Stormwater Irrigation: Can Retention Basins Significantly Improve Soil Moisture?

July 2015

Aaron Kauffman, Southwest Urban Hydrology LLC

The following report was completed for the Soil and Water Conservation Commission with funding from the Water Quality Conservation Grant Program. Administrative support and project collaboration was provided by the Santa Fe-Pojoaque SWCD.

Abstract

Vegetation planted around rain gardens and bio-retention basins presents an opportunity to remediate stormwater pollutants, diversify habitat, and improve community aesthetics in urban settings. In semi-arid regions where water resources are scarce however, it is unclear whether stormwater captured in these basins is sufficient to sustain plant growth without supplemental irrigation. This study examined whether soil moisture could be significantly improved at parking lot curb cuts with rain gardens compared to curb cuts without rain gardens. Results from nine months of monitoring indicate that average volumetric water content of soils in rain gardens significantly increased at multiple depths over areas without rain gardens. Enhancements in soil moisture in rain gardens could potentially sustain vegetation for extended periods without precipitation and thus reduce the burden on potable and effluent water sources for irrigation in urban settings.

Introduction

During recent years there has been a growing national recognition that shrubs and trees in urban landscapes have both environmental and commercial value. Research has shown that vegetation along streets and parking lots can lower urban temperatures and energy consumption; filter, degrade, and accumulate stormwater contaminants; and positively influence consumer behavior by enhancing aesthetics to building exteriors. Research by the city of Albuquerque Parks Department revealed that for every dollar spent in public tree maintenance, $1.31 in benefits were returned from tree canopy in the form of carbon sequestration, air quality improvements, reduced energy consumption, etc (Vargas et al. 2006). Despite these benefits, adoption of urban forestry by municipalities and commercial developers in the arid Southwest can be hindered by the high costs of irrigation and public concern over potable water use during times of drought. For example, between 2007 and 2012 water use by the city of Santa Fe Parks Division averaged 101.8 million gallons/year while irrigation costs amounted to $1.35 million/year (Santa Fe New Mexican, April 14, 2013).

One potential method to alleviate water consumption could be through the establishment of rain gardens and bio-retention basins that harvest stormwater as passive irrigation for urban forestry projects. Questions remain however, as to whether these basins can supplement vegetation year-round in the absence of irrigation systems.

Objectives

To assess the efficacy of basins at improving passive irrigation for plants, volumetric water content (VWC) was monitored at curb cuts with and without rain gardens at the Santa Fe Community College. Specific research questions addressed included:

- Is VWC in the soil profile significantly different between curb cuts without rain gardens (i.e. controls) and curb cuts with rain gardens (i.e. treatments)?
- Is there a significant difference in VWC at varying depths of the soil profile?
- How does the VWC in the soil profile vary in time?
- How does precipitation drive VWC fluctuations at varying depths and treatments?

Study Area

The Kids' Campus asphalt parking lot at the Santa Fe Community College is approximately 25,000 square feet with seven evenly spaced curb cuts on the western edge that serve as drainage. Historically stormwater was allowed to exit the curb cuts onto mild slopes (less than 5%) with a mixture of native grasses. Soils are generally described as Alire loam which includes a well drained mixture of loams and clay loams in the first 45 inches of a typical profile (USDA: NRCS Web Soil Survey).

In October of 2012 and April 2013 two rain gardens were constructed to harvest stormwater from parking lot curb cuts. The dimensions of the basins are approximately 15'x10'x1' for a maximum catchment volume of 1,122 gallons. Over the course of a year with 12 inches of precipitation and no individual storms exceeding one inch, it is expected that the basins would harvest at least 13,464 gallons of stormwater runoff. Basin bottoms were mulched with three inches of wood chips and planted with grasses tolerant of temporary inundation by water. Basin berms were planted with shrubs and trees including Three-leaf sumac (*Rhus trilbata*), False indigo (*Amorpha fruticosa*), Patmore green ash (*Fraxinus pennsylvanica*) and Honey locust (*Gleditsia triancanthos*). Vegetation selection criteria was based on plants that were drought tolerant, helped improve pollinator habitat, demonstrated ability to remediate common stormwater pollutants, and were native or adapted to the region without being invasive. Supplemental irrigation was not provided to plants during soil moisture monitoring (i.e. August 2014-June 2015).

Field Methods

On August 23, 2014 5-inch diameter holes were augured 13 feet west of four curb cuts draining the Kids' Campus parking lot. Two of the holes were created in undisturbed native grasses (Control) and two were excavated in the bottom of the rain gardens (Treatment). The holes were augured 30-inches in depth. Decagon 5TM soil moisture probes were installed vertically into each hole 30 inches below the soil surface before four additional probes were installed horizontally into the soil profile at 6, 12, 18, and 24 inches below the soil surface (total of 20 probes) (Figures 1 and 2). The probes below 18 inches were expected to account for soil moisture beyond the influence of evaporation. The probes between 30 inches and the surface were expected to provide estimates of available soil moisture for transpiration. Excavated soil was reinserted into the holes at comparable bulk density prior to disturbance.

Probe cables were threaded through plastic conduit (to prevent mastication by rodents) and attached to metal fence posts approximately 25 inches west of the augured holes (Figures 3 and 4). The cables were connected to Decagon EM50 data loggers that recorded hourly VWC (m^3/m^3) for 715mL of soil volume per probe. An Onset tipping bucket precipitation gauge was also attached to one of the fence posts to record precipitation (in/hour and in/day).

Analytical Methods

Hourly VWC data for each probe was downloaded and organized by depth and treatment. To assess whether treatments and soil depth influenced VWC, a two-way ANOVA with replication was used on data pooled by rain gardens and controls. Two sample T-tests were used to determine statistical differences by treatments and depths. All statistical comparisons were evaluated at the $\alpha = 0.10$ level of significance. In order to examine the influence of precipitation on soil moisture responses and compare diurnal fluctuations by soil depth and season, VWC data was averaged by treatment and charted against daily or hourly precipitation depth.

Results and Discussion

Treatment and Depth

Comparisons of VWC revealed significant differences in soil moisture by treatment ($F(1, 131030) = 109389.6$, $\rho = 0$) and depth ($F(4, 131030) = 7862.9$, $\rho = 0$) (Figure 5). The interaction of treatment and depth also resulted in significant differences in mean VWC ($F(4, 131030) = 14422.3$, $\rho = 0$). Rain gardens improved VWC 11%, 3%, 24%, 10%, and 49% over comparable depths in soils without water catchment basins. While these increases in VWC could lead to improved growing conditions for plants, the changes appeared to be random across the soil profile (Figure 6). It was expected that rain gardens would increase soil moisture by creating more residence time (i.e. ponding) for stormwater to infiltrate the soil surface, but sustaining soil moisture through time was likely a function of organic matter and soil texture. Organic matter from the wood mulch might have influenced VWC at shallow depths where evaporation was shielded, while differences in water holding capacity by soil textures could have affected VWC throughout the soil profile measured.

According to a Web Soil Survey, Alire loam (i.e. soil at the site) has at least five distinct layers of loam and clay loam textures in the top 45 inches of a typical profile (USDA: NRCS). Assuming soil layers were spatially uniform across the study area, excavating the rain gardens six inches in depth prior to implementing soil moisture probes could have resulted in soil probes being located in disparate soil textures from the control sites (i.e. the rain garden probes inserted 6 inches below the soil surface in basins already excavated 6 inches would lead to that probe being closer to 12 inches deep in control areas). Comparisons of soil moisture probes offset by depth and overlaid on a diagram with typical Alire loam soil profile resulted in more symmetrical VWC lines as seen in Figure 7. Increases in rain garden VWC at 6, 12, 18, and 24 inches in depth over corresponding control depths of 12, 18, 24, and 30 inches amounted to 12%, 8%, 14%, and 47% respectively. It is not clear why VWC diverges rapidly at 24 inches in the rain gardens compared to 30 inches in the controls, however this result is encouraging in the context of vadose zone soil moisture (i.e. groundwater recharge). By maintaining higher moisture in the soil profile, gravitational movement of water to deeper parts of the soil profile could more easily occur.

Fluctuations through Time and Influence of Precipitation

Total precipitation depth measured during the nine month study was 6.23 inches. Precipitation was divided into daily measurements and plotted against hourly VWC averaged between the rain gardens and controls for each depth (Figures 8-12). Chart observations show that soil moisture often spiked with an input of precipitation, however on some occasions the controls did not display a response to precipitation at multiple depths. It is assumed that the concentration of water in rain gardens aided precipitation events as small as 1/100 inch to percolate through the soil profile whereas runoff at control sites did not have the residence time necessary to infiltrate and percolate to depths as shallow as 6 inches.

Spikes in VWC were generally assumed to correspond with saturation of soils. As the VWC dropped and leveled off within a day or two after storms, field capacity (i.e. maximum amount of water a soil texture will hold against gravity) was met. According to Saxton and Rawls (2006) field capacity for loam and clay loam soils is 28% and 36% respectively. Without additional precipitation inputs, evapotranspiration will cause VWC to taper downward towards permanent wilting point (i.e. VWC where plants cannot extract water from the soil). Permanent wilting point (PWP) for loam and clay loam soils is 14% and 22% respectively. Average VWC in the rain gardens and controls did not reach PWP during the 9 months of monitoring (Table 1). By the end of 28 days (March 21st-April 17th) without measurable precipitation however, average VWC in the controls did reach approximately 23% at 6, 12, and 18 inches below the soil surface (Figures 8-10). This represented an 11.9%, 8.9%, and 5.5% decline in VWC during the dry period for the 6, 12, and 18 inch control site depths respectively. Rain garden VWC during the same dry period only dropped 3.2%, 6.7%, and 1.0% for comparable depths. By April 17th rain garden VWC was 29%, 26%, and 31% at 6, 12, and 18 inches in depth, meaning that plant available water content (i.e. the VWC range between field capacity and PWP) was never in jeopardy of being lost. These results indicate that despite the controls having access to stormwater runoff through curb cuts, the absence of ponding at these sites could limit plant available water content during extended periods without precipitation. This is important to consider with regard to whether curb cuts without basins are sufficient to sustain plants in the absence of potable or effluent irrigation.

Diurnal Fluctuations

One of the primary reasons for sustained VWC in the upper soil profile of the rain gardens could be that wood mulch reduces water loss from evaporation. Diurnal fluctuations in VWC were examined for the first week of each seasonal trimester during the 9 month study (i.e. September 1st-7th, December 1st-7th, and March 1st-7th). Charts plotting hourly precipitation against seasonal VWC for 6 and 12 inches below the soil surface are presented below (Figures 13-18). Observations of diurnal soil moisture fluxes (i.e. waviness of the VWC measurements by day and night) are clear in the top six inches of each season. The diurnal signal of the VWC data becomes less obvious at 12 inches in depth for each season, particularly in the rain garden measurements for September. While the diurnal fluctuations never appear to shift more than 1% for any given 24-hour period, the downward trend of VWC during periods without precipitation is clear. For example, during the first week of September VWC at 6 inches in depth dropped 1.8% in the rain gardens versus 2.9% in the controls. Observational fluctuations in VWC were not evident at depths greater than 18 inches.

Conclusion and Management Implications

There are different methods to assess the value of passive irrigation provided by rain gardens. One important factor to consider is the economic savings associated with the cost of water for irrigation. After exceeding seasonal threshold water consumption quantities and associated delivery charges, the city of Santa Fe charges approximately $0.02/gallon ($21.72/1000 gallons) for water. Based on this value, the rain gardens measured at the Kids' Campus would capture $269.28 of free water from associated runoff during an average year of precipitation (13,464 gallons/year). In contrast, the city irrigates trees in street medians with two 5-gallon emitters twice per week for four hours during establishment and four hours every two weeks as they become older (personal communication). This would amount to $6.40/tree/month and $1.60/tree/month respectively. Once trees are established they are irrigated manually if soil moisture drops below 23% (i.e. the approximate VWC that control sites reached in mid-April during monitoring). These numbers indicate that the potential economic savings in irrigation costs from rain gardens could be substantial. These savings are less meaningful however, if passive irrigation in basins cannot sustain vegetation in the absence of irrigation systems.

Studies indicate that water consumption by trees will vary depending on species, maturity, growing conditions, and other factors. On a warm (~0.25 inches ET) spring or fall day a mature tree (~100ft^2 of canopy) might use 7.8 to 14.6 gallons of water per day (Table 2). Based on average VWC at the Kids' Campus monitoring site, the 150 ft^2 rain gardens are estimated to hold approximately 821 gallons of water in the 30-inch soil profile (Table 3). This amounts to 124 gallons (0.33 gallons/ft^3 of soil) more than the control sites and 294 gallons (0.79 gallons/ft^3 of soil) above permanent wilting point. Based on these estimates, rain gardens might harbor ~8 to 16 days of extra water in the soil profile over curb cuts without rain gardens and ~20 to 38 days of extra water above permanent wilting point (Table 2). These inferences appear to be corroborated at rain gardens with less mature trees during a dry spell between March 21st and April 17th.

Measurements of VWC provided from September 2014 through May 2015 indicate that rain gardens can significantly improve soil moisture over areas without catchment basins and potentially sustain mature trees in the absence of irrigation systems. It should be noted that precipitation in the first half of 2015, particularly during the month of May, was above normal for the area around Santa Fe and New Mexico in general. Further monitoring of soil moisture during normal and below normal periods of precipitation, as well as during summer months (June through August), is critical to determining the value of rain gardens during periods of plant stress and the height of the growing season.

Figures and Tables

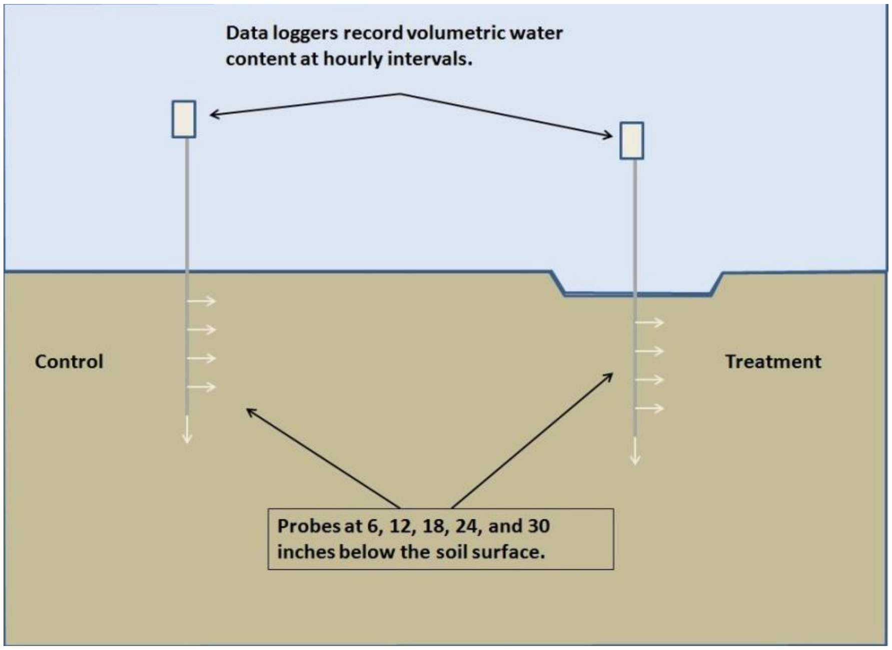

Figure 1. Diagram of field methods used to assess volumetric water content by treatment and soil profile depth.

Figure 2. Decagon 5TM soil moisture probes inserted into an Alire Loam soil profile at 6 inch intervals below the soil surface.

Figure 3. Curb cut without a rain garden (i.e. Control).

Figure 4. Curb cut with a rain garden (i.e. Treatment).

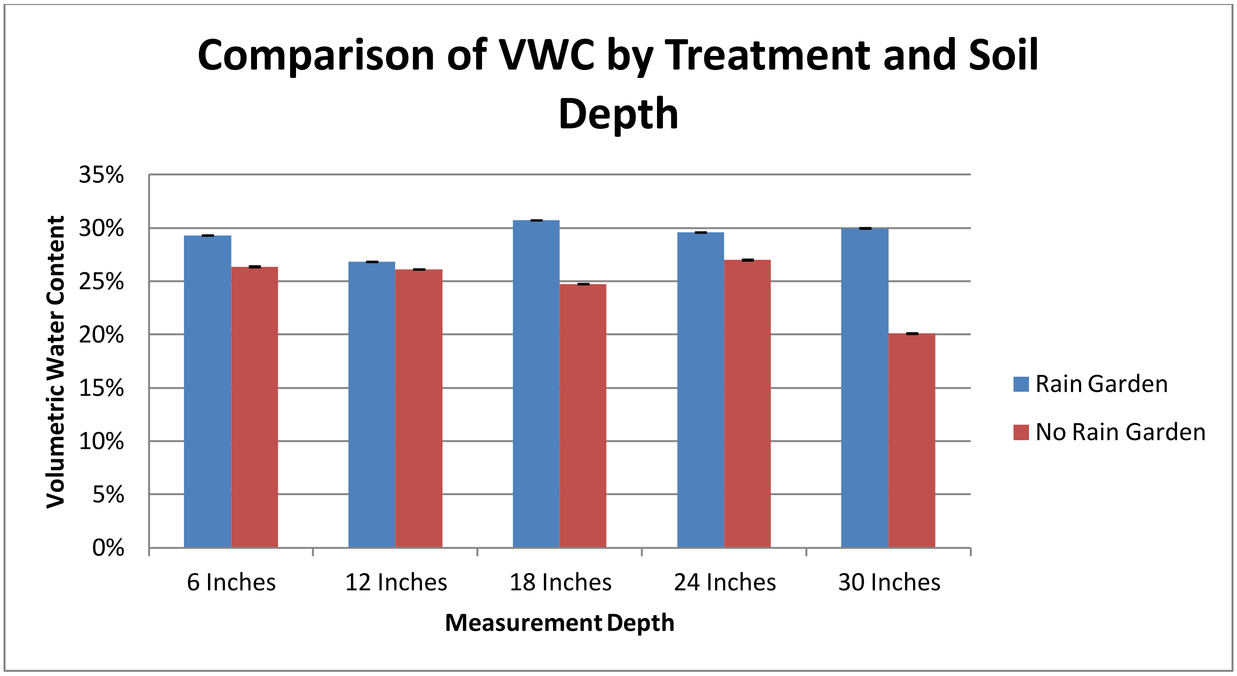

Figure 5. Mean Volumetric Water Content (90% Confidence Intervals) by depth and treatment for a 9-month period (September 1, 2014-May 30, 2015).

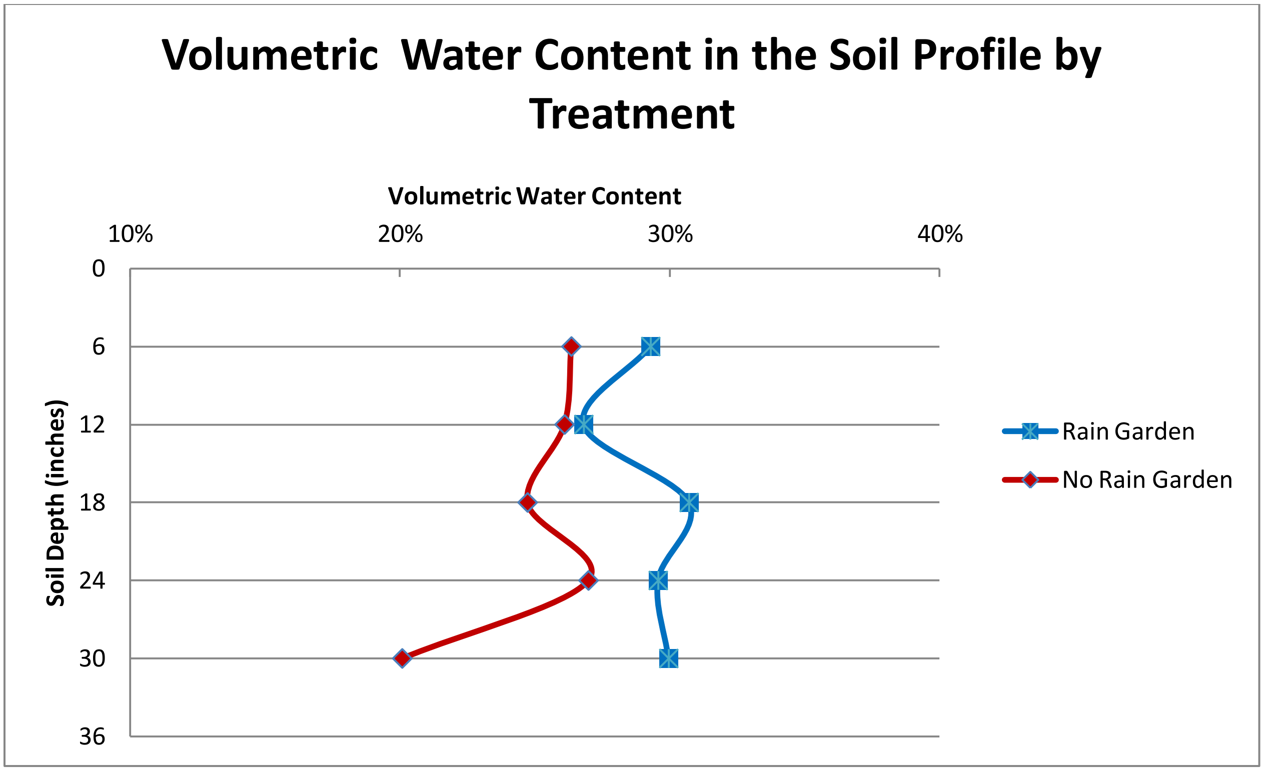

Figure 6. Average volumetric water content in the soil profile measured over 9-months at the Santa Fe Community College.

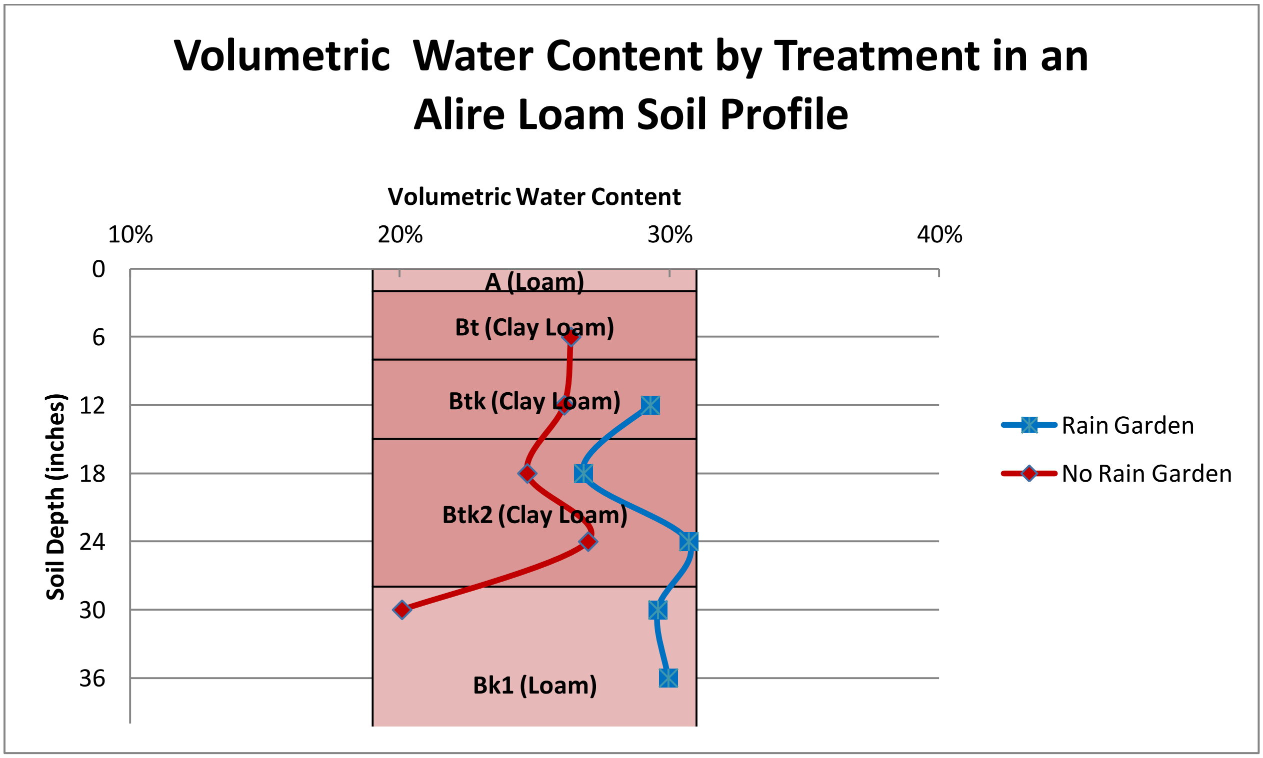

Figure 7. Average volumetric water content in an Alire Loam soil profile measured over 9-months at the Santa Fe Community College. Average measurements are offset according to where soil moisture probes would have been placed in the soil profile after rain garden excavation.

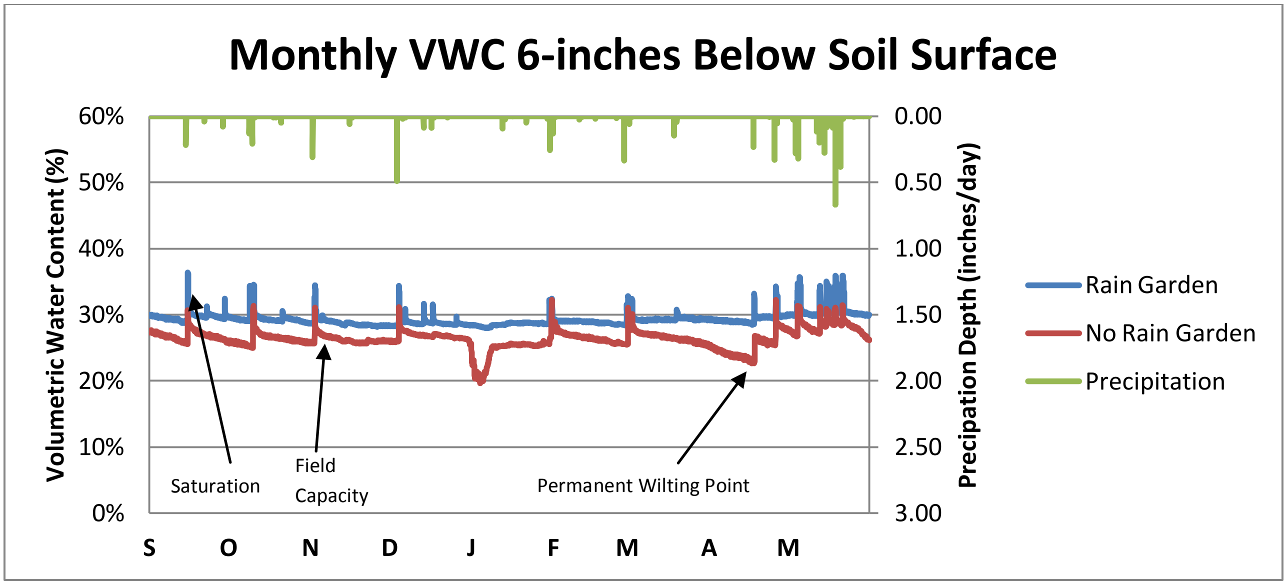

Figure 8. Monthly volumetric water content measurements compared by treatments. The dip in VWC in early January for the control data should be disregarded (probably a consequence of several days of below freezing temperatures).

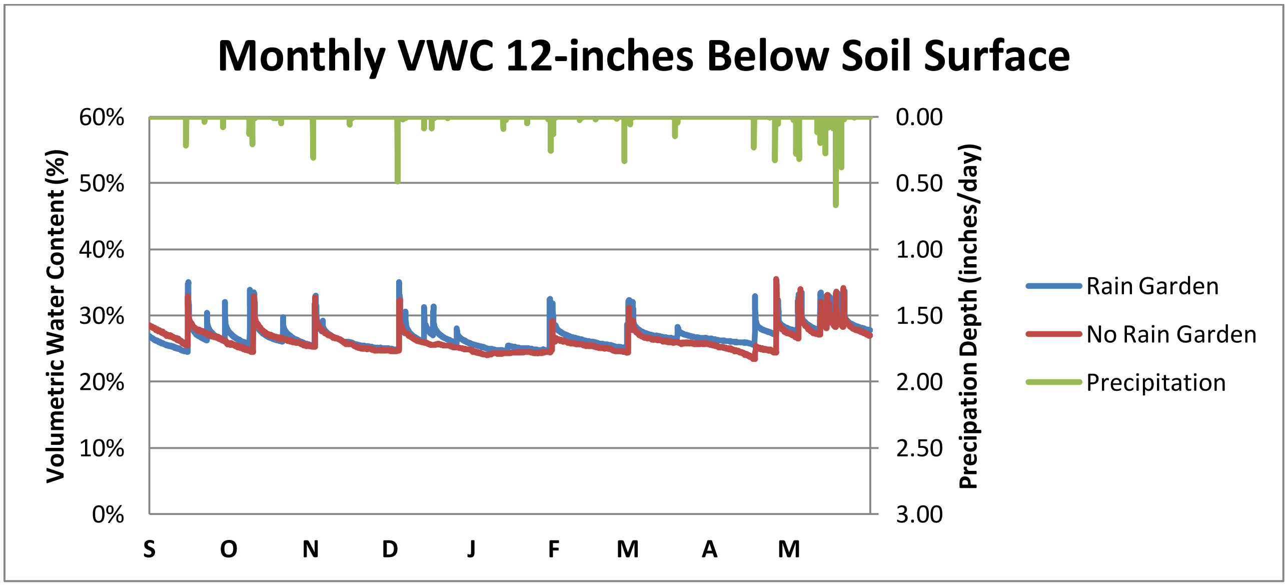

Figure 9. Monthly volumetric water content measurements compared by treatments.

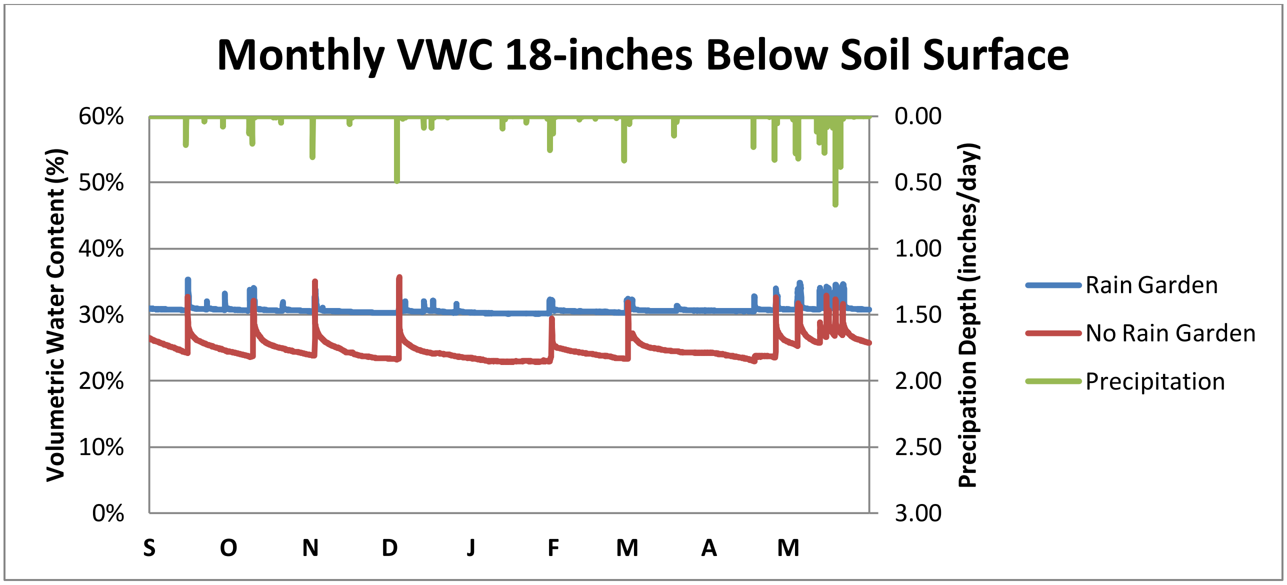

Figure 10. Monthly volumetric water content measurements compared by treatments.

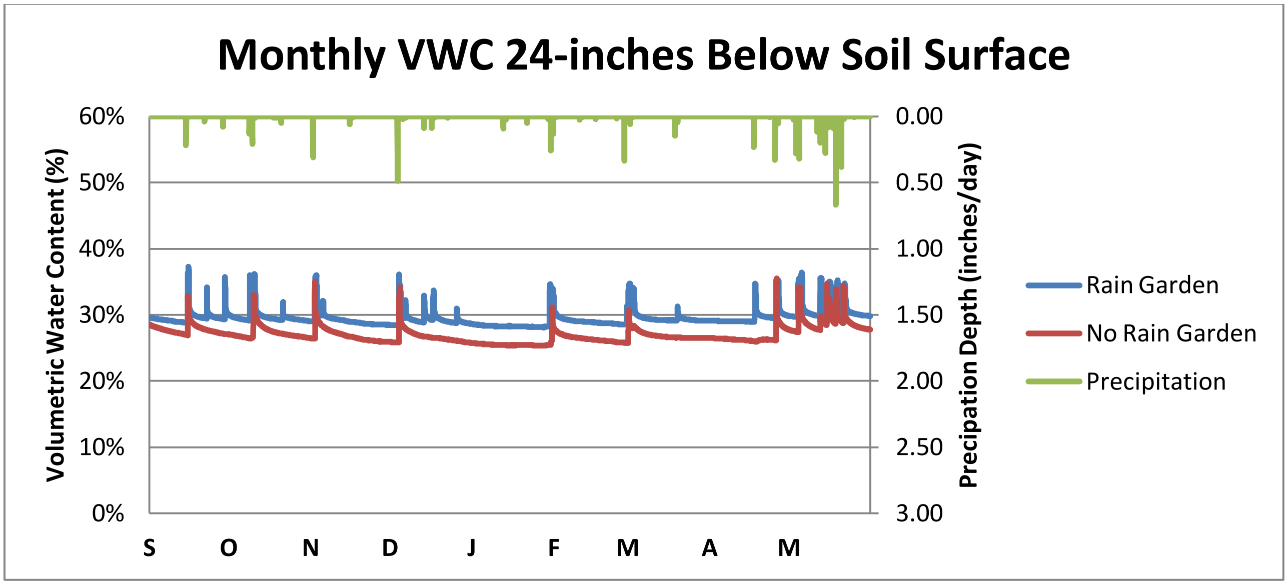

Figure 11. Monthly volumetric water content measurements compared by treatments.

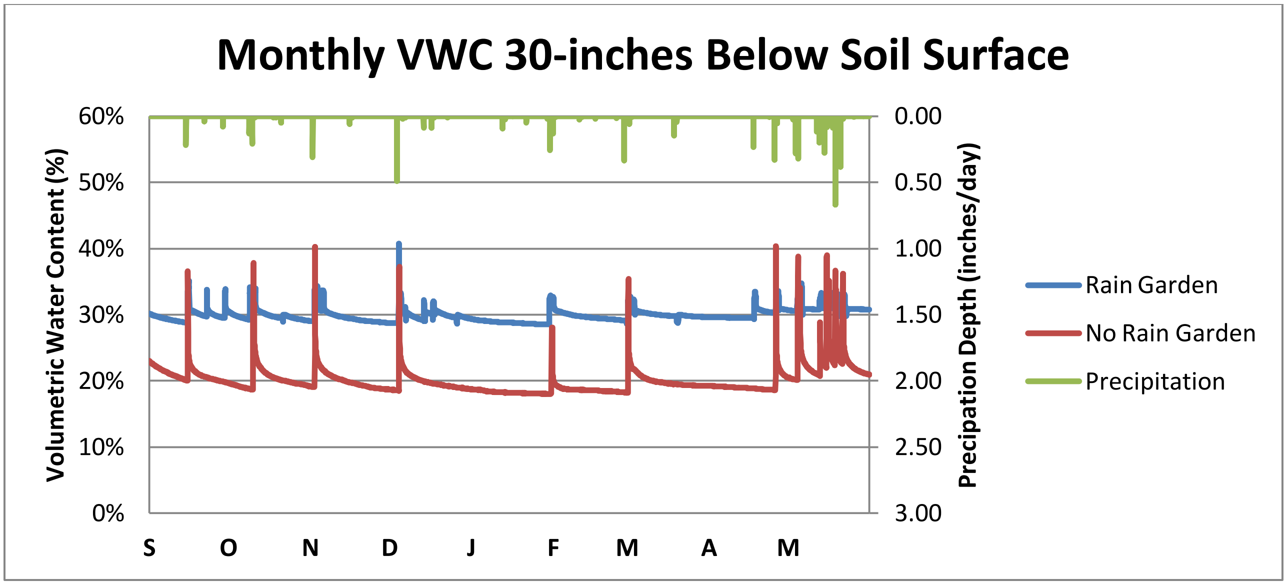

Figure 12. Monthly volumetric water content measurements compared by treatments.

Table 1. Average volumetric water content by treatment and expected soil textures at respective soil profile depths.

Soil Depth	Rain Garden Soil Texture	Rain Garden Average VWC	No Rain Garden Soil Texture	No Rain Garden Average VWC
6	Clay Loam	29%	Clay Loam	26%
12	Clay Loam	27%	Clay Loam	26%
18	Clay Loam	31%	Clay Loam	25%
24	Loam	30%	Clay Loam	27%
30	Loam	30%	Loam	20%

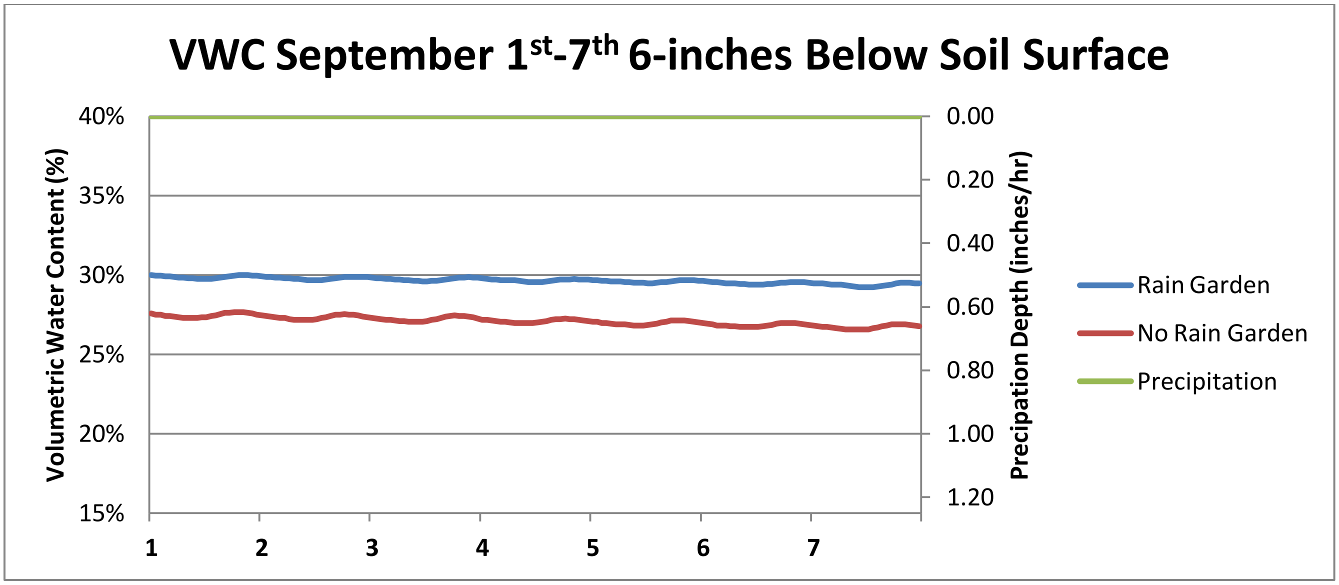

Figure 13. Diurnal fluctuations in volumetric water content by treatment.

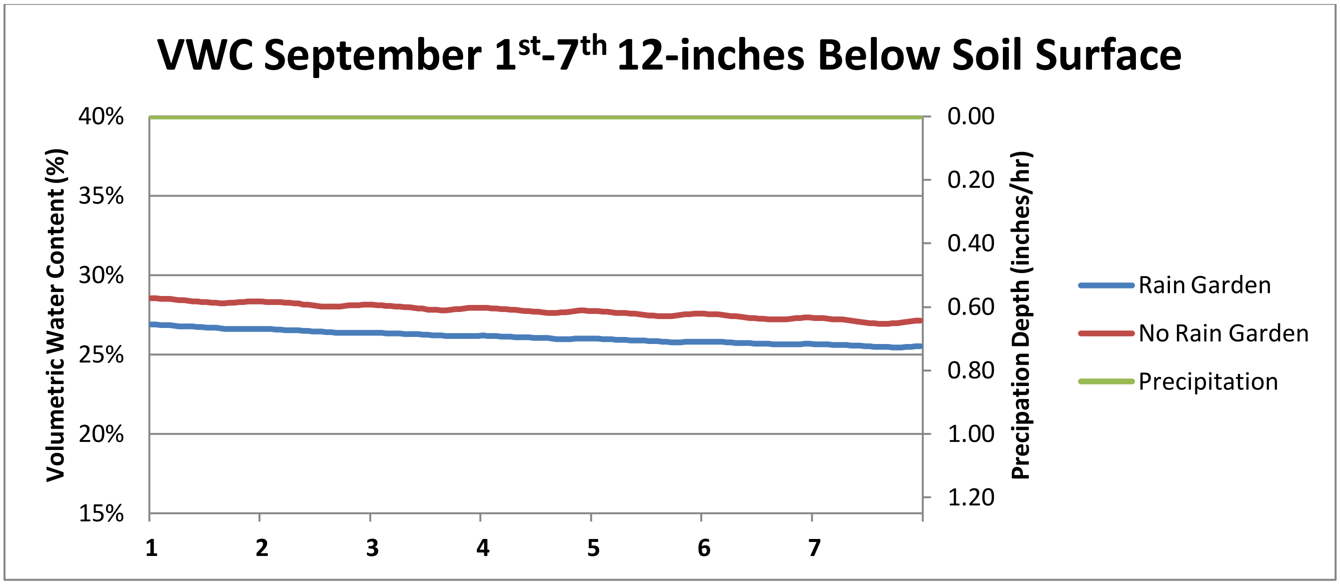

Figure 14. Diurnal fluctuations in volumetric water content by treatment.

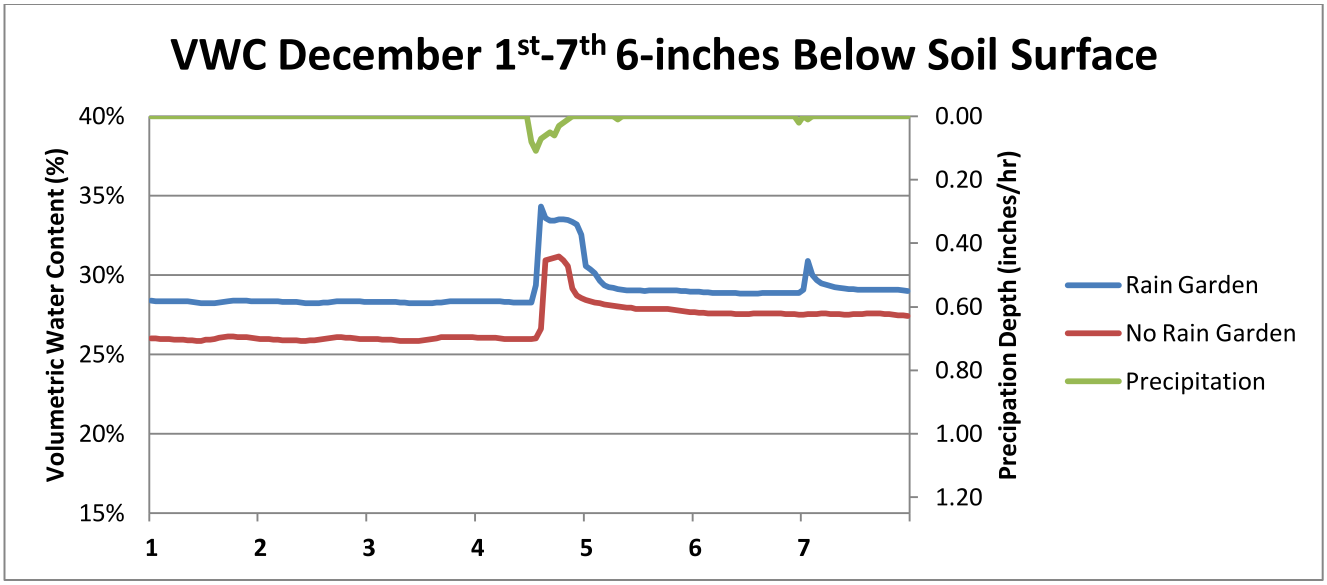

Figure 15. Diurnal fluctuations in volumetric water content by treatment.

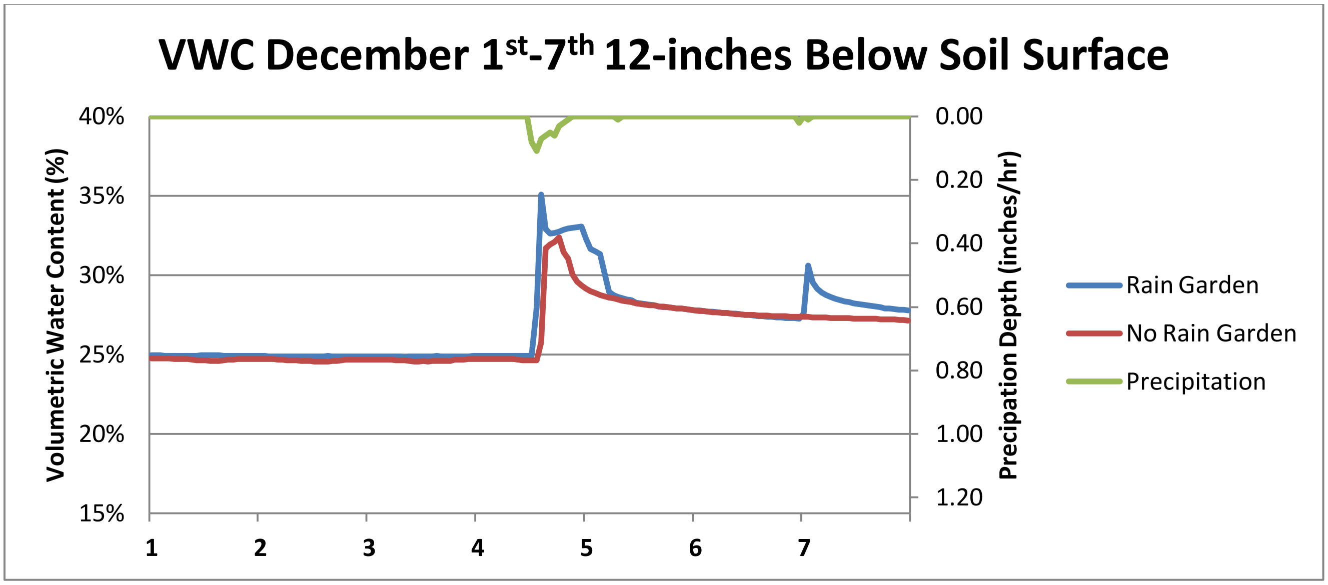

Figure 16. Diurnal fluctuations in volumetric water content by treatment.

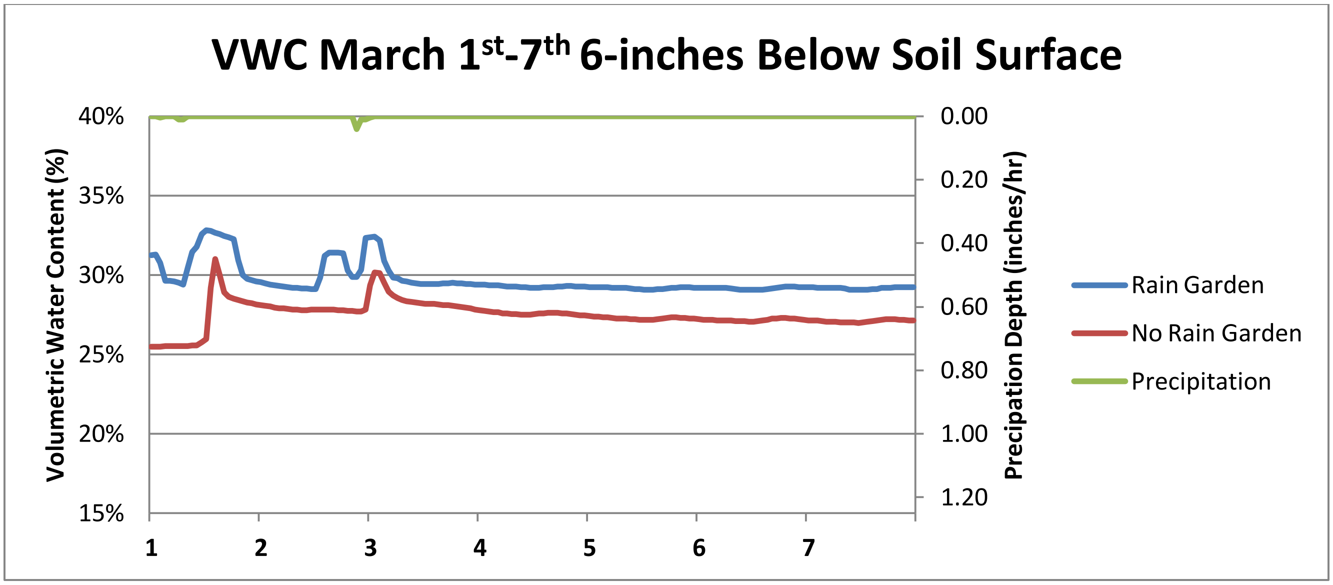

Figure 17. Diurnal fluctuations in volumetric water content by treatment.

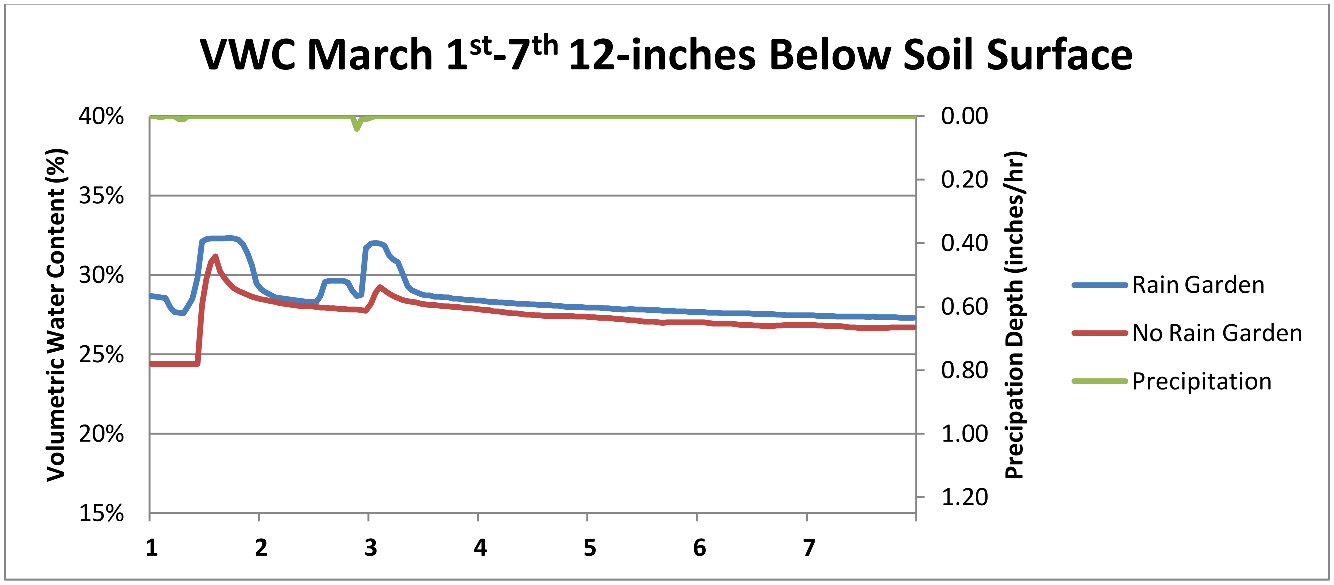

Figure 18. Diurnal fluctuations in volumetric water content by treatment.

Table 2. Estimated water consumption by a mature tree (100 sqft canopy) during a warm (0.25 inches ET) Spring/Fall day. Note that the first two columns are cited in the reference column, while columns three and four are extrapolations based on data from the Santa Fe Community College.

Tree Type	Gallons/Day	Extra Days of Water above Control Sites	Extra Days of Water above PWP	Reference (Gallons/Day)
Not Indicated	7.8	15.9	37.7	University of California Center for Landscape and Urban Horticulture
Fruit Tree	12.5	9.9	23.5	Vossen (2000)
Broadleaf Shade Tree	14.6	8.5	20.2	Utah State University Forestry Extension
Average	11.6	10.7	25.3	

Table 3. Estimated available water content (gallons) by depth, treatment, and anticipated permanent wilting point.

Probe depth	RG Gallons of water in Soil Profile	No RG Gallons of water in Soil Profile (PWP Values)	Difference in Gallons for RG and Control (RG:PWP)
6	164.4	148.1 (123.0)	16.3 (41.4)
12	150.3	146.4 (123.0)	3.9 (27.3)
18	172.2	138.6 (123.0)	33.7 (49.2)
24	166.1	151.5 (79.0)	14.6 (87.1)
30	168.3	112.8 (79.0)	55.5 (89.3)
Total	821.3	697.3 (527.0)	124.0 (294.3)

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Utah State University Forestry Extension http://forestry.usu.edu/htm/city-and-town/tree-care/drip-irrigation/

Acknowledgements

Funding for this study was made possible from a Water Quality and Conservation Grant from the Soil and Water Conservation Commission. Research was completed by Southwest Urban Hydrology LLC with administrative support from the Santa Fe-Pojoaque Soil and Water Conservation District. Special thanks to the Santa Fe Community College, Studio DC, Clara Dubois, Paige Grant, Joseph Marcoline, Melissa McDonald, Shawn Miller, Alex Mundt, Lynn Mundt, Mike Mundt, Cody Stropki, Joe Vinson, Neil Williams, and Xubi Wilson for additional contributions and technical review of this project.

Contact

Aaron Kauffman

Southwest Urban Hydrology LLC

PO Box 2642

Santa Fe, NM 87504

505 401-6095

Santa Fe-Pojoaque SWCD

4001 Office Court Dr.

Bldg. 1000 Ste. 1001

Santa Fe, NM 87507

505 471-0410