Common strategies used in designing low water landscapes include using drought tolerant plants and grouping plants according to their water requirements (8). Since landscape plants are judged by aesthetics and not yield, specific water requirements and drought tolerance are difficult to define (7). Instead, drought tolerance and water requirements of landscape plants are typically combined and expressed as high, medium, and low water use categories based on anecdotal observation (3).

Most water requirement studies have been conducted on agronomic crops or turfgrass. In particular, water requirements for agronomic crops have been well described by de-

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fining a local reference evapotranspiration (ETo), water use of a hypothetical turfgrass stand as affected by solar radiation, wind, air temperature, and humidity (1). Since plant characteristics that regulate transpiration are held constant, ETo allows comparison among times and locations based solely on meteorological conditions. Transpiration characteristics of other species of interest are imbedded in an empirically-derived water loss coefficient (Kc) specific for each species (1). The water use by a species of interest is the product of Kc and ETo. Because of its extensive use in most urban landscapes and its close relationship to ETo, development of Kc values for urban landscapes has mainly focused on turfgrass (12, 13, 14). Species diversity and difficulty in quantifying Kc values has limited development for non-turfgrass, ornamental landscape plants (7). In addition, little information on minimum water requirements and drought tolerance of herbaceous ornamentals exists.

Certain herbaceous perennials, such as purple coneflower (*Echinacea purpurea* L. Moench) have been characterized as drought tolerant based on their ability to maintain open stomata, osmotically adjust, and their low lethal water potential (4). Another study found that changes in leaf gas exchange, leaf water potential, growth, and carbohydrate partitioning of snowbank boltonia (*Boltonia asteroides* L.), eastern white snakeroot *(Eupatorium rugosum* L.), and three-lobed coneflower *(Rudbeckia triloba* L.) during drought conditions were attributed to differences in water use rates (11).

Line source irrigation is an effective tool for evaluating water requirements and drought tolerance among cultivars in uniform stands of agronomic species (5, 6). In a line source irrigation system, a line of sprinkler heads with substantial overlap is laid through the center of a plot perpendicular to the parallel treatment rows (5). Plot width is determined by the wetted diameter of the sprinkler throw radius, typically impact-type heads, creating a linear moisture gradient where the highest precipitation rate is next to the line and progressively decreases towards the edges of the wetted diameter (5). When irrigated according to local ETo, the results can provide useful information about minimum water requirement levels (or Kc values) and drought tolerance of individual species or cultivar treatments.

The effectiveness of a line source irrigation system to evaluate the water requirements of perennial plants is unknown. Using smaller spray heads, rather than impact heads, in a line source would have the advantage of a linear moisture gradient in a compact design with fewer plants, but how wind may impact smaller water droplets and confound application rates, water distribution, and plant responses is not certain. Also, discrete plants with non-contiguous canopies and species with differing crown size and rooting could potentially create uneven rooting volumes and variable water uptake, further confounding plant response data.

In the Intermountain West, an abundance of native, anecdotally drought tolerant herbaceous perennials have substantial ornamental landscape potential (9) but few are commercially available and little is known about their performance under variable irrigation rates. The objective of this study was to evaluate a line source irrigation system experimental design to study the effect of a linear moisture gradient on the growth of twelve commercial and Intermountain West native, herbaceous perennial landscape species, and how the water distribution pattern was affected by wind speed as part of the design.

Materials and Methods

Plant material. The study was conducted at the Greenville Agricultural Experiment Station in North Logan, UT. Species used in the study were *Aquilegia chrysantha* Gray. (golden columbine); *Calylophus hartweggi* Benth. (sundrops); *Echinacea purpurea* L. Moench (purple coneflower); *Eriogonum jamesii* Benth. (buckwheat); *Gaillardia aristata* Pursh. (blanket flower); *Gaura lindheimeri* Englem & Gray. (whirling butterflies); *Geranium viscosissimum* Fisch. & Mey. (sticky geranium); *Linum perenne* L. (blue flax); *Oenothera macrocarpa* Nutt. (evening primrose); *Penstemon pinifolius* Greene (pine leaf penstemon); *Penstemon* x *mexicali* ('Red Rocks' penstemon); and *Sphaeralcea grossularifolia* (Hook. & Arn.) Rydb. (globe mallow).

In May 2001, one-to-two-month-old seedlings grown in 170 cm^3 (10.4 in^3) plugs were transplanted into a field bed of Millville silt loam (coarse-silty, carbonatic, mesic Typic Haploxerolls) soil. After establishment, plants were irrigated once a week at 100% of ETo using Maxipaw impact heads (Rainbird Inc. Azusa, CA; 10 mm/hr suggested manufacturer precipitation rate) such that the entire plot was irrigated uniformly and the plants were well established. Plants received no supplemental fertilization.

Irrigation system. In the spring of 2002, the irrigation system was redesigned so that a single irrigation line was assembled down the middle of the study using spray heads (Model 1800, Rainbird Inc., Azusa, CA; 44 mm/hr suggested manufacturer precipitation rate) spaced 4 m (13.1 ft) apart. Water coverage along the main line was 120% overlap.

Species were randomly assigned to rows perpendicular to the sprinkler line and parallel to the decreasing precipitation rates. Seven individual plants per species per row were randomly assigned to positions within the row. Each position perpendicular to the irrigation line corresponded to a decreasing application rate. Each row of species was uniformly spaced 0.66 m (2.2 ft) apart, and plants within each row were spaced in seven positions 0.66 m (2.2 ft) to 4.60 m (15.1 ft) away from the irrigation line. Each block, consisting of twelve species, was replicated four times with two blocks on either side of the main irrigation line. A border of *Elymus elymoides* Raf., a native Intermountain West, highly drought tolerant grass species, was planted around the plots to ensure competition for water was similar on all sides of the outside rows.

The irrigation system was operated from June 1 to August 31 at 207 kPa (30 psi) one time per week during the mornings when we estimated wind speed to be low. The plot was irrigated on June 1, 2002, and subsequent irrigations were based on a water budget such that the amount applied to positions adjacent to the sprinkler line was equal to 100% of ETo for the previous seven days. A total of 20 mm (0.79 in) of rain fell during the study period, and was incorporated into the water budget and irrigation duration adjusted accordingly.

Catch cup tests were used to measure water application rates and uniformity across the study. One cup (an inverted plastic cone calibrated to mm units) was placed next to each plant in every other row perpendicular to the irrigation line. Seven rows were used per replicate block for a total of 49 measurements per block and 196 measurements per catch cup test. Water was applied for 30 minutes during each catch cup test. Average wind speed was measured at a height of 2 m (6.6 ft) from the ground during the data collection period

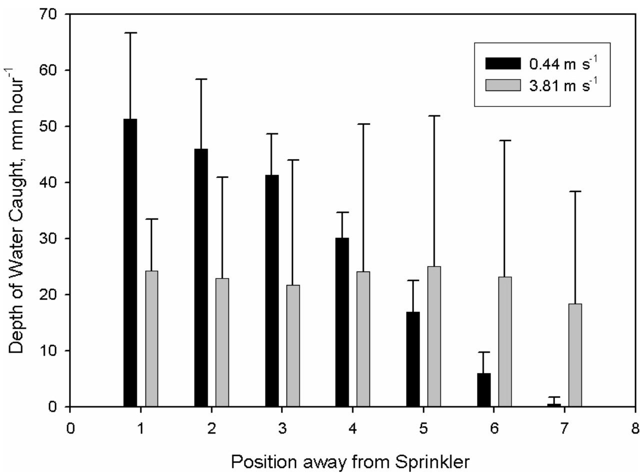

Fig. 1. Effect of position away from the main irrigation line on depth of water collected at two average wind speeds, 0.44 (1.4 ft/s)and 3.81 m/s (12 ft/s)in a line source irrigation system, plus standard deviation. Each spray head position (position 1 was closest to the irrigation line to position 7) on the irrigation line was 0.66 m (2.2 ft) apart.

using a hand held anemometer (Kestrel 1000, Nielsen-Kellerman, Chester PA) facing in the direction of the wind.

The catch cup tests were conducted eight times from August 1 through mid-September to determine application rates at wind speeds ranging from 0.4 to 10 m/s (1.3 to 32.8 ft/s). Four catch-cup tests were conducted as a part of the weekly irrigation in August, and three additional irrigations were inserted during the first two weeks in August and one in mid September to assess application uniformity at wind speeds higher than we would normally irrigate. This amounted to an additional measured application of 55 mm (2.2 in) in excess of ETo. Total water applied to the plants closest to the irrigation line from all irrigations was 613 mm (24.13 in) of water, 110% of ETo, while plants furthest from the line received no supplemental irrigation.

Application rates were corrected to mm/hr. In late September 2002, above-ground biomass for each plant was cut at the soil level and placed in paper bags. Plant tissue was dried at 85C (185F) for 48 hr and dry weight measured.

Data analysis. Irrigation catch cup test data were analyzed by calculating the standard deviation of the application rate for each position perpendicular to the irrigation line. The data were based on 28 measurements per position; 14 on each side of the irrigation line. Mean application rate plus standard deviation at each of the seven perpendicular positions was initially calculated at a high and low wind speed to evaluate the pattern of application rate as affected by wind speed. The coefficient of variation (standard deviation divided by the mean) was then calculated for each position at each wind speed, and the first five positions closest to the irrigation line were regressed on wind speed (application rates at the last two positions were negligible. The equation that yielded the highest F-statistic was selected as the best fit curve (TableCurve 2D ver. 3, Systat Inc., Richmond CA). The data and fitted curve were plotted against wind speed.

Biomass was initially analyzed with PROC MIXED using SAS (SAS v. 9.0, Cary, NC), with species, irrigation, and direction (location on either side of the irrigation line) being fixed variables and replicate block was a random variable. The direction variable assessed the potential effect of wind direction on irrigation on either side of the irrigation line. In our experimental design, the direction variable described two of the replicate plots that were north of the irrigation line and two that were on the south side. We did not test for overall irrigation and species effects on biomass because of autocorrelation of randomization with species, thus there was no error mean square appropriate for the denominator (6), and inherent genetic difference among species biomass did not allow for meaningful species comparisons that would otherwise be possible (2).

The term of interest was irrigation × species such that the analysis essentially became the response of each species to irrigation level. All species in this study have potential use in landscapes and our goal was to characterize the pattern of plant responses to a linear moisture gradient. Consequently, the effect of irrigation on an individual plant species was evaluated by regressing above-ground biomass on irrigation level (using PROC REGRESSION) with the linear option. Instead of defining irrigation level as the position perpendicular to the irrigation line, it was presented as percent of seasonal ETo with the first position closest to the line being

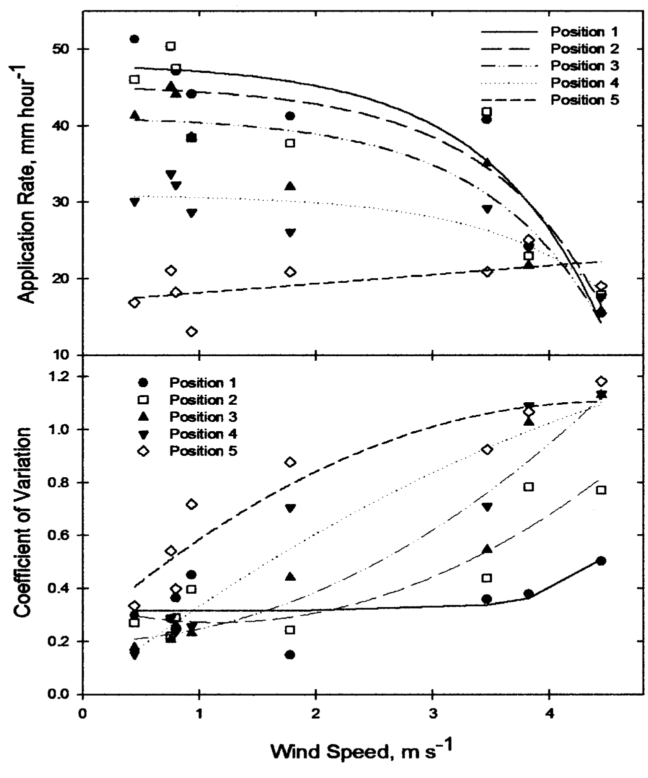

Fig. 2. Influence of wind speed on the application rate relative to the irrigation line at position 1 (r^2 = 0.90, $y = a + be^x$, a = 48, b = –0.40), position 2 (r^2 = 0.77, $y = a + be^x$, a = 45, b = –0.34), position 3 (r^2 = 0.83, $y = a + be^x$, a = 41, b = –0.32), position 4 (r^2 = 0.78, $y = a + be^x$, a = –31, b = –0.15), and position 5 (r^2 = 0.29, y = a + bx, a = 17, b = 1.2), and on coefficient of variation at position 1 (r^2 = 0.38, $y = a + be^x$, a = 0.32, b = 8.8E^{-6}), 2 (r^2 = 0.83, $y = a + bx^3$, a = 0.28, b = 5.4 E^{-4}), 3 (r^2 = 0.92, $y = a + bx^2$, a = 0.20, b = 9.2 E^{-3}), 4 (r^2 = 0.92, $y = a + bx^{0.5}$, a = –0.32, b = 0.44), and 5 (r^2 = 0.92, y = a + blnx, a = 0.34, b = 0.34). Each spray head position (position 1 was closest to the irrigation line to position 5; positions 6 and 7 not shown) on the irrigation line was 0.66 m (2.2 ft) apart.

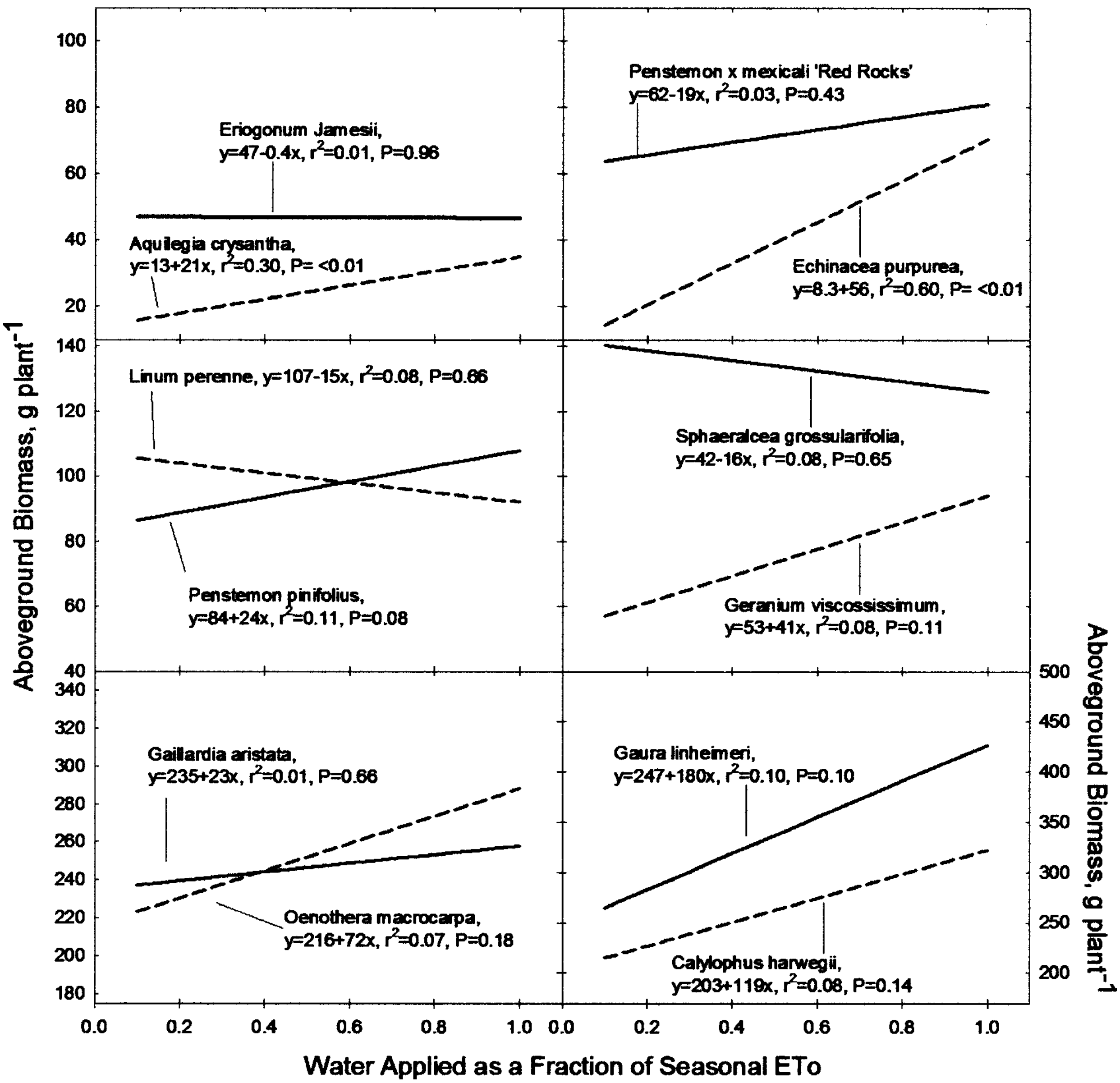

Fig. 3. **Above ground biomass fitted to irrigation level expressed as a percent of ETo (100% = position 1, closest to irrigation line), with fitted curve parameters, and F-statistics for 12 herbaceous perennial species grown using a line source irrigation system.**

irrigated at 100% of ETo (approximating the actual 110% applied).

Results and Discussion

Irrigation rate and uniformity. Application rates decreased linearly with increasing distance from the main sprinkler line under low wind conditions as expected (Fig. 1). At positions 6 and 7, water application rates were negligible. Wind speed had a large effect on the distribution of water away from fixed spray sprinkler heads. Agricultural line source studies typically use impact heads with larger droplet size relative to fixed spray heads and are relatively less subject to the wind disrupting the water distribution pattern (5, 6). At wind speeds ≥3.8 m/s (≥12.5 ft/s) the linear decrease in application rates was disrupted in our study. Wind direction strongly influenced where droplets fell, mostly but not exclusively from south to north. At high wind speeds mean application rates were nearly uniform but highly variable across all positions perpendicular to the main irrigation line (Fig. 1).

We measured wind speeds ranging from 0.44 to 0.93 m/s (1.4–2.9 ft/s) during regular irrigations with additional irrigations under high wind speeds ranging from 1.8–4.4 m/s (5.6–14 ft/s) (Fig. 2). Application rates for positions 1–5 were minimally affected by wind speeds up to 0.8 m/s (2.5 ft/s), as coefficients of variation (CV) were below 0.4 except for one value at position 5. For positions 6 and 7 (data not shown), application rate variability was much higher, as CVs ranged from 1–2, but the rates were low enough that the variation had no meaningful impact on overall rates and were still very separable from positions 5 and 4. Between wind speeds 1 m/s (3.3 ft/s) and 3.5 m (11 ft/s) application rates decreased somewhat at positions 1–3 while remaining relatively constant at positions 4 and 5, but CVs at positions 4–7 (data for 6 and 7 not shown) increased substantially. At the highest wind speeds at 3.8 m/s (12 ft/s) and above, application rates for all positions converged to a common but extremely variable value of 20 mm/s (Fig. 1)

A line source study using fixed spray heads requires attention to wind speed due to the susceptibility of the smaller droplets produced by the spray sprinkler heads to the wind. Hanks et al. (1976) recommended plots be irrigated when wind speeds were <1 m/s (3.3 ft/s), while our data suggest 0.8 m/s (2.5 ft/s) may be a more preferable but not necessarily realistic threshold for spray heads. An analysis of hourly wind speeds at our research site, between May 1 and September 19, 2002, indicated only 14% of all measurements were ≤1 m/s (3.3 ft/s) and only 4% were below 0.8 m/s (2.6 ft/s). The highest probability of low wind speeds was at 7:00 AM,, during June-August, just after sunrise. If run within a one-hour window just after sunrise, a line source system would face a 20% chance of wind below 0.8 m/s (2.5 ft/s), but increasing to 45% if an acceptable threshold were set at 1 m/s (3.3 ft/s).

Plant response to irrigation. We detected a modest irrigation effect on above-ground biomass. A significant direction effect was absent from this study ($P \leq 0.44$), even though the dominant wind direction was from the south, likely due to irrigating at mostly at wind speeds less than 1 m/s (3.1 ft/s). The species × irrigation interaction was also not significant ($P = 0.11$) in a traditional sense, but we believed it was significant enough biologically to examine response among species to irrigation application rates. The muted irrigation effect at the species level was probably due to variation in above-ground biomass production among irrigation levels. Only two species, *Echinacea purpurea* and *Aquilegia crysantha*, exhibited a significant relationship ($P < 0.01$) between biomass and irrigation (Fig. 3). *Echinacea purpurea* had the best fit to, and steepest decline with, irrigation rate, indicating that this species is less drought tolerant than suggested (4). The effect of drought on *Aquilegia crysantha* was somewhat expected since it is commonly found in wet habitats (15). Both species also exhibited scorched leaves at approximately 50% ETo application rates (data not presented).

Above-ground biomass of *Penstemon pinifolius*, *Guara lindheimeri*, and *Geranium viscossissimum* was marginally related ($P = 0.08, 0.10, 0.11$, respectively) to decreasing irrigation. *Geranium viscossissimum* shares a similar elevation range to *A. crysantha* (15) and an overall similar level of drought tolerance, with some leaves scorched at the lowest two irrigation levels at a. *Gaura lindheimeri* and *Penstemon pinifolius* are both native to south central United States, suggesting some degree of drought tolerance that is supported by lower biomass but undiminished leaf quality at about 40% ETo.

Irrigation level did not significantly affect above-ground biomass production of the remaining seven species. These species are generally native to drier areas of the interior West (8, 15), suggesting some degree of drought tolerance not clearly demonstrated in this study due to the probable confounding effects of plant size and layout configuration. Noncontiguous canopies in our study gave larger root zones per plant than a uniform agronomic crop canopy, favoring a larger rooting volume for a smaller species like *Eriogonum jamesii*. A larger rooting volume with high water holding capacity, 0.19 m water/m soil (0.19 in/in) to 2 m (6.6 ft) depth, silt loam soil at this site (10) would also contribute to a diminished drought signal than in a coarser, lower water holding capacity soil.

Line source irrigation with high precipitation rate spray heads can be a useful tool to evaluate drought response of large numbers of herbaceous perennial species. Future line-source irrigation studies investigating water requirements and drought response of perennials would benefit from several precautions. Avoiding wind disturbance of line source spray head distribution patterns, especially at the outer edge of coverage, is possible through analysis of historical daily wind speed data to determine the time of day for irrigation at the lowest possible wind speeds. Timing daily irrigations at low wind speeds would be greatly facilitated with an automated weather station and datalogger to track ETo and wind. Controlling rooting volume is critical and could be accomplished by basing between-row spacing and inter-row plant spacing on anticipated canopy size, or by using drought tolerant border plants or turfgrass between plants.

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