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2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Climate-Based Coefficients for Scheduling Irrigations in Urban Xeriscapes

Daniel Smeal, College Professor, CID CLIA

New Mexico State University, Agricultural Science Center, P.O. Box 1018, Farmington, NM 87499, dsmeal@nmsu.edu

Michael K. O'Neill, Professor

New Mexico State University, Agricultural Science Center, P.O. Box 1018, Farmington, NM 87499, moneill@nmsu.edu

Kevin A. Lombard, Assistant Professor

New Mexico State University, Agricultural Science Center, P.O. Box 1018, Farmington, NM 87499, klombard@nmsu.edu

Richard N. Arnold, College Professor

New Mexico State University, Agricultural Science Center, P.O. Box 1018, Farmington, NM 87499, riarnold@nmsu.edu

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Abstract. *The decrease in water supply/demand ratios in the western U.S. is stimulating the region's municipalities to implement water conservation incentives. In response, many homeowners and businesses are replacing high water-using landscapes with drip-irrigated xeriscapes. Water-requirement information for the plant species that comprise these xeriscapes is lacking. Consequently, plants may still receive more water than necessary to sustain acceptable growth and appearance and water may not be conserved. The objectives of this project were to evaluate the growth and aesthetic quality of various drought-tolerant plants that have potential for use in urban landscapes of the western U.S. Intermountain zone under variable levels of microirrigation and then to formulate climate-based (Penman-Monteith reference ET), landscape coefficients (*K_L*) or plant factors (PF) that may be used along with* *measurements of plant canopy area to develop effective irrigation scheduling recommendations for these plants. A xeriscape garden was split into four differentially irrigated sections (0, 20, 40, and 60% of reference ET) and at least one individual of more than 90 plant species were planted into each section. An average canopy area was used to adjust irrigation treatments and then actual plant canopy measurements were used to formulate PF for each species. While PF varied significantly between species, results indicate that an overall K_L or PF of about 0.3 may be appropriate for water management planning on xeric landscapes.*

Keywords. landscape coefficients, xeriscape, irrigation, reference evapotranspiration, plant factors, scheduling coefficients

Introduction

The populations of western U.S. cities have increased dramatically over the past 50 years but available fresh water to supply the rising demand of these populations has remained relatively constant. In an effort to conserve water for essential needs, many municipalities in the region have implemented incentives such as increasing-block water rate structures, water-use restrictions and/or penalties for water waste. Since outdoor water use represents up to 60% of total water use during the summer months in some of these municipalities, cash rewards have also been offered for removal of high water-use landscape plants such as cool season turfgrasses and imported trees. In response, many homeowners and businesses are converting their sprinkler-irrigated grass lawns to drip-irrigated xeriscapes consisting of native plants or plants more suitable to the arid or semi-arid environments typical of the region. While this measure has the potential to conserve water, savings may not be realized if irrigation management strategies are not developed that match irrigation volumes to those required by each plant to exhibit acceptable growth and quality in the xeriscape.

Climate based irrigation scheduling, which has been used successfully for many years in row crop and turfgrass water management, might also be used to schedule irrigations in drip irrigated xeriscapes. In climate-based irrigation scheduling, a crop's water requirement or evapotranspiration (ET_C) is estimated by the product of reference ET (ET_{ref}), calculated from weather data, and an experimentally derived adjustment factor (AF) or crop coefficient (K_C). Typically, ET estimates and accurate K_C values are formulated under standard conditions where the crop is grown in large, dense monocultures that are disease-free, well fertilized, grown under optimum soil water conditions, and which achieve full production under the given climatic conditions (Allen et al. 1998). Xeriscapes do not typify these standard conditions as they usually consist of isolated shrubs and small trees that are separated from neighboring plants by much greater distances than those of row crops or turf. Acceptable appearance or expected function, rather than reaching full yield potential, is the primary goal. Additionally, most published K_C values have been derived from fields in which the entire soil surface is wetted by sprinkler or flood irrigation. Early in the growing season, the transpiration component of ET_C is limited by each plant's small, live-leaf canopy area and the K_C (or ET_C /ET_{ref}) is small but then increases gradually as the crop's live-leaf canopy area increases. When the entire soil surface is wetted by precipitation or irrigation during this establishment period, soil evaporation exceeds plant transpiration in ET_C until the soil surface dries. Xeriscapes, on the other hand, are usually drip irrigated and the evaporational component of ET_C during plant establishment is much less than in sprinkler or flood irrigation since only a small area of soil around the base of each plant is wetted. Because of these anomalies, it has been suggested the AF for non-turf landscape plants be referred to as a species or landscape coefficient (K_S or K_L) (Costello, 1991) or plant factor (PF) (Pittenger, et al. 2008). While K_C in row crops varies during the season as a consequence of percent canopy coverage, K_S remains constant in a formula that incorporates a variable measured or estimated, single plant, live canopy area (CA) to estimate plant water needs. This approach theoretically helps compensate for non-standard conditions such as variability in plant spacing, varietal differences, plant vigor and other factors that can affect CA.

A number of references pertaining to gardening or landscaping in the U.S. Intermountain Zone have been published (Tatroe, 2007; Tannehill and Klett, 2002; Proctor, 1996; Phillips, 1998; Busco and Morin, 2003; Knopf, 1991; Knopf, 2003; Nold, 2008) and a few of these provide subjective terms (i.e. low, medium, high) to indicate the water requirements for the plant species they recommend. Few studies have been published that provide objective quantifications of plant water requirements when grown in drip irrigated landscapes in the region. In one study, Staats and Klett (1995) evaluated the effects of irrigation, as a percentage of ET_{ref}, on the growth and appearance of three alternative groundcovers as compared to Kentucky bluegrass (KBG) in northern Colorado. Once established, two of the groundcovers (*Sedum acre* and *Cerastium tomentosum*) maintained acceptable appearance at the 25% ET_{ref} treatment (compared to 50% of ET_{ref} for the KBG) but apparently, only *Sedum acre* was considered a potential, acceptable, water-conserving substitute groundcover for KBG.

In California, Costello and Jones (1994) compiled a comprehensive list of that state's landscape plants along with suggested optimum ranges of species coefficients (K_S) for the plants in 'Water Use Classification of Landscape Species' (WUCOLS). In WUCOLS, K_S is adjusted with a microclimate factor (K_{mc}) and a plant density factor (K_d) to derive a K_L for given areas of the state. The K_L is then multiplied by the reference ET (ET_O) that has been calculated using weather data from a nearby California Irrigation Management Information System (CIMIS) weather station to derive a landscape ET estimate (ET_L) for irrigation scheduling. While most of these K_S values were based on speculative field observations, some research-based information has begun to be collected for a small number of these California species (Shaw and Pittenger, 2004). Waller (2010) further described the WUCOLS method for scheduling irrigations of trees and shrubs in northern Arizona using reference ET values available from Arizona's AZMET climate network but provided no scientifically formulated K_S values for landscape species grown there. In another Arizona study, Levitt, et al. (1995) measured the ET of Argentine mesquite (*Prosopis alba*) and live oak (*Quercus virginiana*) grown in containers under well-watered conditions and reported average constant, plant projected canopy area crop coefficients of 1.36 and 1.56 for the oak and mesquite, respectively.

The objectives of this demonstration-research study were to 1) provide a demonstration of plant species that have potential for use in semi-arid, urban landscapes of the western U.S. Intermountain Region; 2) evaluate the effects of drip irrigation on the growth and quality of various drought tolerant landscape plants; and 3) formulate climate-based plant factors or K_S values that can be used to estimate the water requirements of these plants for scheduling irrigations.

Materials and Methods

This study was conducted at New Mexico State University's Agricultural Science Center at Farmington, NM. The center is located in northwestern New Mexico on the Colorado Plateau at an elevation of 1720 m (5,640 feet) above mean sea level. The average annual precipitation (1969 thru 2009) at this semi-arid site is 206 mm (8.1 inches). The 41-year average annual freeze-free period is 162 days from 3 May to 13 October (O'Neill and West, 2010). The soil classification is a Kinnear very fine sandy loam (Typic Camborthid, fine loamy, mixed, calcareous, mesic family) (Anderson, 1970). Daily Penman-Monteith, tall canopy reference ET (ET_r) was calculated using daily maximum and minimum air temperature (^oC), daily minimum and maximum relative humidity (%), daily solar radiation (MJ m^{-2} d^{-1}), and average 24-hour wind speed (m s^{-1}) recorded at an automated weather station (Campbell Scientific, Inc. Model CR10) located less than 300 feet east of the plots using the ASCE-EWRI standardization procedures documented by Snyder and Eching (2002).

More than 90 drought tolerant perennials having potential for use in urban landscapes were planted in 2002. The total planted area of 1,190 m^2 (12,800 ft^2) was split into four, 24 by 12 m (80 by 40 ft) quadrants and at least one individual of each plant species (or variety) was planted into each quadrant. Most of the specimens were transplanted from small starts in 50 to 100 mm (2 to 4 inch) pots obtained from a native plants nursery. During establishment (2002 and early 2003) all plants were irrigated with between 1 and 10 L (0.25 and 3 gals) of water per week. Irrigation frequency and amount within this range varied with plant size, age and atmospheric demand. Newly planted specimens were irrigated every other day with about 1 L (1 qt) of water per application during the first few weeks. As the plants became established and new growth was evident, irrigation frequency was reduced to once or twice per week and irrigation volumes increased to between 4 and 10 L (1 and 3 gallons) per application. Beginning in August 2003, a microirrigation system consisting of 3.78 L (1 gal) per hour emitters with one emitter per plant was used to apply different irrigation treatments to the plants growing in three of the quadrants. Plants in the fourth quadrant received precipitation only. From August through September of 2003 and from 15 May through 15 October in subsequent years through 2009, equation 1 was used to schedule irrigations in each of the irrigated quadrants:

$$I = (ET_r - P) \times TF \times CA \qquad (1)$$

where

I = irrigation applied, (L per plant)
ET_r = sum of daily ET_r values since last irrigation (mm)
P = effective precipitation since last irrigation (mm)
TF = treatment factor (0, 0.2, 0.4, or 0.6)
CA = circular canopy area per plant (m^2)

In the quadrants that received irrigation, water was applied weekly at the appropriate runtimes to apply the volumes necessary to replace 0.2, 0.4, and 0.8 of ET_{rs} minus effective precipitation (P) which was defined as 60% of the sum of events greater than 5 mm (0.2 inch). Rainfall events less than 5 mm were ignored. A mean plant canopy area of 1.16 m^2 (12.5 ft^2) was used in equation 1 from 15 May through 15 October, a period when the live-leaf canopy area of most of the woody perennials was at or near maximum. Actual plant heights and canopy areas were measured in all irrigation treatments in mid-summer and each species was subjectively judged for aesthetic appeal at each treatment level. Actual measurements of plant diameter (D) were used to calculate circular CA ($D^2 \times 0.785$) and a suggested PF for each species was derived from the plant's CA in the lowest irrigation quadrant (minimum TF) where acceptable plant quality was observed. Plants that exhibited poor quality in all quadrants or that were judged to be undesirable for landscape use because of aggressive spreading, ranginess, etc. were not considered. Plants that failed to survive in all quadrants from factors not related to irrigation were also eliminated from consideration.

Results and Discussion

Reference ET

Total ET_r from April 1 to October 31 averaged 1689 mm (66.5 in.) for the years of this study. Daily ET_r increased from about 6.35 mm (0.25 in.) in early April to greater than 10 mm (0.4 in.) in mid June but varied widely from day to day during the spring due to significant diurnal fluctuations in temperature and wind (figure 1). Average ET_r then decreased gradually from about 9.5 mm (0.37 in.) in late June to 4 mm (0.16 in.) in late October. Day to day variability in ET_r during late summer and fall was much less than in spring due to more stable weather conditions (figure 1). From 15 May through 15 August, daily ET_r averaged 9.4 mm (0.37 in.) so weekly irrigation volumes applied to each plant during this period averaged 15, 30, and 45 L (4, 8, and 12 gals) in the 0.2, 0.4, and 0.6 ET_r irrigation treatments, respectively. Plants in the zero irrigation quadrant received precipitation only which averaged 190 mm (7.5 in.) per year from 2004 thru 2009. About 80 mm (3.1 in.) of this precipitation was considered effective based on our definition (sum of events greater than 5 mm).

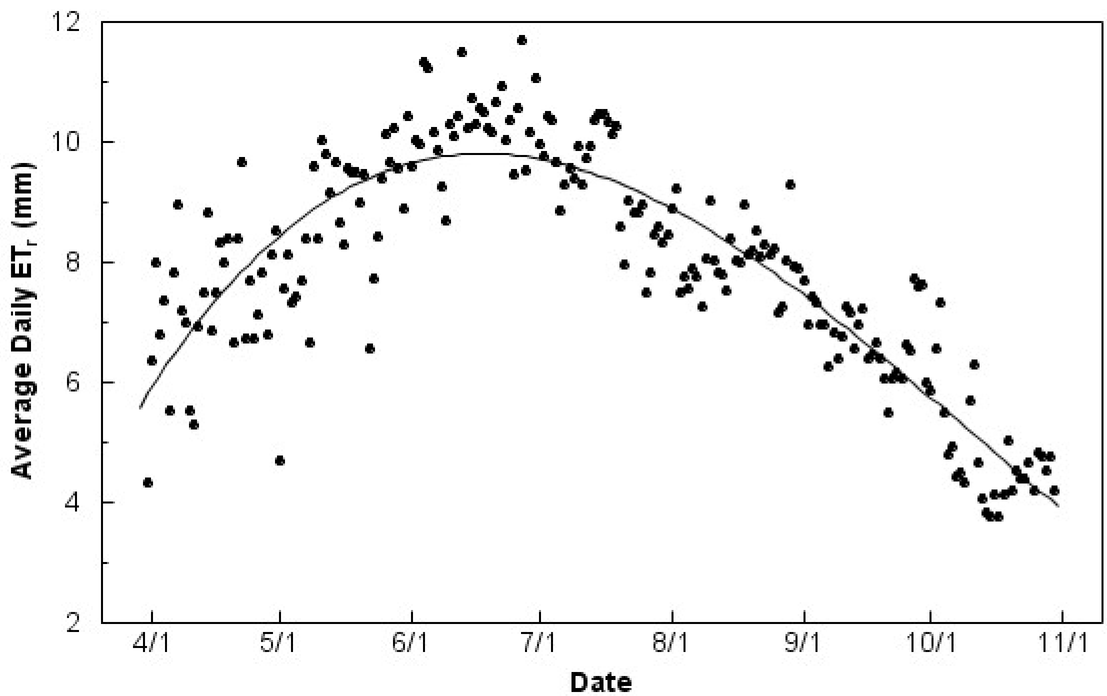

Figure 1. Average daily Penman-Monteith tall canopy reference ET from 1 April thru 31 October at New Mexico State University's Agricultural Science Center from 2004 thru 2009.

Suggested PF (or K_S) values for the species in the xeric plant garden, considering measured plant diameter (or circular CA) and quality observations at the four different drip treatments were derived using equation 2:

$$PF = WA \div (ET_r \times D^2 \times 0.785) \quad (2)$$

where

PF = plant factor or K_S (dimensionless)
WA = weekly applied water (incl. precip.) at the minimum acceptable plant quality (mm)
ET_r = sum of daily reference ET values between weekly irrigations (mm)
D = measured diameter of the plant at acceptable irrigation treatment (m)

Plant factors ranged from 0.01 for several plants that exhibited acceptable quality without supplemental irrigation to 1.66 for a relatively small plant (*Echinacea purpurea*) that did well only in the quadrant receiving the highest irrigation (table 1). The 1.16 m^2 canopy area used to derive irrigation treatments, along with the weekly irrigation frequency, may have resulted in over or under irrigation of plants with small canopy areas such as *E. purpurea* so the PF values reported in table 1 may not result in the optimum irrigation schedule for these plants. The average PF value for all plants was 0.30.

Table 1. Measured plant diameters, suggested plant factors (or species coefficients (K_S), and irrigation requirement per plant (IR) during peak water demand (maximum CA and ET_r) for several xeriscape species at Farmington, NM.

		Diameter		Peak IR[1]
Species	Common Name	m	PF (K_S)	L/week
Amelanchier utahensis	Utah serviceberry	2.43	0.01	0.0
Artemisia abrotanum	Southernwood	1.73	0.21	29.5
Artemisia frigida	Fringed sagewort	1.09	0.05	0.0
Artemisia ludoviciana	Prairie sagewort	1.43	0.32	30.4
Artemisia nova	Black sage	1.52	0.16	15.5
Artemisia tridentata	Big sagebrush	2.14	0.01	0.0
Artiplex canescens	Fourwing saltbush	1.52	0.03	0.0
Berberis fremontii	Fremont barberry	1.02	0.20	7.5
Berlandiera lyrata	Chocolate flower	1.57	0.02	0.0
Brickellia californica	California bricklebush	1.52	0.22	22.7
Buddleia davidii	Butterfly bush	1.85	0.15	23.0
Calylophus berlandieri	Berlandieri sundrops	1.31	0.29	22.9
Campsis radicans	Trumpet vine	2.73	0.11	38.5
Caragana arborescens	Siberian peashrub	2.43	0.01	0.0
Caryopteris clandonensis	Blue mist spirea	0.81	0.54	15.2
Centranthus ruber	Jupiter’s beard	1.14	0.61	37.6
Cerastium tomentosum	Snow in summer	0.91	0.60	22.8
Cercocarpus ledifolius	Curl-leaf mountain mahogany	1.09	0.17	7.4
Cercocarpus montanus	True mountain mahogany	1.50	0.03	0.0
Chamaebatiaria millefolium	Fernbush	2.13	0.01	0.0
Chilopsis linearis	Desert willow	3.68	0.00	0.0
Chrysothamnus nauseosus	Rubber rabbitbrush	1.83	0.13	19.0
Coreopsis lanceolata	Lanceleaf coreopsis	0.95	0.72	30.3
Cowania (Purshia) mexicana	Cliffrose	1.19	0.14	7.3
Datura metaloides	Sacred datura	1.78	0.20	29.5
Echinacea purpurea	Purple coneflower	0.69	1.66	37.7
Eriogonum jamesii	James’ buckwheat	0.67	0.79	15.1
Euphorbia myrsinites	Myrtle (yellow) euphorbia	1.09	0.42	22.8
Fallugia paradoxa	Apache plume	1.54	0.02	0.0
Foresteria neomexicana	New Mexico olive	1.83	0.02	0.0

Gaillardia aristata	Blanket flower	0.86	0.78	26.4
Helianthemum nummularium	Sunrose	1.09	0.60	33.9
Helianthus maximiliani	Maximilian sunflower	1.66	0.20	25.7
Hesperaloe parviflora	Red yucca	1.19	0.19	10.9
Juniperus scopulorum	Rocky Mountain juniper	1.33	0.03	0.0
Koelreuteria paniculata	Goldenrain tree	3.82	0.05	37.8
Krascheninnikovia lanata	Winterfat	1.16	0.15	7.7
Liatris punctata	Dotted gayfeather	0.95	0.47	18.6
Linum perenne	Perennial blueflax	0.86	0.57	18.5
Mirabilis multiflora	Giant four o'clock,	1.88	0.16	25.5
Nassella tennuissima	Threadgrass	1.02	0.62	30.2
Oenothera organensis	Organ Mtn. evening primrose	1.14	0.50	30.2
Opuntia imbricata	Tree cholla	0.48	0.26	0.0
Oryzopsis hymenoides	Indian ricegrass	0.43	1.12	7.6
Parthenium incanum	Mariola	1.02	0.41	18.9
Penstemon abuelitas	Abuelita penstemon	0.78	0.10	0.0
Penstemon ambiguus	Bush penstemon	1.69	0.02	0.0
Penstemon angustifolia	Narrow leaf beardtongue	0.71	0.12	0.0
Penstemon pinifolius	Pineleaf penstemon	0.88	0.36	11.2
Penstemon strictus	Rocky Mtn. penstemon	1.09	0.29	14.8
Peraphyllum ramosissimum	Squaw apple	1.16	0.15	7.7
Perovskia atriplicifolia	Russian sage	1.21	0.04	0.0
Pinus nigra	Black pine	1.71	0.12	15.1
Potentilla fruticosa	Native potentilla	0.90	0.61	22.7
Potentilla thurberii	Red cinquefoil	0.95	0.63	26.1
Prosopis pubescens	Screwbean mesquite	1.54	0.08	7.4
Prunus besseyi	Western sandcherry	1.40	0.10	7.1
Ratibida columnifera	Prairie coneflower	0.86	0.38	11.3
Rhus trilobata	Three-leaf sumac	2.57	0.01	0.0
Rhus trilobata var. pilosissima	Pubescent squawbush	1.66	0.07	7.1
Ribes aureum	Golden currant	1.24	0.09	3.9
Robinia neomexicana	New Mexico locust	3.49	0.04	25.2
Rosmarinus officianalis	Upright rosemary	1.24	0.37	26.0
Salvia greggii	Cherry sage	0.95	0.39	14.9
Salvia pinguifolia	Rock sage	1.52	0.25	26.3
Sedum telephium	Autumn joy sedum	0.67	0.62	11.2
Spartium junceum	Spanish broom	1.73	0.12	15.5

Sporobolus wrightii	Giant sacaton	1.40	0.10	7.1
Stachys byzantina	Lamb's ear	1.12	0.58	34.1
Teucrium arogrium	Greek germander	0.81	0.76	22.6
Verbena macdougalii	Western spike verbena	1.09	0.60	33.9
Yucca baccata	Banana yucca	1.00	0.06	0.0
Yucca elata	Soaptree yucca	1.19	0.04	0.0
Zauschneria californica	Hummingbird plant (trumpet)	1.07	0.69	37.8
Zinnia grandiflora	Desert zinnia	0.83	0.62	18.9

[1]At peak daily average ET_r of 9.4 mm between 15 May and 15 August.

The recommended weekly irrigation requirement (IR) for each species that required irrigation during peak ET_r and full live-leaf CA per plant (15 May thru 15 August) in a typical year with average precipitation (table 1) was calculated using equation 3:

$$IR = ET_r \times PF \times D^2 \times 0.785 \qquad (3)$$

where

IR = irrigation requirement per plant (L)
ET_r = sum of daily P-M tall canopy reference ET values since last irrigation (mm)
PF = plant factor (or K_s) derived from minimum acceptable TF and actual CA
D = measured plant diameter at time of irrigation (m)
0.785 = constant to convert plant canopy diameter to area

Weekly IR from 15 May to 15 August ranged from zero for those species that exhibited acceptable aesthetic quality in the precipitation only quadrant to 38.5 L (10 gallons) per week for the large vine-like plant *Campsis radicans* (trumpet creeper).

Conclusion

While not a rigorous scientific study, the xeriscape demonstration-research garden with differentially irrigated quadrants conveyed some valuable information on the potential growth and quality of more than 90 species of plants at various levels of drip irrigation. While there was considerable variability between suggested PF values for the different species, an overall average K_L of 0.3 appears to be sufficient for irrigation planning on mixed-species xeriscapes of the Intermountain western U.S. Because the average CA used in defining the irrigation treatments for all plants in the garden was considerably larger than the actual CA of small-sized species, future research should focus on identifying the best water management practices for these smaller, xeric-adapted perennials.

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