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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 225 projects at a cost of $25 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Putting Green Rootzone Amendments and Irrigation Water Conservation

Ed McCoy and Kevin McCoy

SUMMARY

This Ohio State University study was conducted to quantify irrigation water savings that could be realized by employing peat alone, or both peat and soil as amendments to a high sand content putting green rootzone; and by employing a deficit-based irrigation protocol. Their findings include:

- Rootzone amendments can translate into irrigation water savings when accompanied with an appropriate irrigation scheduling protocol.
- The extent of irrigation savings is, however, climate-dependent with lesser savings in generally arid climates and greater savings in humid climates.
- The increased rainfall frequency of a humid climate together with the less frequent irrigation requirement of a amended rootzone yields a greater probability that rainfall rather than irrigation will replenish the rootzone available water capacity.

Peat and soil are commonly used amendments in high sand rootzone mixes for putting greens. Extensive research has shown measurable increases in water and nutrient retention from the addition to a specified sand of modest quantities of peat, soil, or both (1, 2, 4, 5, 7). For these high sand content mixes, the increased water retention delays the onset of injurious drought conditions between irrigations and the increased nutrient retention maintains a stable supply of nutrients to the turf between fertilizer applications.

In a sense, these amendment materials provide a physical and chemical buffering capacity to sand to assist in the establishment and management of the turf. Consequently, increasing the available water capacity (AWC) of a sand-based rootzone through use of amendments would rationally provide a means of irrigation water conservation. Yet, employing an amended rootzone alone will not result in irrigation water savings. Golf course superintendents must also adjust irrigation practices, specifically using a protocol that employs available water information and adjust irrigation accordingly.

A widely recognized irrigation scheduling protocol that employs soil available water information is deficit-based irrigation (6). Deficit-based irrigation employs rainfall and evapotranspiration (ET) information together with estimates of available water capacity within the rootzone to schedule the frequency and amount of irrigation. The procedure can be used with regional, monthly mean values of daily rainfall and evapotranspiration (ET); or, when a local weather station is available, the procedure can be fine tuned to use actual daily rainfall and ET measurements. Thus, the potential for water conservation using a rootzone amendment together with deficit-based irrigation practices clearly exists.

This study was conducted to quantify irrigation water savings that could be realized by employing peat alone, or both peat and soil as amendments to a high sand content putting green rootzone; and by employing a deficit-based irrigation protocol.

Photo 1. The field study site showing the contrasting rootzones of the experiment.

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Photo 2. The occurrence of foot-printing on the experimental greens. At this point it was presumed that the turf had depleted the AWC reservoir of the putting green rootzone.

In addition, climatic conditions that generate rainfall and control ET vary greatly across the U.S., with time of year, and reflect year-to-year variability. Thus, estimates of water savings due to amendment use in rootzones must employ a wide range of locations, all seasons of the year, and span a sufficient period of time to address year-to-year variability. For this reason, long-term weather data from diverse regions of the U.S. were employed in the water savings estimation.

Rootzone Available Water Capacity

Central to a water budgeting using deficit-based irrigation is an estimation of available water capacity (AWC) within the rooting depth. Yet, the standard definition of available water published in textbooks and used in irrigation scheduling does not appear to be appropriate for a putting green system. Principally, the standard definition given as the volume of water retained in the soil from field capacity to the permanent wilting point does not address the fact that a superintendent would apply irrigation long before the permanent wilting point is reached. Also, this definition is based on laboratory measurements of a soil sample and does not consider the layering of soil media characteristic of a modern putting green.

To improve water budgeting, we redefined available water capacity as would be appropriate for a modern putting green. The basis for this redefinition was results from a two-year field study wherein a complete water balance was performed on experimental greens supporting a bentgrass turf maintained under putting green conditions. The experimental greens consisted of a 300-mm deep rootzone placed above a 100-mm thick gravel drainage blanket, all contained within a non-weighing lysimeter. The study employed six rootzones: two containing pure sand, two containing sand +10% (vol./vol.) sphagnum peat, and two containing sand + 10% peat + 10% (vol./vol.) topsoil (Photo 1). Two different sands were used with one being slightly finer and one being slightly coarser but both containing about 74% medium and coarse particles.

This field research recorded all rainfall and irrigation inputs, all drainage losses, and from daily soil moisture measurements, calculated daily turf ET. For one instance each during years 2000 and 2001, irrigation was withheld to impose drought stress on the turf to the point where first wilt or "footprinting" became visually apparent (Photo 2). These dry-down periods were initiated by a heavy irrigation or rainfall. Thus, from tracking soil moisture changes and drainage losses during the dry-down period, a field-based estimation of water actually used by the turf from a well watered condition to first wilt was available. This was the basis for the AWC values used in this study (Table 1).

Following the procedure described above, AWC for a pure sand rootzone, a sand + 10% peat rootzone, and a sand + 10% peat + 10% soilroot zone was 23, 31 and 39 mm of water, respectively. These values represent the depth of water available for turf uptake within a 300-mm rootzone depth characteristic of a modern green.

The Weather Data

Due to climate diversity within the U.S., water savings estimates were conducted individually for six metropolitan locations across the country. Selection of the specific cities was further based on a map of soil moisture regimes of the U.S. (3) to ensure a wide span of possible climatic conditions. The six locations chosen were

Rootzone	Available Water Year 2000	Available Water Year 2001
	---------------------- mm	----------------------
Finer Sand	23	23
Finer Sand + 10% Peat	32	33
Finer Sand + 10% Peat + 10% Soil	ND†	ND†
Coarser Sand	23	23
Coarser Sand + 10% Peat	29	31
Coarser Sand + 10% Peat + 10% Soil	38	40

† Not determined because the actual rootzone mix did not meet the soil amendment target.

Table 1. Field estimates of available water contained within a 300-mm deep rootzone overlying a gravel drainage blanket. Available water is defined as the depth of water removed by evapotranspiration (ET) after a heavy rain or irrigation to the first indication of turf wilt (foot-printing).

Phoenix, AZ; Sacramento, CA; Boulder, CO; Houston, TX; Miami, FL; and Columbus, OH.

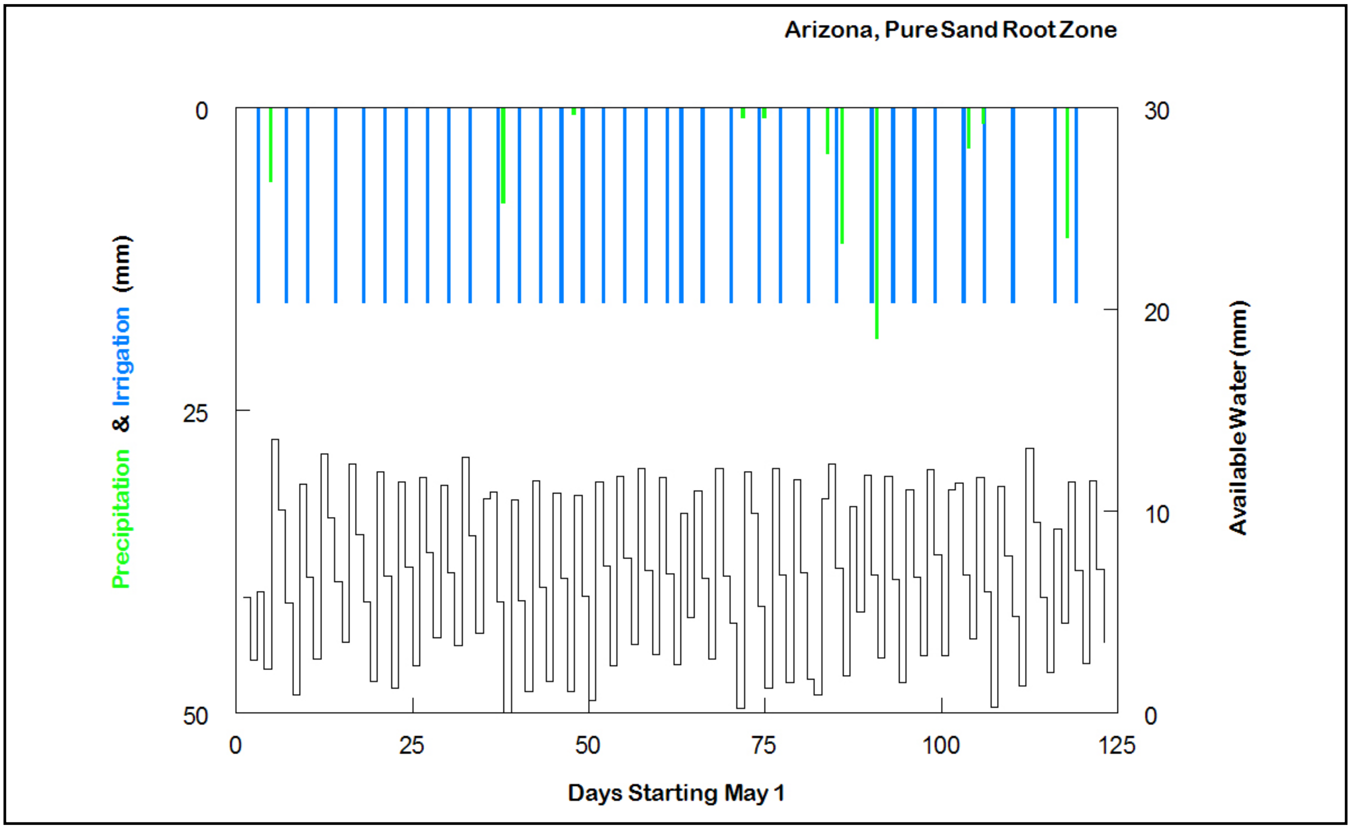
For each location, daily weather data including precipitation, maximum and minimum air temperature, solar radiation, dewpoint and wind speed were required to conduct the analysis. Further, a 20-year span of the daily weather data was chosen as suitably sufficient to account for year-to-year variability. To access this weather data, we used a stochastic weather simulator called GEM6 (www.wcc.nrcs.usda.gov/climate/gem.html) obtained from Dr. Greg Johnson of the USDA-NRCS National Water and Climate Center in Portland, OR. This software delivers a time series (data stream) of daily weather data for as many years of simulated weather as desired for many locations in the continental U.S. The GEM6 generator used in this study is endorsed as the weather generation tool of choice by the USDA, NCRS, and ARS.

The daily precipitation data for the six locations of this study were used directly in the analysis. The remaining weather data was used to calculate clipped grass reference ET (ET_o) using the ASCE Penman-Monteith equation recommended in 2000 by the ASCE Task Committee on Standardized Evapotranspiration Calculations. ET_o calculations were accomplished using the REF-ET software (www.kimberly.uidaho.edu/ref-et) from the University of Idaho.

Finally, a factor was needed to convert ET_o values corresponding to the 4-inch clipping height of the reference grass to comparable values for a closely mown putting green turf. The value of this conversion factor came from our two-year water balance study wherein measured values of putting green turf ET were compared with an evaporation pan reference. Based on this comparison, a conversion factor value of 0.5 was chosen for this study. Thus, the weather data used in this study consisted of a 20-year record of daily precipitation and putting green turf ET for the six metropolitan locations. As with the AWC values, these weather variables were expressed as a depth of water.

Analysis Steps

The analysis began with the total available water capacity available for turf use. Each subsequent day, ET removes a depth of water from this reservoir. If rain occurs, the specified depth of rainfall will partially refill the available water



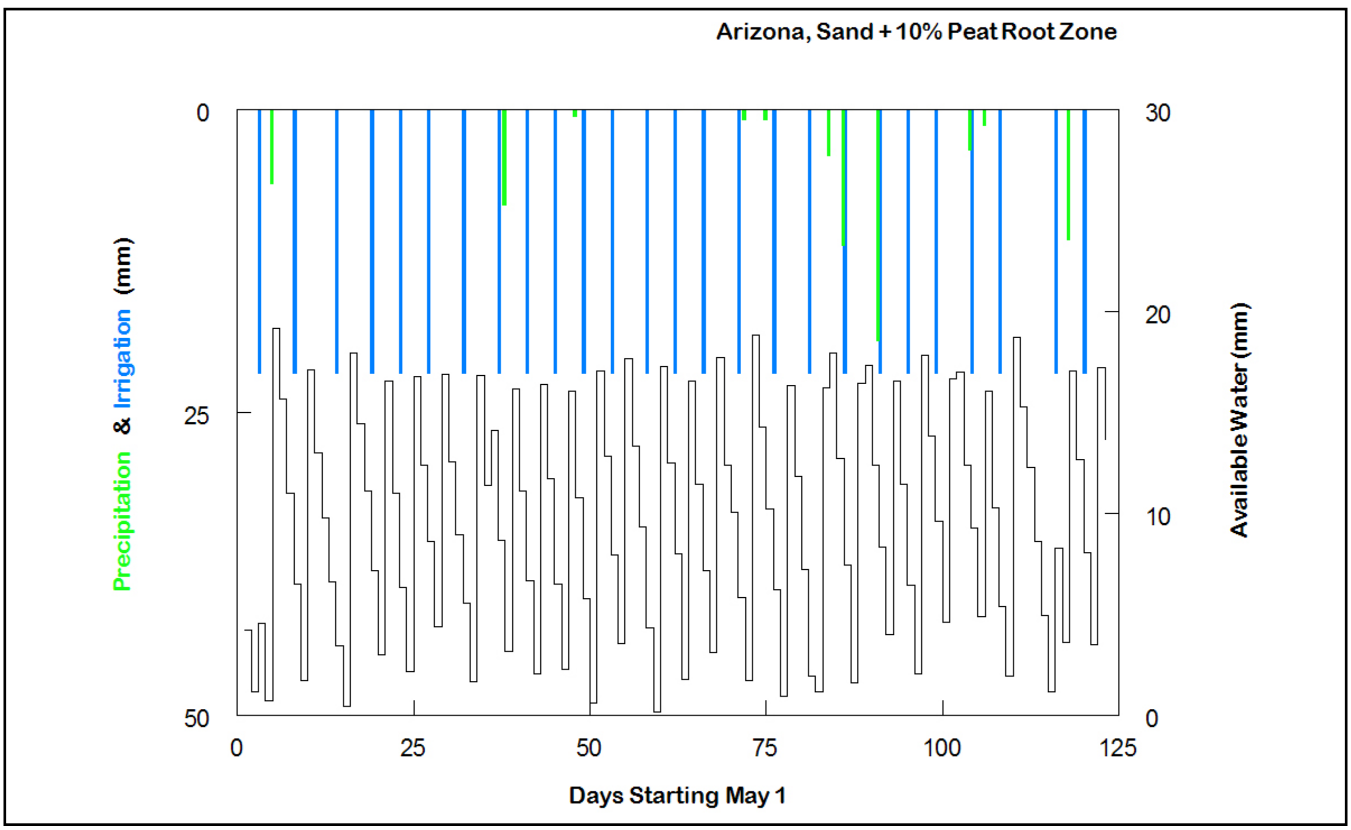


Figure 1. Precipitation, irrigation and available water depths (mm) for 123 days starting May 1 in Phoenix, AZ. This is an example of the results for an arbitrarily selected year of the study. The upper graph is for a pure sand rootzone with 23 mm of AWC and the lower graph is for a sand + 10% peat rootzone with 31 mm of AWC.

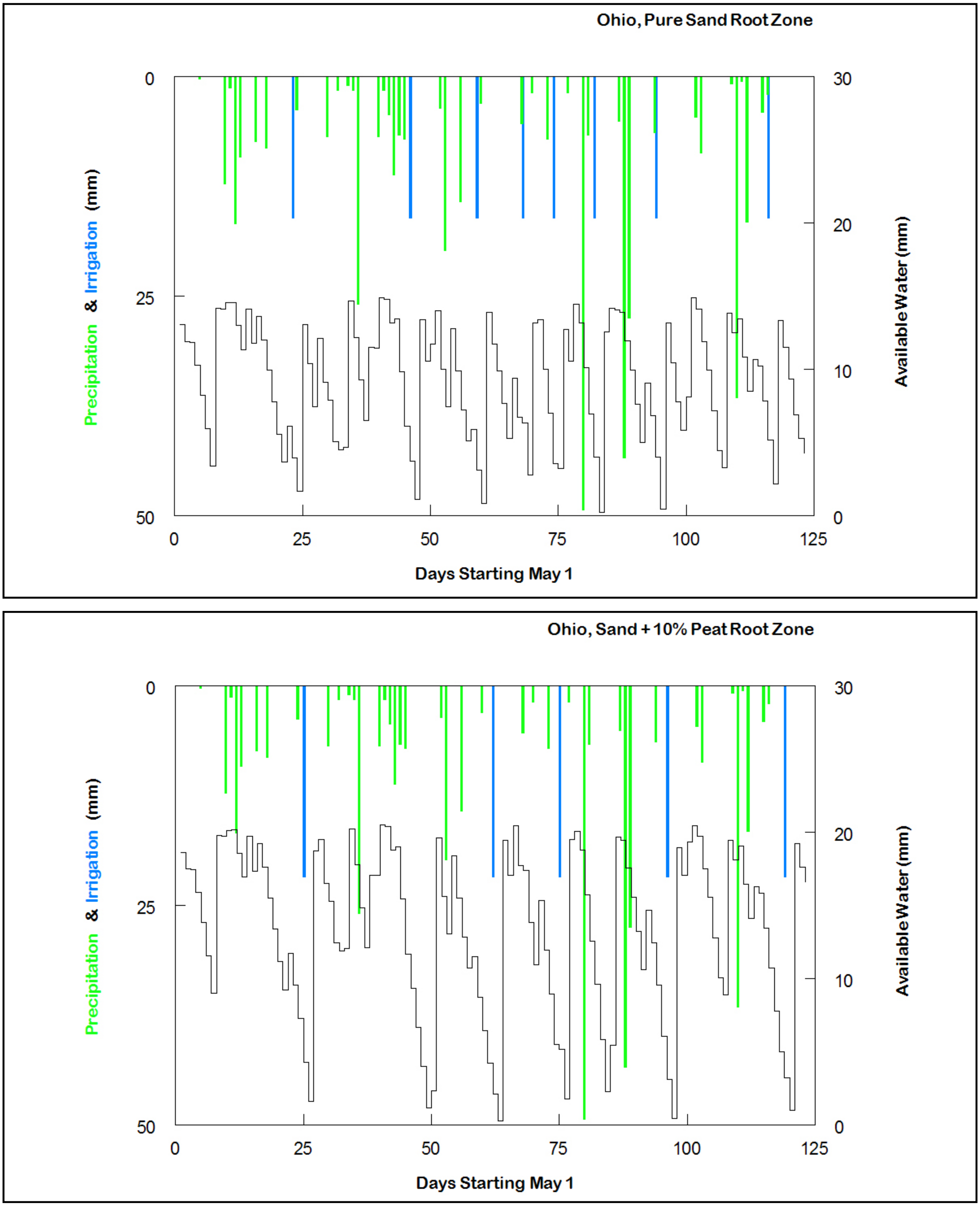


Figure 2. Precipitation, irrigation and available water depths (mm) for 123 days starting May 1 in Columbus, OH. This is an example of the results for an arbitrarily selected year of the study. The upper graph is for a pure sand rootzone with 23 mm of AWC and the lower graph is for a sand + 10% peat rootzone with 31 mm of AWC.

	Pure Sand		Sand + 10% peat		Sand + 10% peat + 10% soil	
	Irrigation depth	Irrigation events	Irrigation depth	Irrigation events	Irrigation depth	Irrigation events
	--cm--		--cm--		--cm--	
70% Depletion†						
Phoenix, AZ	2301	1429	2200	1014	2139	783
Sacramento, CA	1306	811	1240	571	1204	441
Boulder, CO	968	601	871	401	813	298
Houston, TX	747	464	627	289	546	200
Miami, FL	734	456	592	273	508	186
Columbus, OH	315	196	254	117	191	70
50% Depletion†						
Phoenix, AZ	2471	2149	2317	1495	2220	1138
Sacramento, CA	1400	1281	1311	846	1262	647
Boulder, CO	1082	940	980	633	920	471
Houston, TX	889	772	770	496	645	331
Miami, FL	892	776	747	481	640	328
Columbus, OH	432	375	328	211	272	139

† The percent depletion values correspond to management options whereby irrigation is withheld until the indicated proportion of available water is depleted by turf ET; 50% being the more conservative approach.

Table 2. Estimated, 20-year irrigation depth and event count for a 300-mm deep rootzone containing pure sand, sand amended with 10% (vol.) peat, and sand amended with 10% (vol.) peat + 10% (vol.) soil. The results correspond to deficit-based irrigation practices and are generated for six locations from distinct soil moisture regimes of the U.S. (3). The pure sand rootzone contained 23 mm of available water, the sand amended with 10% peat contained 31 mm of available water, and the sand amended with 10% (vol.) peat + 10% (vol.) soil contained 39 mm of available water; where available water was defined as the depth of water retained in a 300-mm rootzone following drainage to the first indication of turf wilt (foot-printing).

reservoir, completely refill the available water reservoir, or refill available water with excess lost to drainage. If available water is diminished to a specified threshold, then irrigation will be required to refill the reservoir.

In this analysis, we chose two thresholds expressed as a percent of AWC. The more conservative threshold of 50% AWC means that if available water is diminished to 50% of its capacity, then an irrigation event would be required to refill it. A less conservative threshold of 70% AWC was also chosen, where irrigation would not occur until 70% of available water was depleted. The amount of irrigation applied is exactly the amount required to refill the available water capacity. Thus, the depth of irrigation applied for each irrigation event will depend on AWC and the specified threshold.

Finally, irrigation was not applied if a five-day moving average of the mean air temperature was below 42º F. This prevented an irrigation event from occurring when the turf was non-active due to seasonally cold weather. Subsequently, the cumulative number of irrigation events and the total depth of irrigation applied were determined for the entire 20-year weather record of each location.

Results

A deficit-based irrigation scenario was generated for approximately 7,300 days for each of the six locations. This scenario indicated precisely when, given the local climate, an irrigation event was needed to refill the available water capacity and avoid drought stress. Further, this irrigation scenario was repeated for the various rootzones of the study.

Examples of the analysis output are given in Figures 1 and 2. These figures show only a small portion of the data series; 123 days starting May 1 for just one of the 20 years. Also, the figures are paired, showing the results from a pure sand rootzone (AWC = 23 mm) and a sand + 10% peat (AWC = 31 mm) rootzone. A threshold of 70% AWC was used in both Figures 1 and 2. In these graphs, precipitation and irrigation amounts extend downward from the top, as shown on the left-hand axis, and the present state of available water extends upward from the bottom, as shown on the right-hand axis.

Figure 1 is for Phoenix, AZ, characterized by generally large ET rates and infrequent rainfall. Correspondingly, irrigation events were frequent (35 shown), particularly for the pure sandroot zone. Whereas precipitation varied in amount as would be expected for natural rainfall, irrigation depths applied were always the same, such as would occur by setting a sprinkler run time and nozzle output. Available water peaked following an irrigation event and was stepwise diminished by daily ET.

Including 10% peat increased AWC such that the frequency of irrigation events could be reduced (26 shown), but with a greater depth of water applied during each event. The rainfall pattern remained the same for the pure sand and sand + 10% peat scenarios because the same Phoenix weather record was used for all rootzone treatments.

	Sand + 10% peat		**Sand + 10% peat + 10% soil**	
	Irrigation savings	Event reduction	Irrigation savings	Event reduction
	%	%	%	%
70% Depletion				
Phoenix, AZ	4.4	29.0	7.1	45.2
Sacramento, CA	5.1	29.6	7.8	45.6
Boulder, CO	10.1	33.3	16.0	50.4
Houston, TX	16.1	37.7	26.9	56.9
Miami, FL	19.3	40.1	30.8	59.2
Columbus, OH	19.5	40.3	39.5	64.3
50% Depletion				
Phoenix, AZ	6.2	30.4	10.2	47.0
Sacramento, CA	6.4	34.0	9.8	49.5
Boulder, CO	9.2	32.7	15.0	49.9
Houston, TX	13.4	35.8	27.4	57.1
Miami, FL	16.5	38.0	28.2	57.7
Columbus, OH	24.2	43.7	37.1	62.9

Table 3. Estimated, 20-year irrigation savings from the addition of 10% peat or 10% peat + 10% soil (vol./vol.). Savings are based on the reduction of irrigation depth and the reduction of irrigation events as compared with a pure sand rootzone.

As can be seen for just a few instances in Figure 1, an irrigation event could be delayed if rainfall occurred during the intervening period, refilling or partially refilling AWC. By increasing AWC using the 10% peat amendment and extending the interval between irrigations, there is an increased probability that rainfall will refill AWC and delay a required irrigation event, reducing overall irrigation requirements.

Figure 2 shows the results for Columbus, OH where, during the summer months, rainfall is more frequent, delivers greater depths of water, and daily ET is less than in Arizona. As a result, few irrigation events are required, and these events are separated by relatively longer time intervals. For the period shown in Figure 2, there were eight irrigation events for the pure sand rootzone and five events for the sand + 10% peat rootzone. Again, however, a greater depth of water was applied for the sand + 10% peat rootzone compared to the pure sand rootzone.

A summary of the results of this study is given in Table 2, where estimated, 20-year irrigation depth and event counts are presented for the six locations and three rootzones considered. Also shown are results for 70% and 50% AWC depletion scenarios. The locations are ordered in Table 2 from those requiring the greatest irrigation depth to those requiring the least irrigation depth when considering the pure sand rootzone. In all cases, incorporating peat or peat + soil served to reduce both the irrigation depth and the number of irrigation events. This benefit is provided by the increased AWC of the amended rootzones. Further, adopting a 70% depletion scenario as compared with a 50% depletion scenario also reduces irrigation depth and event count; although at a greater risk of turf drought stress.

The results also allow for calculation of percentage savings from using 10% peat or 10% peat + 10% soil amendment in a rootzone. The savings in this case are based on the reduction in irrigation depth and number if irrigation events as compared with a pure sand rootzone (Table 3). Using this calculation, savings in irrigation depth from using peat ranged from a modest 4% in Phoenix to a considerable 24% in Columbus, OH. Savings from amending pure sand with peat + soil ranged from 7% in Phoenix to almost 40% in Columbus. These savings reflect differences in irrigation amounts solely on the basis of replenishing AWC. Event reduction, on the other hand, was considerable at all locations ranging from 30 to 60%. Although not specifically determined in this study, reducing the number of irrigation events may also serve indirectly to conserve water by reducing irrigation system inefficiency losses. Finally, the amendment effect shown in Table 3 was not appreciably different between the 50% and 70% depletion scenarios.

The location effects of Table 3 can mostly be interpreted by considering rainfall frequency and ET differences that occur in the various locations. Because rainfall is more frequent in Columbus than Phoenix, by extending the irrigation interval using an amendment, there is a greater probability that rain will (partially or completely) replenish the AWC. Again, with natural precipitation replenishing AWC, the subsequent irrigation event can be delayed, overall reducing irrigation need. The smaller ET of Columbus than in Phoenix performs similarly in that the increased AWC of an amended rootzone will take longer to deplete and also delay irrigation. Thus, both rainfall frequency and ET serve in extending the irrigation interval.

Rainfall amount for a given rainstorm, however, also contributes to the location effects of Table 3. Rainstorms occurring in Columbus generally deliver greater precipitation amounts and are more likely to fully replenish AWC than in Phoenix. For example, there were 330 days in Columbus (11.7% of all rain days) when rainfall equaled or exceeded 16.1 mm (70% of the AWC for sand); whereas there were 54 days in Phoenix (7.4% of all rain days) when rainfall equaled or exceeded this same amount.

This implies that there was a 60% greater chance that a rainstorm in Columbus would completely replenish AWC than in Phoenix. In a sense, incomplete filling of AWC from a given rainstorm would only delay an irrigation event whereas completely filling of AWC would allow to completely skip an irrigation event. Of these three weather factors considered, however, the increased rainfall frequency of Columbus compared to Phoenix is expected to serve the greatest role explaining location effects.

Thus, the results of Table 3 reinforce the role of natural rainfall in influencing the magnitude of irrigation savings when amendments are used to increase AWC. Greater proportionate irrigation savings occur when rainfall is sufficiently frequent, allowing natural precipitation the opportunity to replenish the AWC reservoir. Without frequent rainfall, even though increased AWC allows for less frequent irrigation, the differences are diminished by the system demand for greater irrigation amounts with each application.

Conclusion

Irrigation water conservation from the use of an amendment results from increasing the available water capacity of the putting green rootzone such that less frequent irrigation is required. This provides a greater probability that a rainstorm, rather than irrigation, would replenish the AWC reservoir. The climate where the putting green is located, however, dictates the actual probability of a replenishing rain to occur. Thus, the location of the putting green within the U.S. will influence the absolute magnitude of irrigation water conservation.

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