Effect of Landscape Mulches and Drip Irrigation on Transplant Establishment and Growth of Three North American Desert Native Plants[1]

Catherine K. Singer[2] and Chris A. Martin[3]
Department of Applied Biological Sciences
Arizona State University, Mesa, AZ 85212

Abstract

A two-year experiment was conducted to determine growth responses of three North American desert native plants, brittle bush (*Encelia farinosa*), four wing salt bush (*Atriplex canescens*), and Santa Rita prickly pear cactus (*Opuntia santa rita*) to four landscape mulch treatments (shredded landscape tree trimmings, composted ponderosa pine residue, decomposing granite, or a no mulch control). In addition, brittle bush and four wing salt bush plants were drip irrigated with either 1275 liters (337 gal) or 2550 liters (674 gal) of water·plant^{-1}·year^{-1}. Santa Rita prickly pear cacti were not irrigated. Transplant survivability of brittle bush was differentially affected by mulch treatment. In contrast, mulch treatments had no impact on survivability of four wing salt bush or Santa Rita prickly pear. Mulch treatments also had no effect on growth indices of all plants. Compared to the no mulch control treatment, shredded tree trimming mulch increased relative water content of Santa Rita prickly pear padded stems. Shoot dry weights were greatest for non-irrigated four wing salt bush and brittle bush. These findings suggest that supplemental drip irrigation and inorganic mulches might not be needed to grow some North American desert plants in southwest urban landscapes.

Index words: relative water content, sustainability, water management.

Species used in this Study: *Atriplex canescens* (Pursh.) Nutt.; *Encelia farinosa* (Torr. & A. Gray); *Opunita santa rita* (Griffiths & Hare) A. Rose.

Significance to the Nursery Industry

Use of desert native plants in landscapes throughout the southwestern United States is increasing in response to public demands for greater landscape water conservation. Desert-style landscapes in the Southwest are normally irrigated and covered with inorganic rock mulches such as decomposing granite. Presently there is limited information about the water and mulch requirements of native plants in southwest urban landscapes. This research showed that two North American desert native shrubs performed best under non-irrigated conditions and that transplant mortality of one of the these taxa, brittle bush, was exacerbated by treatments of organic mulch and drip irrigation. In contrast, the aesthetic appearance of non-irrigated Santa Rita prickly pear cactus was enhanced when surrounded by mulch consisting of recycled landscape tree trimmings. Results suggest that in the southwestern United States, the normal landscape practices of drip irrigation and inorganic mulching might not improve transplant establishment and sustainability of desert-style landscapes, especially in the case of some desert native plants.

Introduction

Public concerns about urban landscape sustainability has prompted cities in the southwestern United States to promote landscape water conservation through low water-use planting designs, drip irrigation and use of landscape mulches (17). During the last 10 years in particular, desert native shrubs and cacti are increasingly specificied by designers of urban landscape plantings in place of more traditional exotic landscape shrubs. Though earlier research reports have shown the mulch tolerances and irrigation requirements of some landscape plants from semi-arid and arid climates (6, 14, 18, 21, 22, 23), there are no reports about the effect of landscape mulches and drip irrigation rates on establishment and growth of North American desert native shrubs and cacti after planting.

Landscape mulches have been shown to moderate soil temperatures and lower soil water evaporation rates (3, 4, 8, 15, 20, 24). Landscape mulches are derived from a variety of organic and inorganic parent materials that can differentially affect plant growth (7, 10, 11). For example, growth of desert willow (*Chilopsis linearis*) was increased by gravel and tire mulches (13), but growth of five shrub species was not affected by use of pine bark mulch (9).

In the desert southwest, crushed stone, volcanic pumice, and especially decomposing granite are common landscape mulch materials that are often stipulated exclusively for landscape use by municipal ordinances (5). In contrast, use of organic-based mulch materials as landscape mulch in desert cities is uncommon, possibly because of misconceptions about their effectiveness under arid conditions. Recently however, desert soils covered with organic mulches were found to have lower water evaporation rates and less amplitude in the pattern of diel temperature flucuations than those covered with inorganic mulch (24).

Landscape plants in southwest cities are normally irrigated because annual potential evapotranspiration can be as much as 10 times higher than precipitation. During the last 20 years, drip irrigation has gained wide acceptance as an effective means of increasing landscape irrigation delivery efficiency compared with traditional overhead sprinkler irrigation (2). However, application rates of drip irrigation

[1]Received for publication February 18, 2009; in revised form April 14, 2009. This material is based upon work supported by the National Science Foundation under Grant No. DEB-0423704, Central Arizona — Phoenix Long-Term Ecological Research (CAP LTER). Any opinions, findings and conclusions or recommendation expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation (NSF). The authors gratefully acknowledge the donation of mulch products by DLC Resources Inc. (Phoenix, AZ) and Southwest Forest Products (Phoenix, AZ).

[2]Former Graduate Research Assistant.
[3]Professor. chris.martin@asu.edu

required to establish and grow desert native plant species is unknown. Moreover, the recent impetus on landscape water conservation and the recycling of forest and urban tree waste into urban landscapes has increased the need to know the combined effectiveness of different landscape mulches and drip irrigation rates on growth of desert native plants. Therefore, the objective of this research was to study responses of three North American desert native plants to a combination of landscape mulch and drip irrigation rate treatments.

Materials and Methods

Research was conducted over two years at an outdoor site in Phoenix, AZ, to determine responses of three North American desert native plants, four wing salt bush (*Atriplex canescens*), brittle bush (*Encelia farinosa*), and Santa Rita prickly pear cactus (*Opuntia santa rita*) to a combination of landscape mulch and drip irrigation rate treatments. Phoenix is situated on the northeast edge of the Sonoran Desert in the southwest United States. The Phoenix region is characterized by mild, variably moist winters and intense solar radiation and extreme heat from May through September during which daytime maximum temperatures can exceed 40C (104F) (19).

Species description. All three plants used in this research are native to desert regions of North America and are also found in landscapes in many cities of the desert Southwest. Four wing salt bush (family *Amaranthaceae*) is a Sonoran Desert native perennial shrub with an irregular and spreading habit to 2 m (6.5 ft) height and glaucous, lanceolate, simple leaves to 2.5 cm (1 in) in length. Brittle bush (family *Asteraceae*) is a Mojave and Sonoran Desert native perennial herb with a rounded and spreading habit to 1.5 m (5 ft) height, densely tomentose gray, deltoid shaped foliage to 5 cm (2 in) in length, and an array of colorful yellow flowers in spring. Santa Rita prickly pear (family *Cactaceae*) is a Chihuahuan and Sonoran Desert native cactus to 1.5 m (5 ft) height with round blue to reddish purple, padded stems and an upright and branching habit. In southwest landscape settings, prickly pear cacti are normally not irrigated.

Site description. An outdoor field site in Phoenix that consisted of 14 identical 9 × 9 m (30 × 30 ft) plots was established on level terrain with a homogenous soil type. Soil at the site was a Rillito series gravelly loam (pH = 8.1, C = 2500 mg·kg^{-1}, N = 230 mg·kg^{-1}, P = 240 mg·kg^{-1}) with a 0 to 1% slope. There was at least 1.5 m (5 ft) of space with no vegetation between each plot.

Experimental design. During January 2004, two salt bush and four brittle bush from 3.8 liter (1 gal) containers, and one prickly pear cactus were established at each plot at least 1.5 m (5 ft) apart. For the next two years, one-half of the four wing salt bush shrubs (one per plot) were subsequently drip irrigated weekly at the average rate of 2550 liters (674 gal) water·plant^{-1}·year^{-1}, an irrigation application rate that was similar to previously measured rates of drip irrigation applied to Phoenix residential landscapes (15). Additionally, one half of the brittle bush shrubs were drip irrigated weekly in the following manner: one-quarter of the brittle bush shrubs (one in each plot) were drip irrigated at the average rate of 2550 liters (674 gal) water·plant^{-1}·year^{-1}, and one-quarter of the brittle bush shrubs (one in each plot) were drip irrigated at the average rate of 1275 liters (337 gal) water·plant^{-1}·year^{-1}. Drip irrigation was applied to plants by two 3.8 liter (1 gal)·hr^{-1} emitters positioned beneath the mulch cover after mulch application. Drip irrigation volumes were recorded by totalizing water meters (Precision Meters, Orlando, FL). The remaining salt bush and brittle bush shrubs (one and two per plot, respectively) were hand watered once after transplanting, but otherwise were not irrigated during the course of the study (non-irrigated control treatment). Prickly pear cacti established in each plot were also not irrigated. During the length of the study, all shrubs received no supplemental fertilizers and all plots were hand weeded.

During April 2004, four landscape surface mulches, shredded urban landscape tree trimmings (LTT) from a local landscape management company, composted ponderosa pine residue (PPR) from timber operations on the Mogollon Rim region in central Arizona, Red Mountain Coral decomposing granite (DG) quarried locally from the Salt River drainage, and a no mulch control were applied to plots in an unbalanced completely randomized design; n = 4 for LTT, PPR, and DG mulches; n = 2 for no mulch control. All mulches were applied to a depth of 5 cm (2 in) because local ordinance stipulate that depth for new landscape installations (16). For each mulch type, initial bulk density, organic C and N content were determined (Table 1). Organic C content was determined by combustion method (12) and total P content was determined by dry-ash method (IAS Laboratories, Phoenix, AZ).

Evaluations of percent relative water content (RWC) of four wing salt bush leaves were made seasonally during the spring, summer and fall of 2004 and 2005. Evaluations of the RWC of prickly pear cactus padded stem segments were made only during the fall of each year instead of seasonally due to the limited number of stem segments on each cactus. To determine percent RWC, three recently mature leaves or padded stem segments per plant were harvested at dawn. Leaves or padded stems segments were then weighed as soon as possible for an initial fresh mass after harvest (FM). Leaves or padded stem segments were then floated in water for 24 hr (48 hr for prickly pear cactus stems) at room temperature and weighed for fully turgid mass (SM). Finally, leaves or padded stem segments were dried at 65C (149F) (four wing salt bush leaves for 72 hr; prickly pear cactus stem segments for 28 days) and weighed for dry mass (DM). Percent leaf RWC was calculated according to the formula:

Table 1. Initial physical (± SE) and chemical properties including particle size, bulk density, organic carbon, nitrogen and total phosphorous content of landscape tree trimming (LTT), ponderosa pine residue (PPR) and decomposing granite (DG) mulches.

Mulch	Particle size	Bulk density (g·cm^{-3})	C (%)	N (%)	P (%)
LTT	1.9 cm (0.7 in) minus, unscreened	0.24 (0.08)	48.0	0.97	0.09
PPR	1.9 cm (0.7 in) minus, screened	0.25 (0.08)	54.0	0.15	0.06
DG	0.6 cm (0.2 in) minus, screened	1.69 (0.07)	0.2	0.07	0.07

$$RWC = (FM - DM) \div (SM - DM) \times 100$$

No evaluations of brittle bush leaf RWC were made because leaf surfaces of this shrub are highly tomentose and are resistant to forced hydration.

Volumetric soil water content (VWC) was recorded monthly during March to June 2005 in all 14 plots using a Field Scout TDR 100 soil moisture probe (Spectrum Technologies, Plainfield, IL). The soil moisture probe was inserted vertically into non-irrigated portions of soil in each plot to a depth of 12 cm (5 in). Nine measurements were made per plot in three north-south transects.

Growth of four wing salt bush and brittle bush shrubs was evaluated in December 2005. Growth evaluations included measurements of plant height (h) and diameter of spread in two cardinal directions (w1 and w2) after which shoots were harvested, dried at 65C (149F) for 72 hr and weighed. A growth index (GI) was calculated for each shrub as:

$$GI = (h + w_1 + w_2) \div 3$$

Counts of mortality for both shrub taxa were made when shoots were harvested.

Statistical analysis. The experimental design used for analyses of data varied by research question and treatment structure because of the mixed arrangement of the treatments. An analysis of variance (ANOVA) was calculated for all data using a general linear model (JMP 5.0.1, SAS Institute Inc, 2002). A two-factor split plot design was used in analysis of the effects of landscape surface mulches (whole unit) and irrigation (subunit) treatments on dependent variable responses of four wing salt bush and brittle bush. The whole units were arranged in a completely randomized design structure. The subunits were arranged in an incomplete block design structure with levels of irrigation randomly assigned within mulched landscape plots. Where drip irrigation was not applied, a completely randomized design structure was used in analysis of the effects of landscape mulches on prickly pear padded stem segment RWC and non-irrigated soil VWC. A two-way multivariate model with surface mulch treatment, irrigation treatment and the interaction of mulch and irrigation treatments as independent variables was used for statistical comparisons of four wing salt bush leaf RWC as well as four wing salt bush and brittle bush growth indices and shoot dry mass. A one-way univariate model with landscape mulch type as the independent variable was used for statistical comparisons of prickly pear cactus padded stem segment RWC and VWC. If significantly different ($P \leq 0.05$), then dependent variable mean values were separated using Tukey's HSD multiple comparisons test ($\alpha = 0.05$).

Results and Discussion

Total rainfall and potential evapotranspiration during April 2004 to October 2005 were 499 and 3371 mm (19.6 and 132.7 in), respectively (1). Rainfall during the El Nino enhanced winter (November 2004 to February 2005) was 232.7 mm (9.33 in). In contrast, there was only 15.5 mm (0.06 in) of rainfall during March to June 2005. In March 2005, immediately after the cessation of the El Nino enhanced winter rains, soils under organic mulches had the highest VWC (Table 2). During April and May 2005, VWC was higher beneath all mulched surfaces compared to soil without mulch. By June 2005, VWC of all soils at 12 cm (5 in) depth and not effected by drip irrigation placement had dried to less than 10%.

There was an interactive effect of mulch and drip irrigation treatments on relative leaf water content of four wing salt bush during April, July and October of 2004 and 2005 (Tables 3 and 4). During 2004, leaf RWC was lowest for irrigated non-mulched four wing salt bush during April and July (Table 3). However, during October 2004 relative leaf water was lowest for irrigated four wing salt bush mulched with DG and for non-irrigated four wing salt bush mulched with PPR. During 2005, leaf RWC was lowest for irrigated four wing salt bush mulched with DG during April (Table 4). However, during July and October leaf RWC was lowest for irrigated salt bush mulched with DG or with no mulch and non-irrigated salt bush mulched with PPR. In contrast, four wing salt bush mulched with LTT, whether irrigated or

Table 2. Effect of landscape mulch treatment on mean soil volumetric water content (VWC), March to June, 2005. Landscape mulch treatments were landscape tree trimmings (LTT), ponderosa pine residue (PPR), decomposing granite (DG), or soil without a mulch cover (control).

	VWC (%)			
Mulch	March	April	May	June
LTT	20[z]a[y]	16a	11a	7ab
PPR	20a	15a	11a	6b
DG	17b	15a	12a	7a
Control	14b	10b	9b	6b

[z]Values are treatment means; n = 36 for LTT, PPR, and DG; n = 18 for control.

[y]Mean values within the same column followed by the same letter were not significantly different, using Tukey's HSD test ($\alpha = 0.05$).

Table 3. Effect of landscape mulch and irrigation treatments on mean percent leaf relative water content (RWC) of four wing salt bush during April, July and October 2004. Landscape mulch treatments were landscape tree trimmings (LTT), ponderosa pine residue (PPR), decomposing granite (DG) or soil without a mulch cover (control).

		Four wing salt bush leaf RWC (%)		
Mulch	Irrigation (L/plant/year)	April	July	October
LTT	2550 (674 gal)	77.9[z]a[y]	66.7a	81.8a
	0	79.7a	61.5a	81.1a
PPR	2550 (674 gal)	75.3a	66.4a	81.9a
	0	70.2a	60.2a	71.9b
DG	2550 (674 gal)	75.9a	69.4a	73.1b
	0	77.7a	66.4a	84.6a
Control	2550 (674 gal)	67.7b	59.7b	80.6a
	0	80.8a	74.3a	82.7a
P-values				
Mulch		0.0346	0.2169	0.2743
Irrigation		0.0898	0.9894	0.7333
Mulch × Irrigation		0.0096	0.0026	0.0011

[z]Values are treatment means; n = 12 for LTT, PPR, and DG; n = 6 for control.

[y]Mean values within the same column followed by the same letter were not significantly different for irrigation treatment by mulch treatment using Student's *t* test ($\alpha = 0.05$).

Table 4. **Effect of landscape mulch and irrigation treatments on mean percent leaf relative water content (RWC) of four wing salt bush during April, August and October 2005. Landscape mulch treatments were landscape tree trimmings (LTT), ponderosa pine residue (PPR), decomposing granite (DG), or soil without a mulch cover (control).**

Mulch	Irrigation (L/plant/year)	Four wing salt bush leaf RWC (%)		
		April	August	October
LTT	2550 (674 gal)	79.4[z]a[y]	66.8a	67.5a
	0	76.6a	67.4a	68.8a
PPR	2550 (674 gal)	76.3a	67.0a	71.9a
	0	77.5a	60.1b	62.7b
DG	2550 (674 gal)	67.4b	62.2b	64.8b
	0	74.6a	70.8a	78.5a
Control	2550 (674 gal)	75.9a	62.5b	67.3b
	0	71.0a	76.8a	81.3a
P-values				
Mulch		<0.0001	0.1987	0.0727
Irrigation		0.8728	0.0046	0.0143
Mulch × Irrigation		0.0012	0.0008	<0.0001

[z]Values are treatment means; n = 12 for LTT, PPR, and DG; n = 6 for control.

[y]Mean values within the same column followed by the same letter were not significantly different for irrigation treatment by mulch treatment using Student's *t* test (α = 0.05).

not, or four wing salt bush irrigated and mulched with PPR always had the highest leaf RWC both years.

At the end of 2004 growing season padded stem RWC of Santa Rita prickly pear was not affected by mulch treatment (Table 5). By the end of the 2005 growing season, however, Santa Rita prickly pear mulched with LTT had significantly higher padded stem segment RWC than those growing without mulch, although similar to plants growing in PPR and DG (Table 5).

At the end of the study, shoot growth of brittle bush, four wing salt bush or Santa Rita prickly pear were not affected by mulch treatment ($P > 0.431$, 0.325, or 0.672, respectively; data not shown). Independent of mulch treatment, non-irrigated brittle bush and four wing salt bush had the greatest shoot mass (Table 6). In addition, non-irrigated brittle bush had the greatest growth index.

No four wing salt bush or Sant Rita prickly pear cacti died during the two-year study. Also, there was no death of brittle bush shrubs in plots covered with the DG mulch. In contrast, 13% of the brittle bush grown without mulch died while those mulched with either LTT or PPR had 44 and 38% mortality, respectively. Irrespective of mulch treatment, brittle bush plants irrigated at rates of 2550 liters (674 gal)·plant^{-1}·year^{-1} or 1275 liters (337 gal)·plant^{-1}·year^{-1} had a 36% mortality rate while only 14% of non-irrigated brittle bush died.

It is generally accepted that use of mulch increases soil moisture by reducing evaporation and increasing water infiltration (3), and many studies support this supposition about organic (11, 20) and inorganic mulches (11, 13, 15). Our findings showed that even after abnormally heavy El Nino winter rains in 2005, landscape mulches in a desert region were able to conserve soil moisture derived from rainfall for at least three months. Otherwise, one should expect that landscape mulches in desert regions will conserve soil moisture only if usually light desert rains can penetrate the mulch layer or if irrigation is used in the landscape.

Table 5. **Effect of landscape mulch treatment on mean padded stem segment percent relative water content (RWC) of Santa rita prickly pear cactus during November of 2004 and 2005. Landscape mulch treatments were landscape tree trimmings (LTT), ponderosa pine residue (PPR), decomposing granite (DG), or soil without a mulch cover (control).**

Mulch	Cactus padded stem segment RWC (%)	
	2004	2005
LTT	87.1[z]a[y]	89.7a
PPR	87.3a	86.0ab
DG	84.6a	83.3ab
Control	80.7a	76.3b

[z]Values are treatment means; n = 12 for LTT, PPR, and DG; n = 6 for control.

[y]Mean values within the same column followed by the same letter were not significantly different, using Tukey's HSD test (α = 0.05).

In an effort to conserve water in the urban desert, many municipalities in the Phoenix area encourage residents to limit water use by installing drip irrigation systems, planting low-water use plants and indigenous plants adapted to harsh desert conditions in their yards, and covering landscaped surfaces with inorganic decomposing granite mulches. Our results for brittle bush or four wing salt bush support the earlier findings of Hild and Morgan (9) and suggest that these two North American desert taxa benefit little from use of landscape mulch, and in fact supplemental organic mulches and/or drip irrigation appear to decrease brittle bush landscape fitness. In contrast, aesthetic appearance of Santa Rita prickly pear cactus quantified by padded stem RWC, was improved by use of recycled landscape tree trimmings.

In summary, we found that three North American desert taxa responded dissimilarly to drip irrigation and landscape mulches. Unlike common recommendations (4), applications of drip irrigation and mulch were detrimental to survivability and growth of brittle bush and four wing salt bush. In contrast, growth and appearance of non-irrigated Santa Rita prickly pear cacti were improved by applications of LTT mulch. Results suggest that in the southwestern United States, the normal practices of drip irrigation and inorganic mulching might not improve transplant establishment and sustainability of desert-style landscapes (17), especially in the case of some desert native plants. Additional research efforts are needed to determine the propensity of organic

Table 6. **Effect of drip irrigation rate on mean final harvest growth index [$(h + w_1 + w_2) \div 3$] and total shoot dry mass of brittle bush and of four wing salt bush.**

Plant	Irrigation (L/plant/yr)	Growth index	Shoot mass (kg/plant)
Brittle bush	0	0.98[z]a[y]	0.77a
	1275 (337 gal)	0.59b	0.26b
	2550 (674 gal)	0.63b	0.43b
Four wing salt bush	0	1.12a	1.13a
	2550 (674 gal)	0.90a	0.61b

[z]Values are treatment means; n = 14, except for non-irrigated plants where n = 28.

[y]Mean values by species within the same column followed by the same letter were not significantly different, using Tukey's HSD test (α = 0.05).

mulches to transmit and foster plant pathogens that might in turn cause taxa-specific mulch mortality.

Literature Cited

1. Arizona Meteorological Network (AZMET). Extension Biometeorology Program. College of Agriculture, University of Arizona Cooperative Extension. Accessed April 16, 2009. http://ag.arizona.edu/AZMET/

2. Ayars, J.E., C.J. Phene, R.B. Hutmacher, K.R. Davis, R.A. Schoneman, S.S. Vail, and R.M. Mead. 1999. Subsurface drip irrigation of row crops: A review of 15 years of research at the Water Management Research Laboratory. Agric. Water Management 42:1–27.

3. Brady, N.C. and R.R. Wiel. 2002. The Nature and Properties of Soils. Prentice Hall. Upper Saddle River, NJ.

4. Chalker-Scott, L. 2007. Impact of mulches on landscape plants and the environment — a review. J. Environ. Hort. 25:239–249.

5. Code of the City of Phoenix, Arizona. Chapter 6: ZONING DISTRICTS. Accessed April 16, 2009. http://phoenix.gov//ZONING/ch006.html

6. Costello, L.R., K.S. Jones, and D.D. McCreary. 2005. Irrigation effects on the growth of newly planted oaks (*Quercus.* spp.). J. Aboriculture 31:83−88.

7. Foshee, W.G., W.D. Goff, K.M. Tilt, J.D. Williams, J.S. Bannon, and J.B. Witt. 1996. Organic mulches increase growth of young pecan trees. HortScience 31:811−812.

8. Harris, R.W., J.R. Clark, and N.P. Matheny. 2004. Arboriculture: Integrated Management of Landscape Trees, Shrubs, and Vines. 4th Ed. Prentice Hall, Upper Saddle River, NJ. 580 pp.

9. Hild, A.L. and D.L. Morgan. 1993. Mulch effects on crown growth of five southwestern shrub species. J. Environ. Hort. 11:41–43.

10. Holloway, P.S. 1992. Aspen wood chip and stone mulches for landscape plantings in Interior, Alaska. J. Environ. Hort. 10:23–27.

11. Iles, J.K. and M.S. Dosmann. 1999. Effect of organic and mineral mulches on soil properties and growth of Fairview Flame® red maple trees. J. Arboriculture 25:163−167.

12. Kowalenko, C.G. 2001. Assessment of Leco CNS-2000 analyzer for simultaneously measuring total carbon, nitrogen, and sulphur in soil. Comm. Soil Sci. Plant Anal. 32:13−14.

13. Kraus, H.T. 1998. Effects of mulch on soil moisture and growth of desert willow. HortTechnology 8:588–590.

14. Levitt, D.G., J.R. Simpson, and J.L.Tipton. 1995. Water use of two landscape tree species in Tucson, Arizona. J. Amer. Soc. Hort. Sci. 120:409−416.

15. Li, X.-Y. 2003. Gravel-sand mulch for soil and water conservation in the semiarid loess region of northwest China. Catena 52:105–127.

16. Maricopa Association of Governments. Uniform standard specifications for public works construction. Accessed April 16, 2009. http://www.mag.maricopa.gov/archive/PUB/Document/metric.PDF

17. Martin, C.A. 2008. Landscape sustainability in a Sonoran Desert city. Cities and the Environment 1(2), Article 5:1–16.

18. Martin, C.A. and J.C. Stutz. 1994. Growth of argentine mesquite inoculated with VAM fungi. J. Arboriculture 20:134–138.

19. National Oceanic & Atmospheric Administration (NOAA). National Weather Service Forecast Office Phoenix, Arizona. Accessed April 16, 2009. http://www.wrh.noaa.gov/psr/

20. Pickering, J.S., A.D. Kendle, P. Hadley. 1998. The suitability of composted green waste as an organic mulch: effects on soil moisture retention and surface temperature. Acta Hort. 469:319–324.

21. Pittenger, D.R., D.A. Shaw, D.R. Hodel, and D.B. Holt. 2001. Responses of landscape groundcovers to minimum irrigation. J. Environ. Hort. 19:78–84.

22. Schuch, U.K. and D.W. Burger. 1997. Water use and crop coefficients of woody ornamentals in containers. J. Amer. Soc. Hort. Sci. 122:727–734.

23. Shaw, D.A. and D.R. Pittenger. 2004. Performance of landscape ornamentals given irrigation treatments based on reference evapotranspiration. Acta Hort. 664:607–613.

24. Singer, C.K. and C.A. Martin. 2008. Effect of landscape mulches on desert landscape microclimates. Arboriculture and Urban Forestry 34:230–237.