Effect of Sub-surface Drip Irrigation and Shade on Soil Moisture Uniformity in Residential Turf

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Paper presented at the 30th Annual Irrigation Show
San Antonio, TX
December 2-4, 2009

Abstract

Sub-surface irrigation in turf has advantages over traditional sprinkler systems. Evapotranspiration is reduced and water applied below the root zone promotes deeper root growth. Auditing such applications requires measurement of root-zone soil moisture. Data was taken on a private lawn that had just been rebuilt to include both sub-surface drip and overhead spray irrigation systems. A portable wave reflectometer was used to take geo-referenced soil moisture readings in the top 5 inches of the root zone before and after scheduled irrigation events. Readings were taken in at 3 - 4 foot intervals. Photosynthetic light and soil moisture were logged at 1-hour intervals in sunny and shady areas of the property. Soil moisture distribution uniformity was computed. Soil moisture spatial variability was mapped using on-line software. Data showed that in the spring, soil moisture was driven by light. In the summer, root extraction by trees was a more important factor in locating dry areas of the lawn.

Introduction

Residential water consumption occupies a large fraction of many municipal supplies (Baum et al, 2003). For residences with irrigation systems, external water use can be as high as 70% of total consumption (Toro, 2006). Unless carefully monitored, there is a tendency to apply more water than is necessary. This wastes water and energy and can leach valuable nutrients out of the root zone. As water restrictions are becoming ever more prevalent, political, as well as economic forces will be cause for homeowners to increasingly adopt irrigation practices that conserve water.

Evapotranspiration, which represents the amount of water removed from the soil by the atmosphere and roots, is one way in which the timing of irrigation events can be determined. This data can be accessed from local weather networks or calculated from on-site weather stations. It has been shown that irrigation at 100% ET, is not necessary to maintain acceptable turf quality on fairways planted to bentgrass (DaCosta and Huang, 2006), Kentucky bluegrass (Feldhake et al., 1984) and fescue (Feldhake et al., 1984; Fry and Butler, 1989). Deficit irrigation has been shown to promote deeper root depths and increased drought tolerance (Jiang and Huang, 2001). Conversely, excess water, whether from heavy rain or over-irrigation can yield anaerobic soil conditions and a moist environment that is conducive to the spread of fungal pathogens. Incidents of over-irrigation are more likely to occur late in the season, assuming irrigation schedules have not been adjusted to reflect shallow root systems resulting from summer heat stress. Lacking the root depth typical of early season, the turf can no longer access the same depth of soil-held water. Consequently, turf water consumption decreases without a corresponding decrease in applied water.

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Although in some areas, such as the arid southwestern region of the U.S., there is a trend to taking landscaped areas out of turf, a lawn comprised of grass is still a highly desirable feature for many homeowners. Apart from aesthetic appeal, there are several ancillary benefits of turf. Turf provides a cooling effect for the property which can reduce air conditioning costs. It absorbs millions of tons of dust and dirt each year. Lawns also act as a filter that can capture and break down pollutants before they reach the ground water supply (Toro, 2006).

Irrigation systems for turf are almost universally comprised of overhead sprayers or sprinklers. Overhead irrigation components are straightforward to install and it is relatively easy for a homeowner to make a qualitative assessment of performance. However, the effects of wind, sprinkler overlap, and evapotranspiration can lead to application disuniformities which, in turn, can lead to excess water application. Drip irrigation has been used in horticultural operations since the middle of the 20th century (Hillel, 2008). There have been some investigations of the viability of using sub-surface drip irrigation (SSD) to irrigate turf grass (Zoldoske, 1995; Leinauer and Makk, 2005; Johnson and Leinauer, 2004; Devitt and Miller, 1988; Ferguson, 1994) Some of the benefits of SSD over conventional irrigation are that it operates at lower volumes and flow rates, puts water directly into the root zone, and is thus less susceptible to losses from wind and evapotranspiration. Leinauer and Makk (2005) found SSD had a higher incidence of localized dry spots than sprinkler or sub-irrigated tile systems. Johnson and Leinauer (2004) studied SSD with saline water in warm and cool season grasses. When using similar water quality, sprinkler and SSD had similar rates of establishment. With saline water, SSD was comparable to sprinkler irrigation for warm season grass. Devitt and Miller (1988) studied SSD with saline water in clay and sandy loam soil. Plant response was limited by salinity in the sandy loam soil. The clay soil was more affected by available soil moisture. Drip line spacing must be adapted to the soil texture to avoid striping (Ferguson, 1994) and must be combined with proper leaching fractions to achieve ideal soil moisture uniformity and minimize salt buildup (Devitt and Miller, 1988).

With conventional irrigation systems, one technique for evaluating performance is to perform an irrigation audit. The Irrigation Association has published guidelines for performing irrigation audits (IA, 2007). Catch cans capture the water applied during a typical irrigation cycle. Distribution uniformity is calculated as the ratio of the average from the 25% of cans that collected the smallest amount of water to the average across all cans (Kieffer and O'Connor, 2007). A similar parameter, Emission Uniformity (EU) can be calculated for drip systems (Schwankl and Smith, 2009). A typical data set would be the amount of water discharge after 30 seconds from each of 36 emitters located between the head and end of laterals across the entire irrigated area. The EU can then be calculated as:

$$EU\% = 100 * \frac{\overline{D}_{lq}}{\overline{D}_{total}}$$

Where:

$\overline{D}_{lq}$ = Average 30-second discharge of the lowest 25% emitters.

$\overline{D}_{total}$ = Average 30-second discharge of all emitters.

A design EU of 90% is considered excellent while an EU less than 70% is considered poor (Peacock, 1998; Lamm et al, 2001). Unfortunately, for an installed SSD system, it is not possible to collect emitter discharge data.

In recent years, there has been interest in using soil moisture data to compute the uniformity coefficients (Mecham, 2001; Dukes et al, 2006; Vis et al, 2007, Kieffer and O'Connor, 2007). Li et al (2001) found water redistribution to be more important than irrigation uniformity, while Hunsaker and Bucks (1987) determined that soil texture was a more important factor. Miller et al (2005) found no correlation between catch can DU and soil moisture DU. The volumetric water content (VWC) at field capacity, which is soil texture dependent, is a parameter that has been found to have a similar pattern of spatial variability to other stable landscape parameters (Krum et al, 2007). Spatial maps of VWC provide useful information for managing turf grass. Krum et al (2008) used maps of VWC and the normalized difference vegetative index (NDVI) to create site-specific management units for precision agriculture applications. Kieffer and Huck (2008) mapped the spatial distribution on a fairway of catch can data and soil moisture data. Soil moisture distribution was similar at different sampling depths and sampling dates but had no correlation to the distribution measured by catch cans.

Managing turf in shade is not easy. When growing turf in shade, it is important to monitor soil moisture and disease pressure (Rackliffe; Koh and Bell, 2006). Koh et al (2003) studied the effect of light and airflow on golf course greens. They found no difference in soil moisture content between treatments.

This paper looks at how soil moisture variability in a lawn irrigated with sub-surface drip is influenced by light and tree root activity.

Materials and Methods

Data were collected in 2008 and 2009 on the lawn of a private residence in northern California. This lawn was subject to a major renovation in 2008, during which approximately 12 inches (approximately 320 yards) of poor-quality, clay soil was removed and replaced with a sandy loam soil. A sub-surface drip system (Netafim-USA Inc., Fresno, CA) and a surface spray system (Hunter Industries, San Marcos, CA) were installed. The drip system is the main irrigation apparatus. The surface irrigation was used to aid with establishment of the sod as well as to perform periodic flushing of the root zone. The drip system consists of 8 irrigation zones (figure 1) which take into account the microclimate (sun and wind exposure), root intrusion from existing large trees (Redwood, Oak, and Willow), and topography. Zones A and H are in full shade. Zone A is relatively flat while zone H is steep and slopes toward the patio. Zones G and F are partial or filtered sun. Zones B, C, D and E are in full sun. Zone C is relatively flat except near the boundary with B. Zone B has a sharp change in grade of 6 inches in 2 feet. Zone E is fairly steep and flattens out as it progresses into zone D. The main irrigation line runs horizontally across the lawn, passing through zones A, C, and F. The soil around the main line was not compacted as heavily as other parts of the lawn when the new soil was added.

Figure 1. Outline of Irrigation Zones

All lateral drip lines were set at 12-inch spacing with emitter spacing of 12 inches (figure 2). The smallest zone is 300 sq. ft. and operates at 3 gallons per minute (GPM) using 1 inch of fill. The largest zone is 2800 sq. ft and operates at 28 gallons per minute (GPM) using 1½ inch of fill. Before laying the sod, the soil surface was inoculated with mycorrhizal fungi to aid root development and plant health. 12,000 sq. ft. of sod (Dwarf Fescue) was installed and ready for mowing in three weeks.

Figure 2. Adding soil over sub-surface system in Zone A

During the summer of 2009, volumetric water content and photosynthetically active radiation (PAR) were measured at a shaded and full-sun location with two WatchDog mini-stations (Spectrum Technologies, Plainfield, IL). The full-sun station was located in zone B, the full-shade station was located in zone H.

The spatial variability of soil moisture was measured using a TDR300 portable wave reflectometer (Spectrum Technologies, Plainfield, IL). Sampling was done to a depth of 4.8 inches. Readings were taken at 4 ft intervals along the boundary of the property. The interior of the property was grid-sampled at the same interval. Data was geo-referenced with a GPS 72 GPS receiver (Garmin International, Olathe, KS). The property had been sampled before the renovation. Soil moisture readings were taken regularly from just after the sod was first mowed (September, 2008) until October, 2009. 2-dimensional contour plots of each data set were generated using the SpecMaps

Web Mapping Utility (Spectrum Technologies, Plainfield, IL). Lower quartile distribution uniformity (DU_{lq}) was calculated for each data set. DU_{lq} is the ratio of the average the 25% of the driest data points to the average the entire dataset.

$$DU_{lq} = 100 * \frac{\overline{VWC}_{lq}}{\overline{VWC}_{total}}$$

Where:

$\overline{VWC}_{lq}$ = Average the lowest 25% of readings in the data set.

$\overline{VWC}_{total}$ = Average of all VWC readings.

Results and Discussion

The site of this study is a private residence in northern California. It has been managed by Water Scout Inc. for 12 years. The property is relatively flat in the center and western sections. But, the northern and eastern portions slope, sometimes steeply, toward the northern patio area. The combined effect of topography, light and wind levels, and drastically different soil textures made maintaining aesthetic uniformity an ongoing challenge. Figure 3 shows light levels from areas of the property in full sun (center) and partial shade (outer perimeter). In July, maximum photosynthetically active radiation (PAR) was about 2100 µmoles/m^2/s in the full-sun areas and 1500 µmoles/m^2/s in the shaded areas. The accumulated daily light integral (DLI) for July varied between 1507 moles/m^2 in sun to 677 moles/m^2 in the shade. By September, the maximum PAR values were down to 1600 µmoles/m^2/s in sun and 750 µmoles/m^2/s in the shade. Monthly DLI was 1128 moles/m^2 in sun and 346 moles/m^2 in shade.

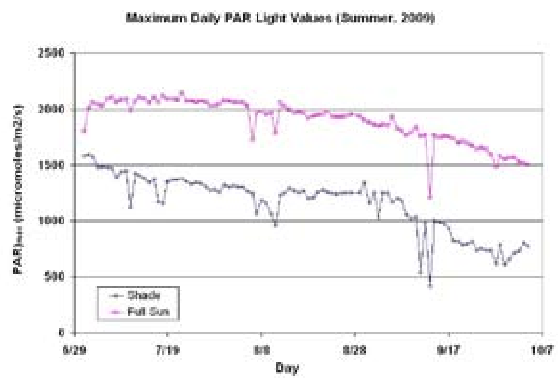


Figure 3. Maximum photosynthetically active radiation (PAR) levels in shaded and sunny zones of property.

Because there was an amalgam of different soils, there were areas that would become waterlogged while others would remain excessively dry. In 2008, the homeowner ordered a major renovation of the lawn. Figure 4 shows a map of the variability of the soil moisture across the property before the renovation. The distribution uniformity of the soil moisture on this sampling date was 57% which was typical for this site. There was a wide gap between the wettest and driest areas of the lawn which is partially a function of the multiple soil types present. On this date, the soil moisture gradient roughly follows the topography of the site.

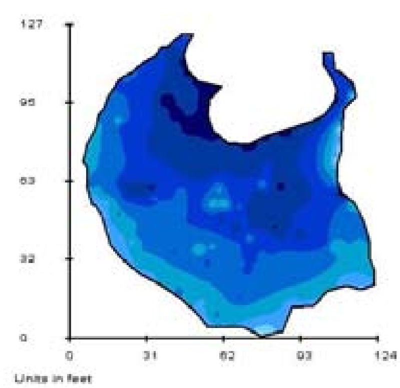


Figure 4. Map of soil moisture variability before renovation (DU=57%)

Figure 5 shows data taken during the period just after the sod was laid in the summer of 2008. The soil needed to be kept very wet during this time to ensure the sod properly knitted. During this period, approximately 60% of the irrigation was from overhead spray and 40% was supplied by the sub-surface drip system (SSD). At this time, environmental impacts on the lawn are not yet visible in the image of soil moisture variability. Data from several sampling sessions during this period yielded DU's of about 85%. Because the irrigation frequency was high at this point, this can be considered near optimum for the newly built lawn.

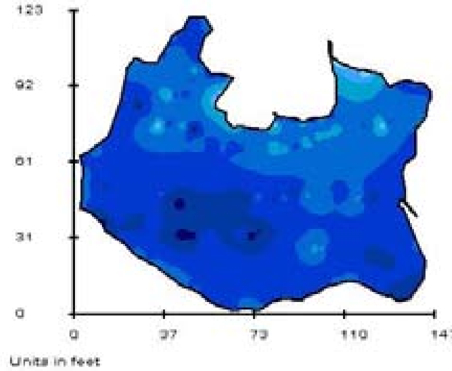
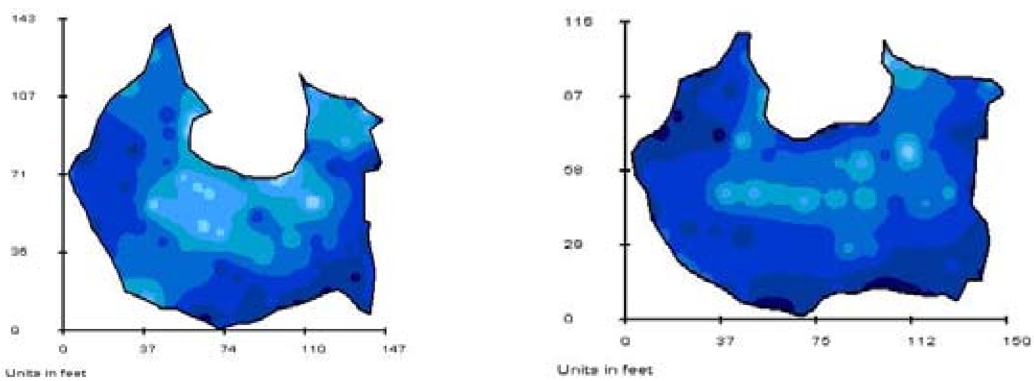


Figure 5. Soil moisture variability map just After laying of sod in summer of 2008 (DU=85%).

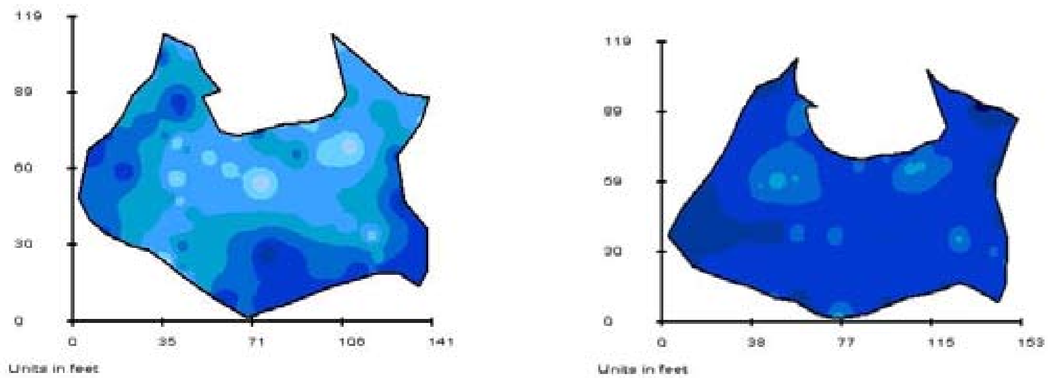
Figure 6 shows the results of data sets taken before and after an irrigation cycle. At this point overhead and SSD irrigation are still being employed. The pre-irrigation data show a DU of 80%. In figure 6b, the data set taken one hour following a full irrigation cycle, the soil moisture pattern is visibly less variable and the DU increased to 87%. The soil moisture movement in this strip of the lawn is currently displaying differences from the adjacent parts of that zone. Inspection of the pre-irrigation map (figure 6a), shows that the soil moisture variability is aligned roughly along the lines of the irrigation zones. The drier (light blue) areas are located in zones B, C, and E while the wetter parts of the lawn are in A, F, and H. Zone G is also seen to be drier. This is attributed to a magnolia tree located in the very middle of that zone. In figure 6b it is possible to see the location of the buried main line which, in this case, is drier than the surrounding soil.



a. **b.**

Figure 6. Soil moisture variability maps from early spring, 2009. a.) data taken prior to irrigation (DU=80%), b.) data taken after irrigation (DU=87%)

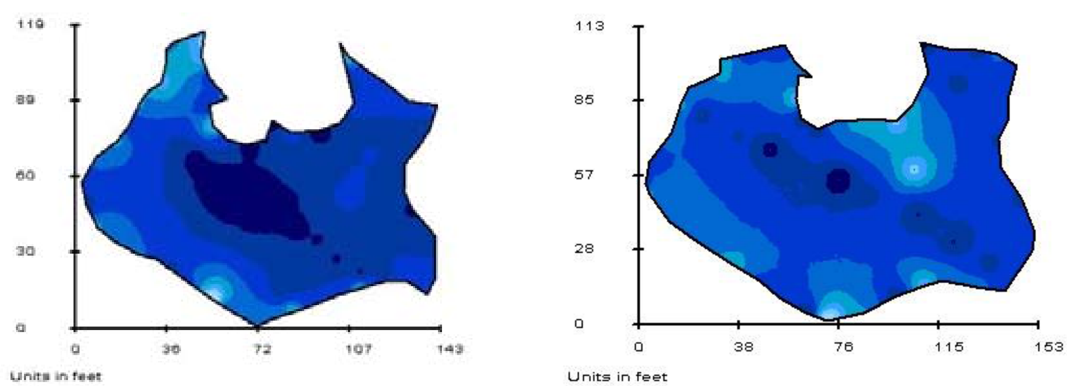
In figure 7 are examples of maps of the property with dramatically different soil moisture levels. These maps were created in the spring of 2009. Both maps are using the same color legend. The map in figure 7a was taken just after it was discovered that there was an electrical failure in the control system that left the lawn un-irrigated for 2 days. It is very clear that the lawn is much drier than in figure 7b which was created later in the season when the lawn received ample water. The DU for the dry sampling date was 73%. The DU for the well-watered lawn was 89%. The maps can, again, be seen to align with the irrigation zones. The driest areas are in the middle and the wetter areas are on the periphery.



a. **b.**

Figure 7. Soil moisture variability maps from late spring, 2009, a.) data taken prior to irrigation (DU=73%), b.) data taken after irrigation (DU=89%).

Starting in July, there was a transition in the soil moisture variability maps. Figure 8 shows data from July and August. The DU for both data sets is about 81%. However, the dry areas have shifted from the zones in full sun to the shaded areas on the periphery. It appears that the roots from the trees are now the dominant influence for extracting water from the lawn. The portion of the lawn above the main line is very visible in these images. However, at this point, it is the wetter part of the lawn. Also visible in figure 8b is a very dry spot in zone E. This is due to two failures in the system. First, a short in the controller wire that left that area un-watered by the drip system. At the same time, there were hardware problems with the overhead sprayers. This left that zone extremely dry and required immediate attention.



a. **b.**

Figure 8. Soil moisture variability maps from autumn, 2009, a.) data taken prior to irrigation (DU=81%), b.) data taken after irrigation (DU=80%).

Figure 9 shows a map of a data set from the autumn. The light level is less and the pattern of variability of soil moisture continues to be driven more by tree root activity than by ambient light. This data set was taken just before a full irrigation from the drip system and the DU is about 78%.

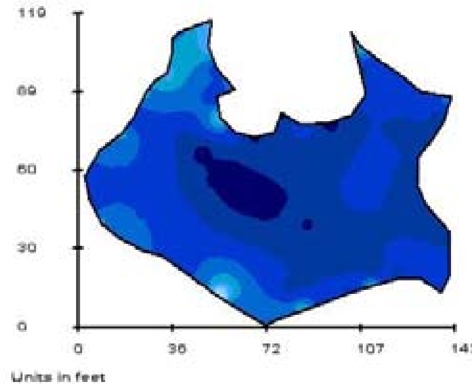


Figure 9. Soil moisture variability maps from autumn, 2009 (DU=78%).

Conclusions

A portable wave reflectometer was successfully used to track the effects on the spatial variability of soil moisture on a constructed turf landscape. The site is primarily irrigated with subsurface drip irrigation (SSD) but an overhead spray irrigation system is also installed and can be used for leaching applications or when the SSD system malfunctions. Tracking soil moisture is critical for managing irrigation because traditional irrigation audit techniques using catch cans cannot be used for subsurface applications. Irrigation zones on this site were delineated mainly by light level and topography. In the spring, soil moisture variability appears to be influenced by the amount of light in each irrigation zone. However, beginning in July, there is a transition. At this point, water extraction by tree root zones better describes the pattern of soil moisture variability. Distribution uniformity of soil moisture was greatly improved on this property after the SSD system was installed. DU went from 57% before reconstruction to DU's of around 80% after. Comparison of data sets taken before and after irrigation found that DU was slightly higher following irrigation events.

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