Stormwater Irrigation

A comparison of soil moisture at curb cuts with and without rain gardens

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During recent decades there has been a growing national recognition that shrubs and trees in urban landscapes have both environmental and socioeconomic value. Research has shown that vegetation along streets and parking lots can lower urban temperatures and energy consumption (Halverson and Heisler 1981, Scott et al. 1999); filter, degrade, and accumulate stormwater contaminants (Peer et al. 2005); and positively influence customer behavior by enhancing aesthetics of building exteriors (Wolf 2005).

Research by the city of Albuquerque Parks Department revealed that for every dollar spent in public tree maintenance, \$1.31 in benefits was returned from tree canopy in the form of carbon sequestration, air quality improvements, reduced energy consumption, etc. (Vargas et al. 2006). Despite this, adoption of urban forestry by municipalities and commercial developers in semiarid regions can be hindered by the high costs of irrigation and public concern over potable water use for landscaping during times of drought.

One potential method to conserve water resources is through the establishment of rain gardens that harvest stormwater as passive irrigation from streets and parking lots. Questions exist as to whether these basins can supplement vegetation year-round in the absence of irrigation systems. To assess the efficacy of basins at improving passive irrigation for plants, volumetric water content (VWC) was monitored at two curb cuts with (treatment) rain gardens and two curb cuts without (control) rain gardens at the Santa Fe Community College (SFCC, Figure 1).

Figure 1. ***Left:*** **Example of a curb cut without a rain garden (control);** ***Right:*** **Curb cut with a rain garden (treatment). Each drains stormwater from approximately 3,500 square feet of parking lot.**

Study Area and Methods

Santa Fe, NM, is a high elevation (~7,000 feet), semi-arid community in the southwestern part of the United States. Average annual high and low temperatures for the area are 65.0°F and 34.8°F (US Climate Data 1981–2010). Precipitation measurements vary for the region from 9.53 inches per year (Western Regional Climate Center 1941–2016) at the Santa Fe Airport 9.5 miles west of the city center to 14.21 inches per year (US Climate Data 1981–2010) at the Santa Fe 2 weather station 5.5 miles south of the city center. Differences in precipitation measurements could be a consequence of the increasing influence of orographic factors caused by the Sangre de Cristo Mountains to the east. For comparative purposes in this study, average monthly precipitation data estimates from the Santa Fe 2 gauge were used because of the station's closer proximity to the study site at SFCC. (The college is 1.85 southwest of Santa Fe 2 and 4.75 miles southeast of the Santa Fe Airport.)

This study was conducted at the Kids' Campus asphalt parking lot located at SFCC. The parking lot was approximately 25,000 square feet with seven curb cuts along the western edge that each drain about 3,500 square feet. Historically, stormwater was allowed to exit the curb cuts onto mild slopes (less than 5%) with a mixture of native grasses. Soils in the area are generally described as Alire loam, a classification predominantly composed of clay loam textures in the top 30 inches of a typical profile (USDA: NRCS Web Soil Survey, June 2015).

In October 2012 and April 2013, rain gardens were excavated by high school students to capture stormwater from two of the parking lot curb cuts. Excavated soil was placed around the sides and downslope perimeter of the rain garden as a berm to retain stormwater. The berm was shaped to 3:1 slopes before being walked on for compaction, seeded with wildflowers and grasses, and mulched with 4- to 8-inch cobble. The berm perimeter left an interior stormwater pooling area roughly 15 feet by 10 feet by 1 foot, for a maximum open-volume catchment (i.e., not including soil porosity) of 1,122 gallons. Over the course of a year with an average of 14.21 inches of precipitation and a runoff coefficient of 0.8, it is expected that each curb cut would drain approximately 24,800 gallons of stormwater runoff.

Basin bottoms were mulched with 3 inches of wood chips mixed with composted soil and planted with six 1-gallon plugs of little bluestem grass (*Schizachyrium scoparium*) tolerant to temporary inundation by water. Berms were planted with 1-gallon shrubs and 5-gallon trees including three-leaf sumac (*Rhus trilobata*), false indigo (*Amorpha fruticosa*), and a 1-inch-diameter Patmore green ash (*Fraxinus pennsylvanica*) or honey locust (*Gleditsia triacanthos*). Plant species were selected because they are known to be drought tolerant, provide pollinator habitat, have demonstrated ability to remediate common stormwater pollutants, and are native or adapted to the

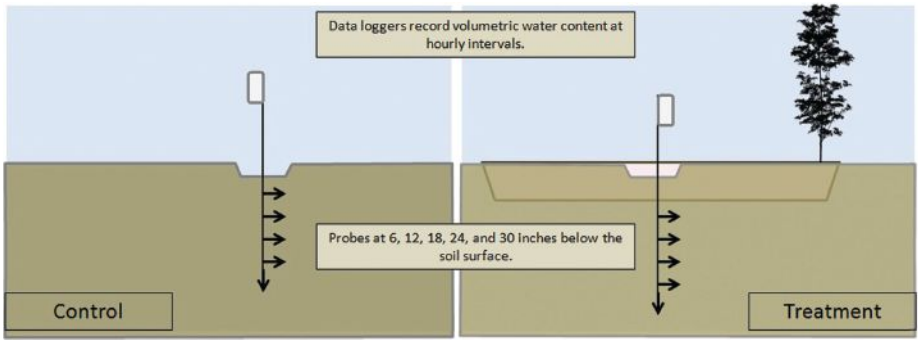

Figure 2. Soil moisture probe installation in a soil profile predominantly composed of clay loam. Probes were installed 13 feet from two curb cuts without a rain garden (controls) and 13 feet from two curb cuts with a rain garden (treatments).

regional climate without being invasive. Curb cuts without rain gardens were allowed to maintain existing plant cover such as blue grama (*Bouteloua gracilis*) and other drought-tolerant grasses and forbs. Supplemental irrigation was not provided to plants during soil moisture measurement periods (September 2014–August 2015).

A 5-inch-diameter auger was used to drill holes in the soil profile 13 feet from the curb edge at each of the control and treatment points. Decagon 5TM soil moisture probes were inserted into the soil profile at 6, 12, 18, 24, and 30 inches below the soil surface at each point for a total of 20 probes (i.e., four sample points with five probes each) before soil was refilled to a similar bulk density (Figure 2). The probes below 18 inches were expected to account for soil moisture beyond the influence of evaporation and potentially available for deeper-rooted shrubs and trees. Measurements of VWC for each probe were recorded hourly (8,760 measurements per probe) with Decagon EM50 data loggers. To assess whether VWC varied relative to soil depth, season, and treatment, data were pooled by curb cuts with and without rain gardens before averaging by treatment depths, months, across the year of measurements. An Onset tipping bucket rain gauge was also installed at the site to provide estimates of soil moisture responses to daily precipitation events and total precipitation depth by month.

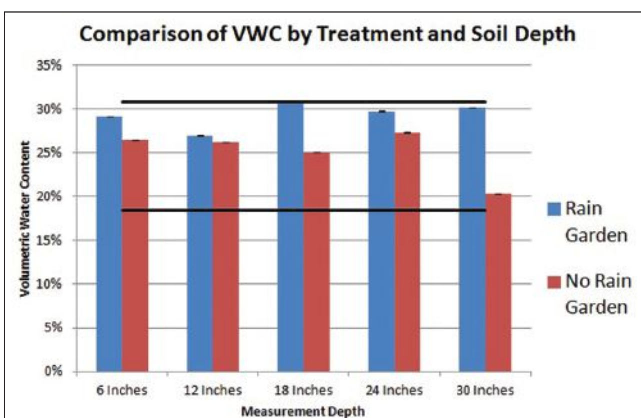

Figure 3. Average annual VWC by depth for curb cuts with (treatment) and without (control) rain gardens (α =10). Soil moisture would be expected to be even lower than the controls along streets and parking lots that do not have any form of curb cut used as drainage. Horizontal lines at 31% and 18% are field capacity and permanent wilting point, respectively, for a clay loam soil (Ratliff et al. 1983).

Results and Discussion

Soil Moisture Relative to Soil Depth. Average annual VWC at 6-inch incremental depths for soil profiles with and without a rain garden is displayed in Figure 3. Soil moisture increased by 10, 3, 23, 9, and 49% at each 6-inch increase in depth within the rain gardens compared to corresponding depths at curb cuts without rain gardens. The primary reason for improvements in soil moisture is believed to be a consequence of slowing and pooling stormwater in the rain gardens. By increasing the residence time of runoff in the basins, stormwater was given the opportunity to infiltrate the soil surface and percolate to lower depths. Enhancements in soil moisture within the rain gardens might also be a function of the wood mulch layer on the soil surface reducing evaporative loss and improving soil structure as the organic matter decomposed.

The increases in soil moisture measured at each depth in the rain gardens could be beneficial to current and future plant growth. According to Ratliff et al. (1983), field capacity (i.e., the maximum VWC a soil texture can hold against gravity) for a clay loam soil is 31%, while the permanent wilting point (i.e., the VWC at which plants struggle to or cannot extract water from a soil texture) is 18%. The median of these two values (24.5%) is often used as a threshold for landscapers to begin irrigating plants. Average VWC across the entire 30-inch profile in the rain gardens was 29.4%. VWC was particularly enhanced at 18, 24, and 30 inches (30.8, 29.8, and 30.2%, respectively). Plant available water content at these depths was essentially maximized for the year, leaving a reservoir of soil moisture accessible for shrubs and trees to utilize as they mature and become more deeply rooted. In the case of the control sites, average annual VWC across the 30-inch soil profile (25.1%) was barely over the median point for initiating irrigation, and plant available water content at 30 inches (20.4%) was nearly depleted.

Results indicate that opportunities to establish more deeply rooted vegetation at the controls, similar to species planted around the rain gardens, could be limited without supplemental irrigation. It is important to note while the controls would likely require irrigation during the year to maintain more deeply rooted plants, VWC is probably still higher than soil profiles next to most city curbs. This is because streets and parking lots typically have storm drains that convey stormwater through pipes instead of curb cuts that allow for some moistening of soils adjacent to an impervious surface. Insufficient funding did not allow for monitoring VWC in soils without curb cuts.

Monthly and Seasonal Soil Moisture. In addition to understanding where water is stored in the soil profile for extraction by plant roots, determining how VWC fluctuates by season could provide information whether plants require irrigation at certain times of the year. Whereas cool months might provide opportunities for recharging soil moisture while plants are dormant, warmer months could deplete soil

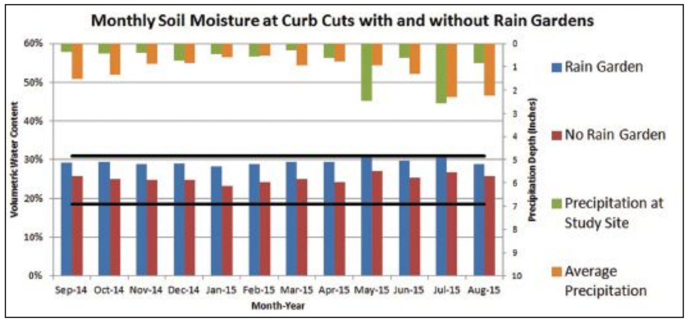

Figure 4. Monthly VWC for curb cuts with (treatment) and without (control) a rain garden. Average monthly precipitation is based on records from the Santa Fe 2 weather station (US Climate Data 1981-2010).

moisture due to higher evapotranspiration (ET) rates. A rain gauge at the study site recorded a total of 10.26 inches of precipitation between September 1, 2014, and August 31, 2015. This amounted to 72% of the long-term average of 14.21 inches per year. Despite reduced precipitation, average VWC in the rain gardens was maintained above the 24.5% irrigation threshold for every month of measurements (Figure 4).

Similar to VWC measurements at various depths over the course of the year, monthly soil moisture measured in rain gardens was consistently higher compared to soil moisture at curb cut locations without basins. The lowest average VWC for a month for both treatment and control areas was January. VWC for the month was maintained at 28.3% in the rain gardens versus 23.2% at the curb cuts without a rain garden. While neither value was assumed to jeopardize plant growth at the time due to cool-season dormancy, the maintenance of higher soil moisture during cool months could be crucial to plants as they emerge in the spring. In the case of the rain gardens, VWC was maintained above 24.5% in the rain gardens leading up to leafing times in April. At the curb cuts without rain gardens, however, monthly VWC ranged between 23.2 and 24.9% from January through April, meaning irrigating plants would have been recommended as temperatures warmed in the spring.

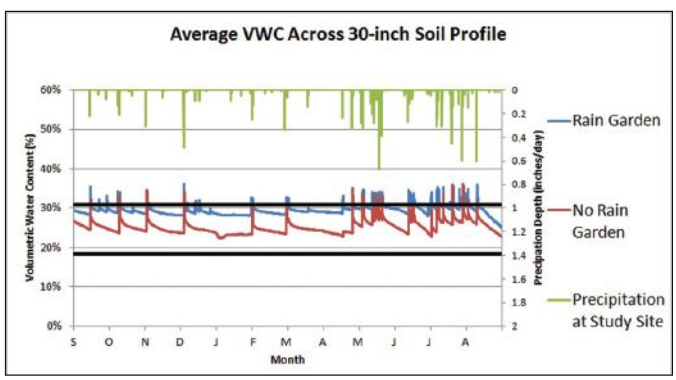

Figure 5. Hourly VWC (with corresponding daily precipitation included in green) for curb cuts with (treatment) and without (control) a rain garden

As temperatures rise in late spring and early summer, ET rates are assumed to also increase. Extraction of water from soil by plants without replenishment by precipitation can result in permanent wilting point being reached in soils. May and June in Santa Fe are typically dryer than subsequent warm-season months which receive increased monsoonal rains starting in July. May 2015 was unusually wet, having received 2.47 inches at the study site (0.94 inches on average). This increase in rainfall resulted in higher VWC than winter months in both treatments and controls. VWC was 30.7 and 27.0%, respectively, which would have eliminated the need to irrigate plants during May. Despite improved conditions, VWC in the controls quickly subsided to 25.2% in June, which received 0.63 inch, about half the normal precipitation for the month (1.30 inches on average). This dip in plant available soil moisture approached the aforementioned threshold of 24.5% during which many landscapers initiate irrigation to sustain vegetation. Soil moisture in the rain gardens, however, remained near field capacity at 29.8%, effectively eliminating the need to irrigate plants during a hot and drier-than-normal month.

The height of the monsoon season (July, August) in Santa Fe typically receives 4.56 inches of rainfall, which makes up 32% of annual precipitation (US Climate Data 1981–2010). The study site received higher-than-normal precipitation for July (2.57 in.) and less-than-normal for August (0.84 in.), for a total of 3.41 inches (only 75% of normal). The extra precipitation in July resulted in VWC for the rain gardens being maintained near field capacity at 30.8% before dropping to 28.8% in August. Despite lower anticipated transpiration rates at the controls due to having only shallow-rooted grasses and forbs, VWC was held at 26.7 and 25.8% for July and August. Results suggest that the higher VWC in the rain gardens, compared to the controls, could improve plant growth during the height of the growing season.

Soil Moisture Responses to Precipitation Events. Dividing VWC across months presents an understanding about seasonal shifts in soil moisture, but hourly measurements of VWC could assist in providing information about how soil moisture responds to individual precipitation events. Hourly VWC averaged across all depths was charted for treatment and control sites and compared to daily precipitation for the period of study. There were 82 days of measureable precipitation at the study site with amounts ranging 0.01–0.67 inch. As shown in Figure 5, not only was soil moisture consistently higher in the rain gardens between storm events, but spikes above field capacity (i.e., 31%) as a response to precipitation were more frequent.

Spikes in VWC above field capacity indicate that the soil was saturated, and thus excess water could move deeper in the soil profile under gravity. In essence, water was percolating beyond the soil depths influenced by ET and potentially toward the aquifer. Of the 82 measured precipitation events, soil moisture exceeded field capacity roughly 32 times (39%) in the rain gardens, versus 16 times (20%) in the controls. Whereas a storm as small as 0.02 inch resulted in saturation across the soil profile in the rain gardens, at least one storm greater than 0.25 inch never caused the soil to become saturated in the controls. Results suggest that not only is maximum plant available water content being replenished more regularly in treatments compared to controls, but also excess water from small events could be creating a column of soil moisture that helps recharge the aquifer.

Conclusion and Management Implications

In many communities, stormwater from impervious surfaces is treated as a pollutant to be expelled from an area. Rain gardens could help redefine stormwater as a valuable resource in semiarid regions for irrigation of trees in urban landscaping. VWC monitored at curb cuts with and without rain gardens in Santa Fe indicated that soil moisture was significantly improved at multiple depths and by season. Enhancements in soil moisture in rain gardens could potentially sustain vegetation for extended periods without precipitation and thus reduce the burden on potable water sources for irrigation in urban settings. Rain gardens also led to soils becoming saturated more frequently than at comparable sites without basins, possibly resulting in increased aquifer recharge. Continued examination of VWC over additional years and during periods of severe drought is recommended to determine whether rain gardens are a viable solution for street-side landscaping over the long term.

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