CHAPTER 5

Bihourly Moisture Depletion Patterns in Fairway Turfs

Abstract

Syringing during hot afternoons is a common practice in fine turf management. However, timing criteria for syringing are mostly based on visual observations. Time domain reflectometry (TDR) was used to monitor soil moisture depletion in bihourly time steps at four depths under three irrigation regimes for established annual bluegrass and creeping bentgrass fairway turfs. The objectives were: i) to establish the time of the day when soils moisture depletion is highest under fairway turfs; and ii) compare the summation of bihourly moisture depletion during daylight hours to daily adjusted ET. The irrigation treatments were: i) apply 2.5 mm daily; ii) apply 25 mm upon the appearance of wilting stress; and iii) return the soil to field capacity daily based on soil moisture depletion as measured by TDR. This study was conducted at the Hancock Turfgrass Research Center at Michigan State University to evaluate soil water dynamics in fairway turfs during daylight hours on three different dates with contrasting evaporative demand in 1993 and 1994. Bihourly moisture depletion by species and irrigation treatment were compared to weather based ET. Moisture depletion varied by turf species, soil depth, irrigation treatment and time. Moisture depletion patterns were also dependent on initial moisture content and evaporative demand. The

greatest change in moisture content was from the 0-5 cm depth for the field capacity and 2.5 mm daily irrigation treatments between 0900 and 1300 h confirming that syringing in the early afternoon may reduce moisture and temperature stress. Moisture depletion data as measured by TDR for the irrigation treatments were generally more conservative than the adjusted Penman estimate from a weather station on site. This suggests that potential water savings could be made from soil moisture depletion-based turf irrigation scheduling. However, agreement between moisture depletion and Penman estimates was poor.

Introduction

The competition for water and declining water resources call for more efficient water management strategies in turf as in conventional agriculture. Improved water conservation may delay the search for alternative water sources and reduce possible contamination of surface and ground waters. One method of conserving water is through the development of environmentally sound and efficient irrigation scheduling programs.

Accurate application rates and timing are critical management decisions in turf irrigation management. Several factors must be considered in developing timing criteria for golf course irrigation scheduling. Among these are the prevention of wilting stress and reduction of disease incidence (Vargas, 1994) and leaching of agricultural chemicals into ground water (Augustin and Snyder, 1984). Another factor is interference with play or cultural activities (Beard, 1973).

Few golf courses have automatic weather stations that provide site-specific evapotranspiration (ET) data. Although such technology facilitates the decisions on how much water to apply, it does not provide answers to the question of when to irrigate. Furthermore, it is difficult for turf managers to justify the purchase of such expensive equipment. For the most part, irrigation scheduling on golf courses is based on visual observations of wilting stress, foot printing or as a security measure, light daily applications (Vargas, 1994). Efficient irrigation scheduling remains a major challenge for most turf managers as they strive to maintain a delicate balance between growing quality turf and environmental concerns.

Syringing is commonly used to moderate canopy temperature during hot days. However, studies on the effect of syringing on canopy temperature show variable results. Duff an Beard, (1966) reported a 1 to 2 °C reduction in temperature lasting 2 h following the application of 6.4 mm of irrigation at 1200 h, while Hawes (1965) concluded that application of 3 mm of irrigation between 1130 and 1500 h resulted in canopy temperature reductions between 0.8 to 4 °C for up to 600 s. On the other hand, Dipola (1984) found no significant difference in canopy temperature 1 h after syringing regardless of timing or syringing amounts over a certain range. Ideally, irrigation should be applied prior to the appearance visual signs of stress (Beard, 1982). Soil moisture depletion monitoring could improve timing criteria for turf irrigation (Carrow, 1991) and possibly for syringing on hot days.

Despite good correlation between mini-lysimeters and weather based ET estimates (Feldhake et al., 1984) mini-lysimeters have been criticized for having soil-container interfaces that interrupt upward and lateral water flow and for not being representative of field turf conditions. Weather-based ET estimates fail to account for soil moisture status even when adjustments are made by multiplying the potential ET by a turf or crop coefficient as suggested by Carrow (1991). Comparing various modifications of the Penman equation, Allen (1986) reported 10-25% error compared to large weighing lysimeters.

Although models have been developed that estimate moisture depletion in hourly or shorter time steps (Ritchie, 1990), field methods for soil moisture determination needed to verify such models usually require longer waiting periods and thus fail to serve as effective tools for model validation. For the gravimetric method, at least 24 h are needed to obtain soil moisture data (Hanks, 1992). In addition to destructive sampling, this method is also subject to errors from spatial variability (Hillel, 1980).

While neutron scattering requires considerably shorter waiting periods, the problems of exposure to radiation and the need for routine calibration remain (Hillel, 1980). Also, the neutron probe is not amenable to the shallow rooting depths encountered in turf due to errors from neutrons escaping to the surface (Snyder et al., 1984). Finally, the dependence of the spatial resolution of the neutron probe on the degree of wetness is of concern to some scientists (Arnon, 1992).

Moisture depletion measurements in soils integrate plant, soil and atmospheric interactions into a single measurement. Kirsch (1993) used neutron scattering and gravimetric measurements to locate the zero flux plane and estimate ET with errors of up to 153 %. He acknowledged that techniques such as TDR may yield more reliable ET estimates.

In sand-based soils with low moisture retention, low-volume, high-frequency irrigation is required to supply adequate amounts of water for quality turf maintenance. This implies that methods for rapid and accurate moisture determination are needed to provide adequate and timely supplies of water to the turf, in order to reduce overwatering and the incidence of wilting stress.

In the last decade, time domain reflectometry (TDR) has become an acceptable method for soil moisture determination. This method is accurate, fast, and precise, and does not involve radioactive risks associated with the neutron probe or gamma-attenuation techniques (Topp et al., 1980; Dalton, 1992). Despite the potential benefits of TDR and other soil moisture sensors, their use in real-time turf irrigation scheduling and modeling has not been fully explored.

The literature is replete with articles on the theoretical development and potential agricultural applications of TDR. However, few studies have addressed the use of TDR in real-time irrigation scheduling for field crops (Topp and Davis, 1985) or for turfgrass irrigation (Carrow, 1991; Saffel, 1994). The use of TDR in turf irrigation scheduling may result in more efficient water application rates and timing on greens and fairways and eventually, on home lawns, when the technology becomes affordable.

This study evaluated bihourly moisture depletion patterns in annual bluegrass (*Poa annua* L. var. reptans) or creeping bentgrass (*Agrostis palustris* Huds. L.) fairway turfs under three irrigation regimes. The specific objectives were: i) to monitor moisture depletion patterns of annual bluegrass and Penncross creeping bentgrass fairway turfs under three irrigation regimes and ii) to compare Penman ET to daily moisture depletion.

Materials and Methods

This study was conducted at the Hancock Turfgrass Research Center at East Lansing, MI. The soil type was an Owosso sandy loam (fine-loamy, mixed Typic, Hapludalf) with an average field capacity of 0.28 $cm^3\,cm^{-3}$. Bihourly volumetric moisture content was determined by TDR from 0700 to 2100 h on 13 Aug. 1993 and 16 Aug. 1994, and from 0700 to 1900 on 13 Sept. 1994. From long-term weather forecasts, all three dates were expected to be sunny, with high temperatures and high evaporative demand. In 1993, 198 readings were taken bihourly, whereas only 66 readings were taken in 1994 due to some dysfunctional probes.

Pairs of TDR stainless steel rods 3.2 mm in diameter and 200 mm long, with 50 mm center-to-center spacing, were installed at 2.5, 7.5, and 12.5 cm from the soil surface in three replicates (Topp et al., 1980; Saffel, 1994). A fourth set of probes of similar configuration was also installed, with one rod at 17.5 cm and the other at 22.5 cm in only two replicates due to restrictions on the number of positions on the rotary switch used to move between sets of probes. These probe pairs measured VMC in the 0-5, 5-10, 10-15, and 15-25 cm depths respectively.

Three irrigation treatments were evaluated on Penncross creeping bentgrass or annual bluegrass turfs. The irrigation treatments were: i) apply 2.5 mm daily (Vargas, 1994); ii) return the soil to field capacity (0.28 $cm^3 cm^{-3}$) daily based on TDR readings; and iii) apply 25 mm only upon the appearance of wilting stress. Irrigation treatments served as whole plots with dimensions 11 x 11 m in three replicates. Each irrigation plot was split in half (11 x 5.5 m) and planted at random to pure stands of either annual bluegrass (*Poa annua* L. var. reptans) and Penncross creeping bentgrass (*Agrostis palustris* L. Huds.) established in 1989 (Saffel, 1994). Both species were maintained according to standard management practices for cool-season fairway turfs in Michigan with a cutting height of 16 mm.

Evapotranspiration data for each date were recorded from a Rainbird automatic weather station at the site 2 m above the ground. Soil moisture depletion (mm) for each depth was calculated from the equation of Arya et al. (1975):

$$(VMC_{n+1} - VMC_n) * \text{depth of soil layer (mm)}$$

where n is initial VMC reading and n+1 represents successive VMC readings.

The experimental layout was a 3*2*4 factorial split-strip design with three replicates. Time domain reflectometry installations at four depths served as the strip. Bihourly VMC data were analyzed using repeated-measures analysis of the general linear model and Student Neuman-Keuls (SNK) mean separation procedures (SAS Institute, Inc., 1994).

Results and Discussion

Solar radiation, minimum and maximum temperatures values for the three study dates are given in Fig. 5.1. Temperatures from 0600 to 1700 h were similar for 13 Aug. 1993 and 16 Aug. 1994. However, minimum and maximum temperatures on 13 Sept. 1994 started about seven degrees lower than on the other days. Temperatures increased rapidly from 0700 to 1100 h, with similar slopes on all dates. After 1100 h, the rate of increase declined and temperatures remained fairly constant until 1900 when maximum temperature peaked again for all dates, although this was more pronounced on 13 Aug. 1993. Solar radiation trends were about the same on all days, except that changes between 1600 and 1700 h were more drastic on 13 Sept. 1994 (Fig. 5.1). This date also had shorter daylight hours.

Bihourly relative humidity and wind velocity for study dates are presented in Fig. 5.2. Relative humidity ranged from 85% (between 0600 and 0900 h) to a low of 60% at 1600 h on 13 Aug. 1993 and 16 Aug. 1994 but rose back to 85% and 75%, respectively. Relative humidity on 13 Sept. 1994 was significantly lower than on other dates, with a maximum of less than 60% early in the morning to a low of 25% at 1800 h.

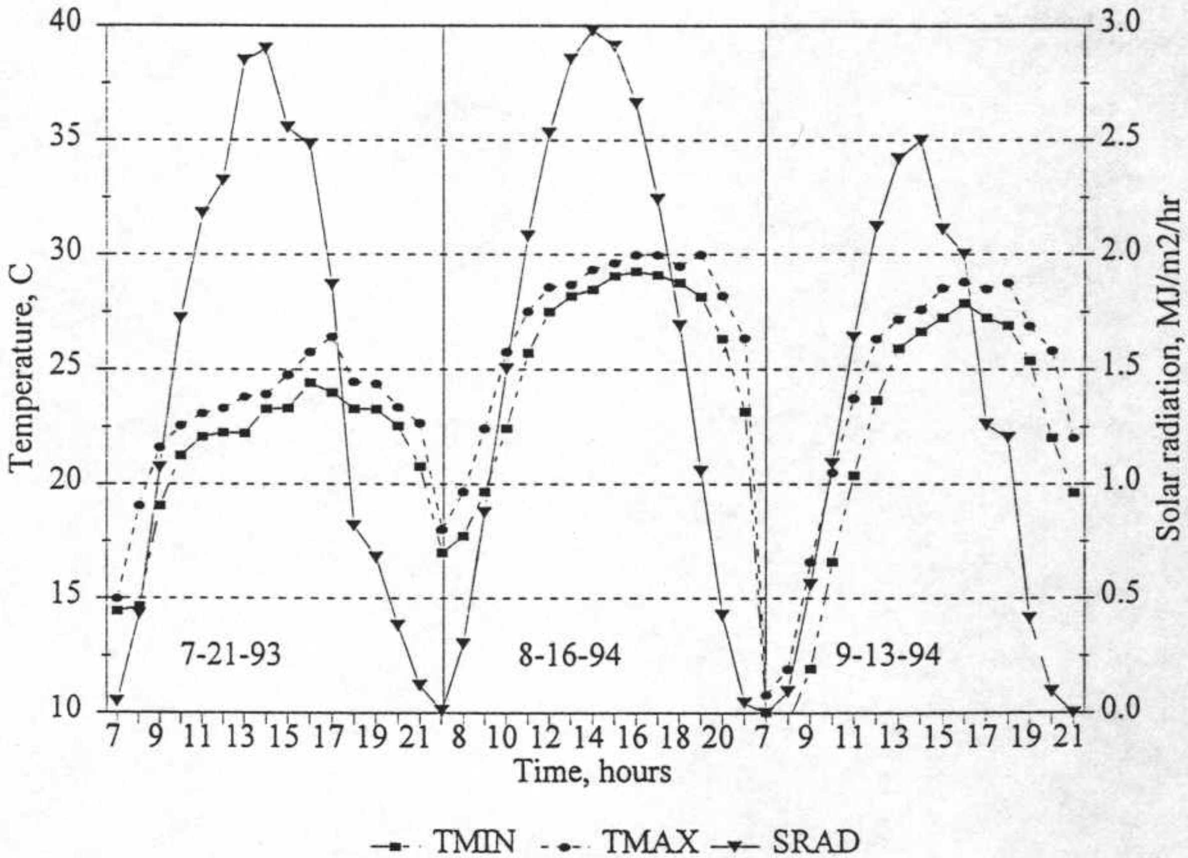

Fig. 5.1. Bihourly minimum temperature (TMIN), maximum temperature (TMAX) and solar radiation (SRAD), for 13 August 1993, 16 August 1994 and 13 September 1994.

Wind velocities for both dates in August were comparable and were much higher than those on 16 Sept. 1994. Turfgrass leaves were wet early in the morning either from dew, guttation or irrigation. By 1100, most of the moisture had either infiltrated into the soil or evaporated as solar radiation and temperature increased.

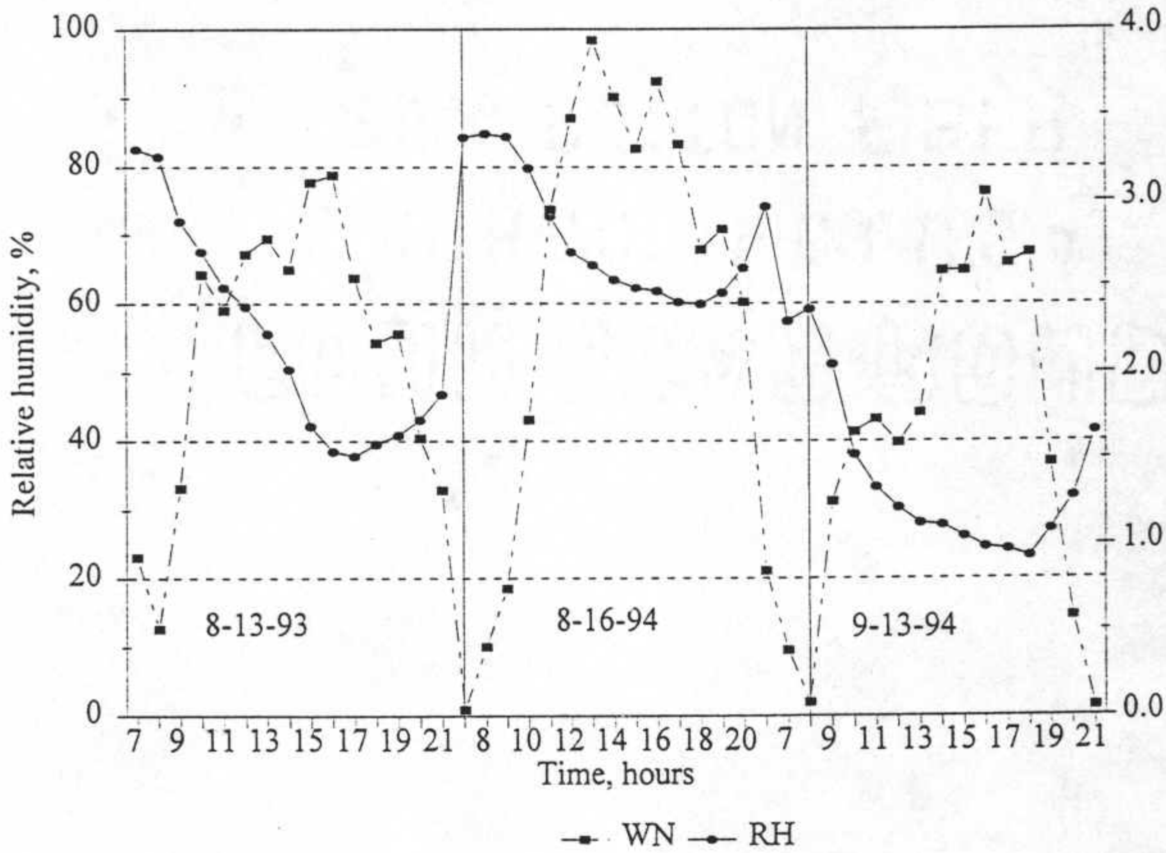

Fig. 5.2. Bihourly relative humidity (RH) and wind velocity (WV) for 13 August 1993, 16 August 1994 and 13 September 1994

The analysis of variance (Table 5.1) showed that irrigation treatment (TRT) and the TRT*DEP (sampling depth) interaction significantly affected VMC for all sampling dates while species (SPE) and sampling depth (DEP) were significant only on the first two dates. The effect of species on VMC was significant on 13 Aug. 1993 and 16 Aug. 1994, but not at all intervals on 13 Sept. 1994. The significance of the TRT*DEP interaction was due to inherent moisture-retention capacities for the various soil depths as shown earlier (Fig.3.6).

Table 5.1. Analysis of variance for the test of hypotheses for between- (among-) subject effects for bihourly volumetric moisture content.

Source	13 Aug. 1993		16 Aug. 1994		13 Sept. 1994	
	df	*MS*	*df*	*MS*	*df*	*MS*
REP	2	0.003	2	0.001	2	0.0003
TRT	2	2.013***	2	0.029***	2	0.584***
REP*TRT	4	0.003	4	0.003*	4	0.007
SPE	1	0.046***	1	0.005*	1	0.004
TRT*SPE	2	0.013*	2	0.001	2	0.011
REP*SPE*(TRT)	6	0.004	6	0.003	6	0.002
DEP	3	0.015**	3	0.022***	3	0.004
TRT*DEP	6	0.043***	6	0.003*	6	0.016**
SPE*DEP	3	0.001	3	0.001	3	0.001
TRT*SPE*DEP	6	0.002	6	0.002	6	0.002
Error	162	0.003	30	0.001	30	0.003

*,**,***Significant at the P = .05, .01, and .001 levels, respectively.
REP, DEP and SPE are replicate, depth and species respectively.

The repeated measures procedure (SAS Institute Inc., 1994) was used to analyze the data since multiple observations were taken per experimental unit at different times. The analysis of variance for repeated measures showed a time dependent variation of VMC during the course of the day as expected (Table 5.2). Variations in solar radiation, temperature, relative humidity and wind speed with time resulted in variable moisture redistribution within the soil profile for each sampling date. The TIME*DEP and TIME*TRT interactions were significant ($p > 0.01$) on all sampling dates.

Table 5.2. Repeated-measures analysis of variance for the test of hypotheses for VMC among subject effects.

Source	13 Aug. 1993		16 Aug. 1994		13 Sept. 1994	
	df	*MS*	*df*	*MS*	*df*	*MS*
TIME	7	0.0030*	7	0.0019***	7	0.0009***
TIME*REP	14	0.0001	14	0.0017	14	0.0001**
TIME*TRT	14	0.0001	14	0.0002	14	0.0001
TIME*REP*TRT	28	0.0001	28	0.0002	24	0.0001
TIME*SPE	7	0.0001	7	0.0001	7	0.0001
TIME*TRT*SPE	14	0.0002*	14	0.0003	14	0.0001
TIME*REP*SPE*(TRT)	42	0.0001	42	0.0002	42	0.0001
TIME*DEP	21	0.0003***	21	0.0004**	21	0.0001**
TIME*TRT*DEP	42	0.002*	42	0.003*	42	0.0001*
TIME*SPE*DEP	21	0.0039	21	0.0001	21	0.0000
TIME*TRT*SPE*DEP	42	0.0043	42	0.0002	42	0.0000
Error (TIME)	1134	0.0135	210	0.0002	180	0.0000

*,**,***Significant at the $P = .05$, .01, and .001 levels, respectively.
REP, DEP and SPE are replicate, depth and species respectively.

Bihourly volumetric moisture content (VMC) changes, however, were not greater than the measurement error for TDR and thus fail to provide conclusive evidence of soil water movement. Except for the stress treatment on 16 Aug. 1994, all maximum VMC values for the irrigation treatments were recorded at 0900 h for each date. All minimum VMC values were recorded at 2100 h on 13 Aug. 1993. On 16 Aug. 1994 and 13 Sept.

1994, minimum VMC values were recorded either at 1700 or at 1900 h for all treatments. There was no significant difference between the 2.5 mm daily and the field capacity treatments, both of which were significantly higher than the stress treatment.

Initial VMC by depth for 13 Aug. 1993 (Fig. 5.3) and 16 Aug. 1994 (Fig. 5.4) ranked 0-5 > 5-10 > 10-15 > 15-25 cm depths. Graphs for moisture depletion with time for the 5-10 and 10-15 cm depths for field capacity treatment on 13 Aug. 1993 (Fig. 5.3) were about the same and followed the same moisture depletion pattern throughout the period of data collection. However, variations in VMC trends occurred with time for most other depths and treatments on both dates. For example, both annual bluegrass and creeping bentgrass showed a decrease in VMC for the 0-5 cm depth from 1700 to 1900 h, with a corresponding increase in VMC for the 15-25 cm depth for the stress treatment.

Moisture depletion from the 2.5 mm daily treatment on 13 Aug. 1993 showed contrasting trends between species and among depths (Fig. 5.3). At 0700 h, VMC by depth was in the order 0-5 > 5-10 > 10-15>15-25 cm, as expected since water wets the surface during irrigation. By 0900 h, the 0-5 and 5-10 cm depth for the bluegrass species had the same VMC. The greatest moisture depletion in the bluegrass plots was evident between 0700 and 0900 h for the 0-5 cm depth. While the high root density for this depth may explain greater water depletion there was no logical explanation for the timing since temperature and solar radiation were still increasing. Similar depletion for the bentgrass species was between 0900 and 1300 h (Fig. 5.3) suggesting a difference in timing between annual bluegrass and creeping bentgrass response to changes in environmental conditions.

Generally, the 0-5 cm depth for the irrigated treatments had significantly higher moisture content than all other depths. This may have been due to higher organic matter

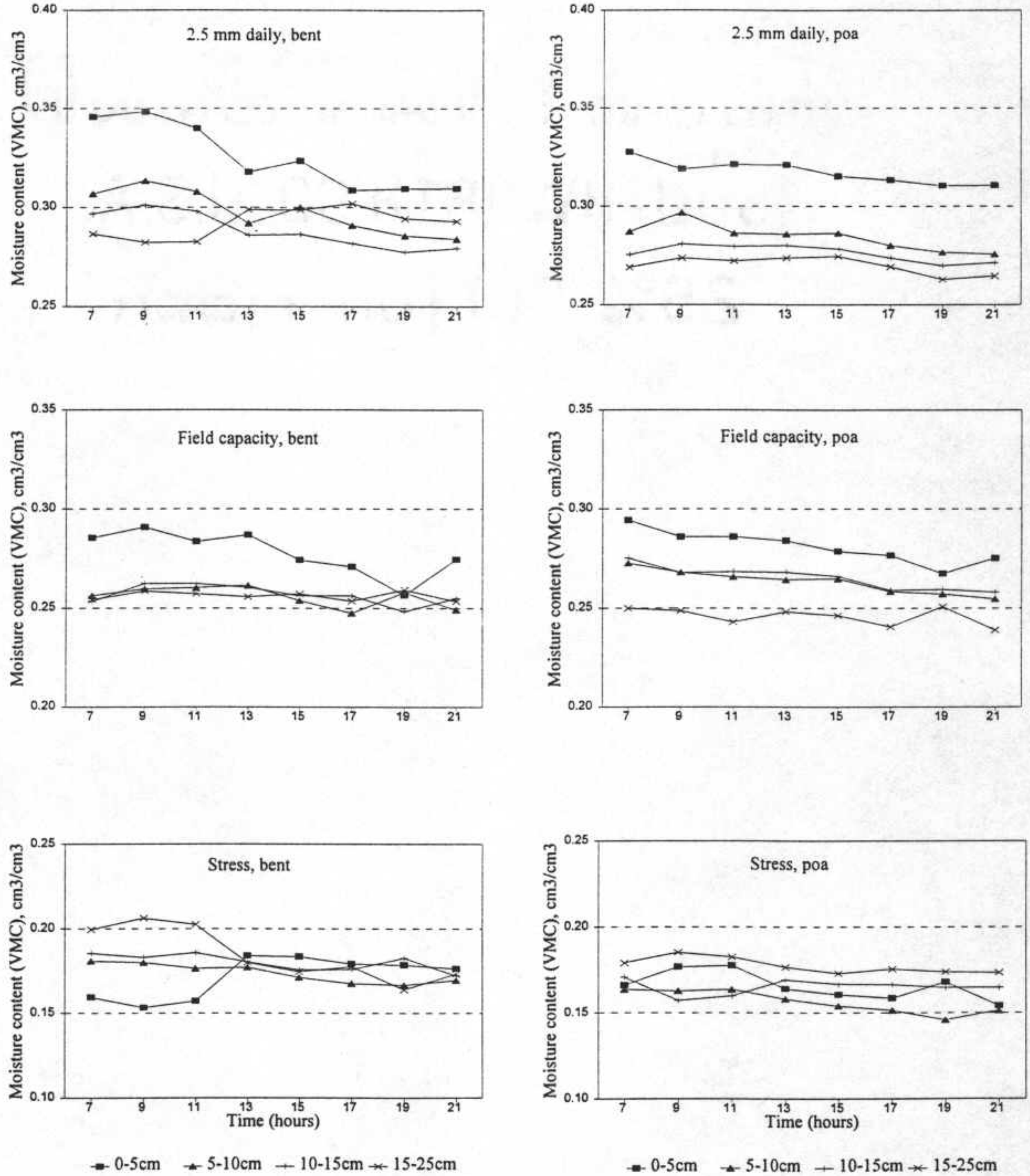

Fig. 5.3. Bihourly moisture depletion patterns for annual bluegrass and Penncross creeping bentgrass by irrigation treatment 13 August 1993.

content or it may indicate that TDR detects water in root tissues (about 70% of the root mass was in the 0-5 cm depth). Moisture depletion from the irrigated treatments was higher than from the stress treatment because VMC was lower for the stress treatment. The 15-25 cm depth for the stress treatment had the highest VMC levels until 1300 h. Whereas this trend persisted for the bluegrass species, VMC for the bentgrass species (0-5 cm depth) increased rapidly between 1100 and 1300 h.

Symmetrical moisture depletion and accretion patterns between depths suggest preferential as well as differential moisture uptake and redistribution by species for the different depths. The 15-25 cm depth for the bentgrass species showed the greatest increase in soil moisture content for both species on 13 Aug. 1993 in the stress treatment (Fig. 5.3). Moisture depletion for the bentgrass species showed similar patterns for all depths except the 15-25 cm depth (Fig. 5.3). Between 1300 and 1500 h, VMC for the 0-5 and 5-10 cm depths increased slightly. This increase may have been due to hydraulic lifting of water by the roots, coinciding with partial closing of the stomata (Jensen and Taylor, 1971). From 1700 h to the end of the day most depths showed only a minor depletion in moisture as solar radiation and temperature had dropped substantially.

On 13 Aug. 1993, volumetric moisture content means across treatments and depths for the bentgrass species were significantly higher than for the annual bluegrass for all sampling time intervals (Fig. 5.3) but not on the other two dates. All treatments showed an increase in VMC from 0700 to 0900 h except the stress treatment on 16 Aug. 1994 and the field capacity and stress treatments on 13 Sept. 1994. Since no irrigation was applied during this time course experiment significant increases in VMC suggest net water movement from one depth to another.

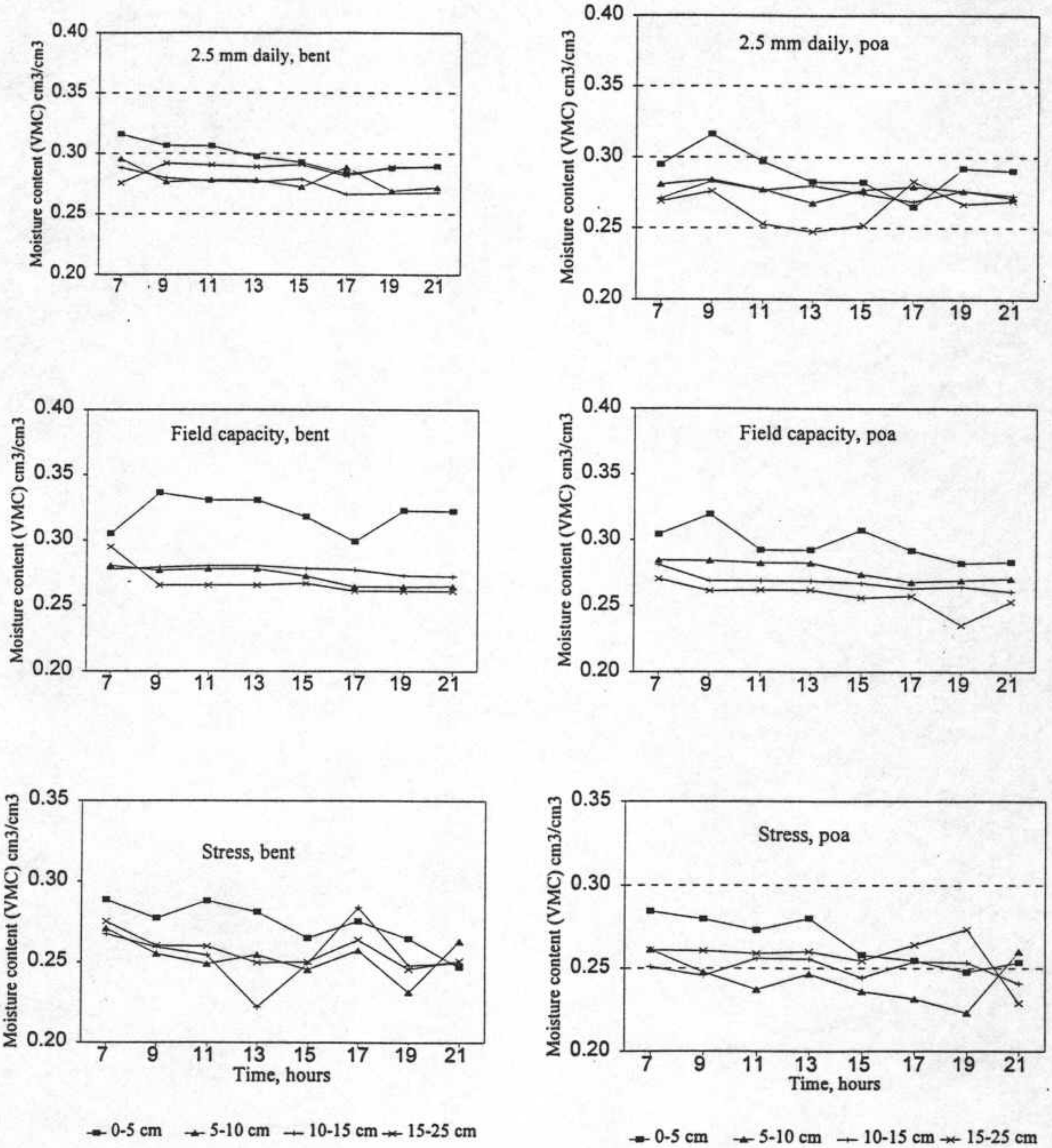

Fig. 5.4. Bihourly moisture depletion patterns for annual bluegrass and Penncross creeping bentgrass by irrigation treatment, 16 August 1994.

The mechanisms governing upward flow observed in this study were not investigated but deserve further study. Upward flow of water may be due to hydraulic lift by roots (Murphy et al. 1994), capillary rise (Hillel, 1980) or vapor diffusion if there is a high temperature gradient. Beard (1973) stated that dew may contribute as much as 0.3 to 0.4 mm a night under favorable conditions. While dew formation or guttation may explain the increase in VMC in the late afternoons, it is difficult to discard their contribution to increases in VMC during early morning hours. For the most part, changes in VMC were again within the margin of error of TDR.

Although moisture changes in soil varied by depth, species, and irrigation treatment, there was no clear-cut trend for moisture depletion by irrigation treatment, species, or depth. Symmetry between moisture accretion and depletion patterns between the 0-5 and 5-10 cm depths for annual bluegrass in the stress treatment suggests a net flux of water from one depth to another over certainn time intervals (Fig. 5.3). For the bentgrass species, the less pronounced symmetry between the 0-5 and the 15-25 cm depths from 0700 and 1300 h may be the effect of deeper roots used in water uptake causing a net flux of water from the 15-25 cm depth to the 0-5 cm depth. Between 1700 and 2100 h, VMC was fairly constant for both species. The greatest moisture depletion was from the 0-5 cm depth of the daily treatment between 0900 to 1300 h for the bluegrass species on August 16, 1994. Moisture content for the 0-5 cm depth for the bentgrass species decreased steadily till 1700 h. (Fig. 5.4).

Moisture depletion patterns for the 2.5 mm daily treatment on 16 Aug. 1994 were characterized by many interactions among depths (Fig. 5.4). The increase in VMC observed in the bluegrass species for the 2.5 mm daily treatment for all depths from 0700 to 0900 h was seen only in the 15-25 cm depth for the bentgrass species.

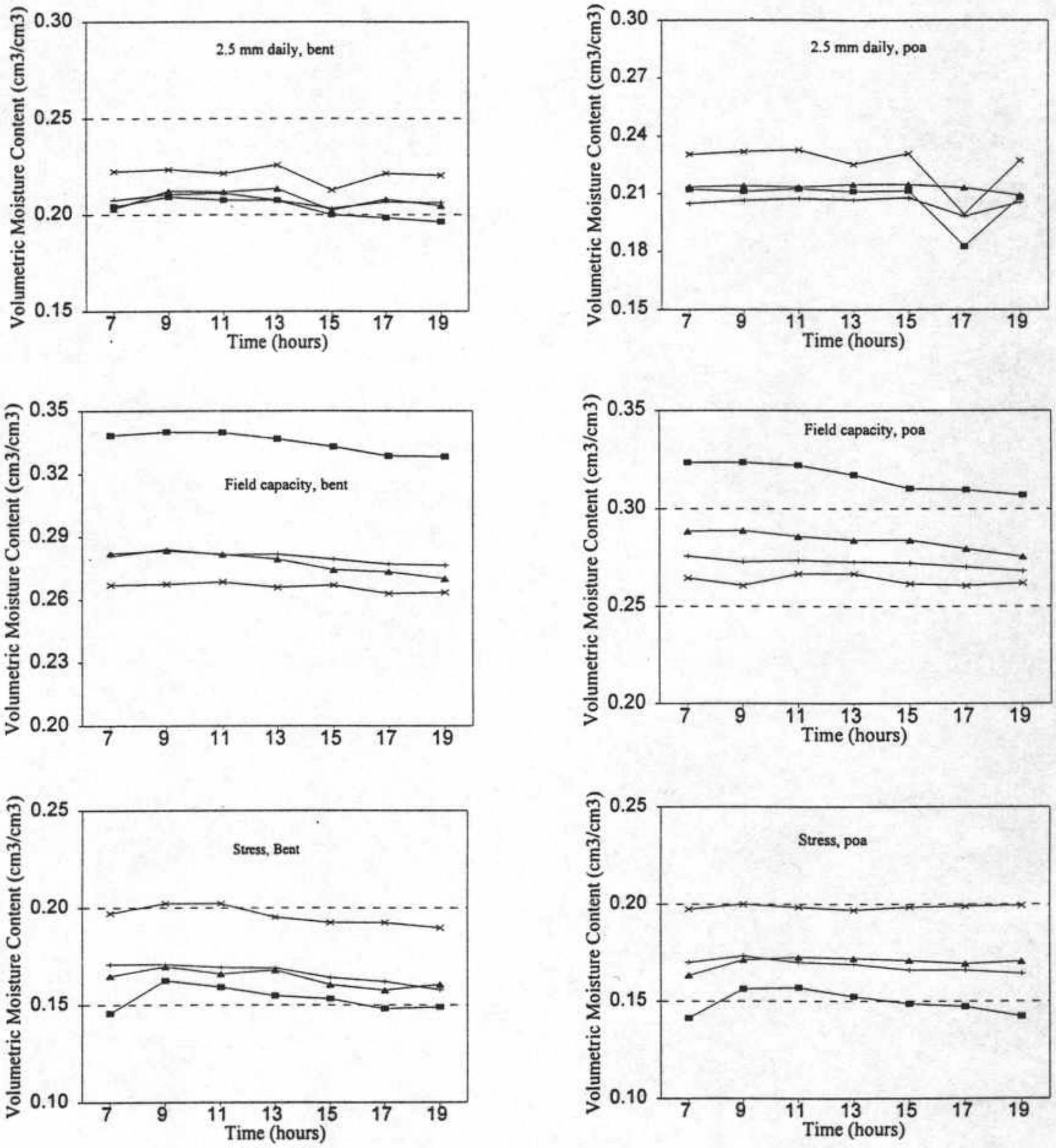

Fig. 5.5. Bihourly moisture depletion patterns for annual bluegrass Penncross creeping bentgrass by irrigation treatment 13 Septemberr 1994.

Initial moisture contents for the 0-5 cm depth for the field capacity treatment for both species were about the same at 0700 h and increased until 0900, but decreased between 0900 and 1100 h (Fig. 5.4). Although the largest decrease in VMC for the 15-25 cm depth occurred between 0700 and 0900 for bentgrass, the major decrease at this depth for the bluegrass species was between 1700 and 1900. As temperature and solar radiation had dropped significantly this decrease could either be due to rapid uptake of water following the opening of the stomata or due to TDR error as the computer battery was running low.

The stress treatment showed the most variation in VMC on 16 Aug. 1994. Initial VMC for the 0-5 cm depth for both species was about the same at 0700 h. For both species, there was no increase in moisture content in this treatment between 0700 and 0900 h on this date. However, VMC for the bluegrass species decreased until 1100 h, but the decrease in bentgrass species lasted until 0900 h. Symmetrical moisture depletion patterns were more obvious in the bluegrass species than in the bentgrass species. The deeper rooting depth of bentgrass compared to annual bluegrass may have contributed to more uniform water uptake along the soil profile. The largest increase in VMC was observed in the bentgrass species at 1700 h for all depths; only the 10-15 and 15-25 cm depths showed a corresponding increase between 1500 and 1900 h.

On 13 Sept. 1994, the 2.5 mm daily treatment showed similar moisture distribution patterns with respect to initial moisture content by depth at 0700 and 1300 h (Fig. 5.5). Whereas maximum depletion for the bluegrass species occurred at 1700 h, maximum depletion for the bentgrass species occurred at 1500 h. The large decrease in VMC observed toward the end of the day may have been due to TDR error.

On 13 Sept. 1994, cloudy skies and shorter day length accounted for low evaporative demand. The 15-25 cm depth had the lowest VMC, whereas the 0-5 cm depth had the highest VMC levels for both species in this treatment. However, by the end of the day, moisture levels for the 5-10, 10-15, and 15-25 cm depths were about the same (Fig. 5.5). This suggests differential moisture extraction patterns by depth for both species. Different rooting habits for annual bluegrass and creeping bentgrass during the heat of the summer (Koski, 1983; Murphy et al., 1994) may be a possible explanation for this. Also, Saffel (1994) suggested differential water uptake by depth for annual bluegrass.

Table 5.3. Comparison of soil moisture depletion (mm) across species by irrigation treatment and daily adjusted ET from a weather station at the Hancock Turf Research Center, Michigan State University.

Date	Irrigation Treatment DLY	FC	STR	ET (adjusted)
	mm			
13 Aug. 1993	3.0 (46)	3.0 (46)	2.0 (64)	5.6
16 Aug. 1994	3.5 (29)	3.8 (22)	3.3 (32)	4.9
13 Sept. 1994	3.3 (32)	2.8 (42)	2.3 (52)	4.8

† Values in parentheses reflect potential percent water savings for each irrigation treatment by date compared to the adjusted ET from a Rainbird weather station on site

On 13 Sept. 1994, all four depths for the annual bluegrass species in the 2.5 mm daily treatment had different initial moisture content (Fig. 5.5). Initial VMC for the bentgrass species showed only two distinct moisture levels. Only minor depletions were observed for the bentgrass species. This is probably due to the high soil moisture content in this treatment on this date. For the bentgrass species, the 5-10 and 10-15 cm depths had identical moisture depletion patterns throughout the day, increasing only from 0700 to 0900 h. Moisture depletion occurred mostly in early afternoon. Differences in moisture depletion patterns between species may be attributed to preferential moisture uptake by species and/or differential rooting patterns by depth (Saffel, 1994). This suggests that moisture depletion in response to evaporative demand is moderated by turf species and hence the need for site/cop-specific turf coefficients.

On 13 Sept. 1994, VMC differences by depth for the bentgrass species were not as great as those for the bluegrass species. For both species, moisture content for the 0-5 and 5-10 cm depths increased from 0700 to 0900 h. The 15-25 cm depth showed very little variation in the bluegrass plots, whereas all other depths showed a gradual decrease in VMC through the course of the study.

Initial water content for the bentgrass species was higher than for the bluegrass species in the 2.5 mm daily treatment. Changes in VMC for the bluegrass species observed in the 2.5 mm daily and field capacity treatments were lowest between 1100 and 1300 h (Fig. 5.5). In particular, the 2.5 mm daily treatment showed only minimal gains or losses in soil moisture content for the depths of interest over this interval, even though this coincided with peak values for solar radiation, minimum relative humidity and high temperatures, conditions that favor high evaporative demand. Possible explanations for these observations are: i) the stomata closed to the extent that plant water uptake was about the same as the evapotranspiration thus maintaining a steady VMC, and ii) the shallow root system of annual bluegrass may not be as efficient ın water uptake as that of creeping bentgrass.

There was no distinct pattern to the data with respect to irrigation treatment or species. This suggest that the different species show variable response to different levels of evaporative demand. This variation may be based on amount of available water, root distribution within the profile, and time of the day. While bentgrass species have been shown to have higher and deeper root mass than annual bluegrass (Murphy et al., 1994; Saffel, 1994). It must be cautioned that higher root mass may not necessarily imply higher water and nutrient uptake efficiency.

Moisture depletion as measured by TDR ranked FC > DLY > STR for all sampling dates because dates selected for bihourly moisture depletion studies coincided with dry periods. Although the Penman ET recorded on August 13, 1993 was highest, the moisture depletion data were highest on August 16, 1994 for all treatments. This illustrates the discrepancies in comparisons between ET and soil moisture depletion and underscores the complex nature of the interactions between plant species and soil under different evaporative demand. It also illustrates the need for conjunctive use of weather based ET and soil moisture depletion measurements in irrigation scheduling.

Moisture depletion data shown on (Table 5.3) were more conservative than the adjusted ET from the modified Penman equation for all dates and treatments probably due to upward water movement. The percent difference between soil moisture depletion and weather based ET (shown in parenthesis in Table 5.3) indicate potential water savings of up to 46 % for the irrigated treatments from soil moisture depletion based irrigation scheduling compared to the adjusted Penman ET. These results show less variation than those of Kirsch (1993) and confirm his prediction that instruments with better resolution like TDR could improve assessment of plant water use.

Conclusions

The above results show that TDR could be used as a tool for soil moisture monitoring and irrigation scheduling even in turf ecosystems. However, bihourly VMC changes were within the margin of error of TDR measurements and thus fail to provide conclusive information on moisture depletion patterns.

Evidence of upward flow at different times under different conditions, even under the shallow rooting depths for turf species suggest that water drained below the root zone may again become available to the plant following moisture redistribution. Moisture depletion measurements such as these reflect actual VMC changes in response to variable irrigation treatments, plant species and evaporative demand.

Time domain reflectometry estimates of moisture depletion were more conservative than weather based ET estimates even after adjustments have been made. Water savings of up to 46 % could be achieved from moisture depletion based irrigation scheduling compared to weather based estimates. Despite widespread efforts to equate moisture depletion to ET, it should be noted that weather based ET estimates fail to account for upward flow of water to replenish water extracted from the root zone. This may explain in part the difference between ET and TDR estimates. When it becomes affordable, widespread use of this soil moisture sensor could reduce overwatering and the potential for leaching of agricultural chemicals into ground water.

Moisture depletion patterns were highly variable between annual bluegrass and creeping bentgrass during the course of the day although daily means of VMC by species show no significant differences. Bihourly moisture patterns show three major trends: they upward water movement, water from guttation or infiltration of dew during morning hours.

Moisture depletion from transpiration or soil evaporation in response to evaporative demand also contributed to observed differences. Stomatal regulation during hot periods may account for reduced water loss by turf leaves as turfgrass strive to maintain osmotic balance in the tissues under conditions of high evaporative demand. Generally, the greatest moisture depletion occurred between 0900 and 1300 h suggesting that syringing after this period may be optimum timing to minimize heat and moisture stress. Periods that show no moisture change may reflect steady states between moisture loss and gains.

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