CHAPTER 7

An Evaluation of Turfgrass Irrigation Scheduling Using the Soil Conservation Service (SCS) SCHEDULER Model

Abstract

Modeling has become an important tool in crop research. The use of models in turfgrass studies, however, has been very limited. A three-year study (1992-1994) was conducted at the Hancock Turfgrass Research Center to simulate evapotranspiration, available water and drainage losses (excess water) from turfgrass plots under three irrigation regimes using the Soil Conservation Service (SCS)-SCHEDULER model (Shayya and Bralts 1994). Irrigation treatments were: i) apply 25 mm upon the appearance of wilt stress (STR), ii) apply 2.5 mm daily (DLY), and iii) maintain soil at field capacity daily (FC) based on time domain reflectometry (TDR) measurement. Predicted daily potential evapotranspiration (ET_p) values during 152 day season over a three year period ranged from 0.5 to 7.6 mm. Predicted turf ET (ET_t) for the stress treatment was lower than the actual ET for all years, suggesting that soil moisture levels for the stress treatment did not meet the optimum amounts and frequency needed for optimum turf growth. The ranking for amounts of applied irrigation by treatment was DLY > FC > STR during wet periods and FC > DLY > STR during dry periods. In all years seasonal cumulative rainfall exceeded the cumulative potential ET, but poor rainfall distribution necessitated supplemental irrigation. Poor rainfall

distribution resulted in inefficient use of rainfall water, with a high potential for drainage losses. Excess rainfall and irrigation ranked DLY > FC > STR. During wet periods, the excess water from DLY treatment was higher than from the field capacity and stress treatments. Simulated available water content did not agree well with field measurements. These disparities suggest that further modifications are necessary to improve the agreement between field observations and model output. Additional site-specific seasonal rooting depth data may be necessary to improve model AWC and TDR observations. Since, the SCS-SCHEDULER model does not account for upward water flow, predicted daily moisture depletion values were much larger than normal.

Introduction

Considerable water savings can be achieved in turf management through efficient irrigation scheduling based on soil moisture depletion measurements (Augustin et al., 1984; Snyder et al., 1984; Carrow, 1991). Economical irrigation requires the determination of actual evapotranspiration. The multiplicity of ET models and the lack of agreement among methods (Penman, 1948; Jensen and Haise, 1963; Doorenbos and Pruitt, 1977; Wright, 1981) makes it difficult to choose anyone model. Operational estimates for most ET models are based on the assumptions of Penman (1948) or some modification of them. The basic assumptions of Penman's definition of potential ET (ET_p) do not match the conditions encountered in turf culture. Thus, adjustments are necessary to accommodate variations in climate and model specifications.

Two important considerations in crop ET calculation are; crop coefficients needed to estimate actual ET; and plant height that influences the aerodynamic component or wind function of the Penman model. The cutting heights recommended for turf maintenance range from less than 4 mm on greens to more than 80 mm on some low maintenance turfs. This cutting height range is well below the specifications of Doorenbos and Pruitt (1977) or Jensen and Haise (1963). The lack of agreement among ET models by location, even after adjustments have been made to obtain realistic ET values, suggests a higher level of empiricism into an otherwise physical model. Crop coefficients are used to adjust ET_p to actual turf ET (ET_t). Mini-lysimeters are used to estimate actual or turf ET (ET_t) and hence the turf coefficient (K_t) (Carrow, 1991) from the ratio:

$$Et_t \; / \; ET_p = K_t$$

Turfgrasses show a wide degree of genetic diversity and adaptive radiation reflected in the variability in water use rates. Evapotranspiration rates have been shown to vary by species (Tovey et al., 1969; Biran et al., 1981; Kneebone and Pepper, 1982; Kim and Beard, 1988) and even by cultivar (Biran et al., 1981; Shearman, 1986; Kopec et al., 1988). Johns et al. (1983) developed a method of classifying turfgrass ET that assigns the following ratings: low for ET values less than 4 to 4.9 mm per day, medium for ET values from 5 to 7.5, and high for ET values above 8 mm.

Ideally just enough water should be applied to wet the rooting zone. Suggested recommendations for turf irrigation include: application of water to replace daily ET or some fraction thereof; irrigation using timers to apply fixed amount of water on regular basis for example 2.5 mm daily or 2.5 mm every other day (Vargas, 1994); or irrigation upon the appearance of wilting stress. Although some recommendations are successful in maintaining turf quality, there has been no quantitative evaluation with respect to total water use or excess water for each of the above irrigation scenarios.

An initial step in the development of moisture-depletion-based irrigation scheduling is the establishment of the "setful" point or field capacity (also called the drained upper limit, DUL) and the refill point based on the management allowable depletion (MAD) (Campbell and Campbell, 1982), where MAD ranges from 30-50% of available soil water (AW) . The basic assumption is that when the soil moisture is between (DUL) and MAD, moisture stress is less likely to occur. Below the MAD, turf growth and quality could be adversely affected.

Conventional methods for soil moisture determination include the gravimetric method, resistance blocks, neutron and gamma attenuation techniques. These methods are time consuming, labor intensive, involve radioactive sources or destructive soil sampling. Spatial variability from changing sampling sites during successive measurements also introduces errors into these soil moisture-evaluation methods. Despite good accuracy (Simpson and Meyer, 1987), the neutron probe is not amenable to the shallow depths encountered in cool-season turf management (Augustin and Snyder, 1983). However, there is still a need to develop affordable and dependable soil moisture sensors for evaluating turf irrigation requirements in addition to ET estimates.

In recent years, time domain reflectometry (TDR) has been widely applied in determining soil moisture and salinity (Topp et al., 1980). Time domain reflectometry uses the relationship between the composite soil dielectric constant and volumetric moisture content (VMC) proposed by Topp et al. (1980). Compared with other methods of determining VMC, TDR is adaptable for automation and multiplexing (Wraith and Baker, 1991), and remote retrieval of soil moisture data on a continual basis by a single TDR (Baker and Allmaras, 1990). Good agreement between simulated values and TDR estimates is necessary to establish confidence in the modified model for turf irrigation scheduling. One such model, the Soil Conservation Service (SCS)-SCHEDULER (version 3) was developed by Shayya and Bralts (1994) at Michigan State University. A previous version of this model has been described as one of the most accurate irrigation scheduling and evaluation software for field crops (Allan, 1991).

The SCS-SCHEDULER model uses the FAO-modified Penman equation to calculate potential ET (ET_p), actual ET (ET_a), and cumulative ET. Moisture depletion within the rooting zone is calculated using the following method (Hillel, 1980):

rainfall + irrigation - (change in soil moisture content + drainage + runoff) = ET

Estimates of excess rainfall and irrigation are important for improving irrigation application rates and reducing the frequency of drainage losses. Good agreement between model output and field data would indicate that the model may serve as a management tool (Ritchie, 1991) for irrigation managers. The SCS-SCHEDULER has a short-term forecasting routine based on historic or actual data that predicts irrigation scheduling for up to 60 days, for a given location. It also. Like other models, it allows for ad hoc experimentation without the labor, delays, and costs associated with field experimentation (Ritchie, 1991).

Although considerable turf irrigation research has been reported in the literature (Danielson et al., 1981; Aronson et al., 1987), the data are not reported in a form that can easily be incorporated into models. With increased use of computers in turf irrigation programming and research, modeling will no longer be restricted to researchers and consultants. Innovations in technology may eventually reduce the cost of soil moisture sensors. Conjunctive use of soil moisture sensors such as TDR with computers models will bring turf irrigation management another step into the computer age.

Model Description

The SCS-SCHEDULER (Shayya and Bralts, 1994) is an irrigation scheduling and evaluation package. This model provides a viable option for interactive crop irrigation scheduling and evaluation for periods of up to 60 days. The input requirements include local crop, soil, and weather data. The model computes the water balance within the rooting zone or depth of interest and suggests irrigation scheduling for optimum crop management. Evapotranspiration, rainfall, irrigation, and deep percolation are used to calculate excess water (excess rain + irrigation). The model quantifies various irrigation scheduling scenarios and their effects on plant-available water.

The objectives of this study were to: i) adapt the SCS-SCHEDULER model for use in turf irrigation; and ii) compare ET, soil moisture depletion and excess water under three turf irrigation regimes.

Materials and Methods

Three irrigation treatments were applied on an annual bluegrass (*Poa annua* var. reptans L.) and a Penncross creeping bentgrass (*Agrostis palustris* Huds. L.) fairway turfs established in 1989 at the Hancock Turfgrass Research Center at Michigan State University (Saffel, 1994). The soil type was a modified Owosso sandy loam (fine-loamy mixed mesic Typic Hapludalf). The turfs were mowed three times a week at a cutting height of 16 mm and were maintained according to standard practices for cool-season fairway turfs in Michigan. Because there were no significant differences in water use by species, the data were pooled across species.

The irrigation treatments in this study represented a range of prevalent irrigation practices in Michigan: i) apply 25 mm only upon the appearance of wilt stress; ii) apply 2.5 mm daily (Vargas, 1994); and iii) return the soil to field capacity based on TDR-measured moisture depletion.

Weather data for the summers of 1992, 1993, and 1994 were down-loaded from a Rainbird Maxipaw TM station located at the site. The weather data were converted into arrays compatible for use in the SCS-SCHEDULER by a routine in Quick Basic written for this study by Walid Shayya, visiting Professor and V. F Bralts Professor of Agricultural Engineering at MSU. This model uses the FAO-modified Penman equation (Penman, 1948) to calculate ET. The calculated ET serves as the basis for estimating soil moisture depletion, and excess irrigation and rainfall, and scheduling irrigation for various field crops.

Irrigation treatments served as whole plots (11 m by 11 m) with split plots (5.5 x 11 m) seeded randomly to either annual bluegrass or creeping bentgrass. Pop-up irrigation heads were located at each corner of the plot. Irrigation was applied at 0300 h and TDR readings were taken between 0700 and 0900 h. The application and distribution uniformities were greater than 85% (Saffel, 1994). However, lower values were obtained during windy conditions early in the morning.

The model inputs included crop, weather, and soil data files. Seasonal turf coefficients, rooting depth, and management allowable depletion (MAD) used for the SCS-SCHEDULER simulations are presented in Table 7.1. The values were selected from the literature (Feldhake et al., 1983; Aronson et al., 1987; Kim and Beard, 1988), where available, or estimated from established values for field crops in the SCS-SCHEDULER data base.

7.1. Seasonal crop coefficients, rooting depth, and management allowable depletion used for the SCHEDULER simulations.

Growing Season	Rooting Depth	Crop Coefficient	Minimum Available Water Before Irrigation
(%)	cm	K_t†	%
0	15.2	0.45	50
10	20.3	0.50	50
20	21.6	0.60	50
30	12.7	0.70	50
40	16.5	0.75	50
50	14.0	0.75	50
60	15.2	0.75	50
70	17.8	0.70	50
80	17.8	0.60	50
90	16.5	0.50	50
100	15.2	0.40	50

† Initial K_t values were obtained from Kneebone and Pepper, (1982). The rooting depth variation with time was adapted from Koski (1983).

Data used to develop the crop curve (turf curve), root zone expansion curve used in the simulations were adapted from the rooting-depth patterns of cool-season grasses in response to temperature stress during the warm summer months (Koski, 1983). Turf coefficients (K_t) ranging 0.50 to 0.85 have been reported in the literature (Kneebone and Pepper, 1982). However, the moisture depletion rates using the above values were so high that simulated AWC was much lower than values obtained by TDR or gravimetric methods. The K_t values were lowered progressively until there was agreement between simulated AWC and field measurements. The coefficients presented in Table 7.1 were reduced sequentially to obtain the best fit to the field data.

Table 7.2. Farm (turf)-specific input data for SCS-SCHEDULER simulations.

Plant type		Turf
Starting date		May 1
Ending date		October 1
Duration of simulation		152
Degree days or % season		% season
Management allowable depletion (MAD)		50%
Available water content by depth		100%
Allowable excess water above field capacity		105%
Available water-holding capacity by depth	0-5 cm	0.155 cm^3cm^{-3}†
	5-10 cm	0.145 cm^3cm^{-3}
	10-15 cm	0.135 cm^3cm^{-3}
	15-25 cm	0.125 cm^3cm^{-3}

†The available water-holding capacity of each soil depth was assumed to be half of the volumetric soil moisture content, expressed as equivalent depths. The weighted volumetric moisture content for all depths is 0.28 cm^3 cm^{-3}.

Simulations began on May 1 (DOY 122 for 1992, and DOY 121 for 1993 and 1994) of each year and ended on October 1, resulting in 152 days of simulation each year. The default MAD value of 50% of soil-available water content was used for all simulations (Table 7.1). This value, commonly used in most irrigation models, indicates that irrigation is suggested when half the available water content is depleted (Campbell and Campbell, 1982). Below

50% available water left in the soil, the plants expend higher amounts of energy per unit of water uptake, hence the model calculates an adjusted ET (ET_a). Also, the default allowable excess water (105%) of field capacity was utilized for all simulations. Above this value, the water is lost either through drainage or as runoff and labeled excess water. Excess water amounts and frequency estimates were based on the amount and frequency with which soil moisture content exceeded the allowable excess water in the rooting depth (Table 7.2).

The plot used in this study had a slope of approximately 1.5%, so runoff would be limited unless the rainfall intensity was high. In this model, water lost by percolation or runoff was considered excess water.

Results and Discussion

Seasonal rainfall, temperatures and means are presented in Table 7.3. Rainfall maxima and means increased from 1992 through 1994. For example rainfall in 1992 and 1993 were 0.75 and 0.87 times that for 1994. Mean maximum and minimum temperatures showed less variation compared to rainfall. The range within minimum temperatures and maximum temperatures were strikingly similar for all years.

The lowest and highest potential evapotranspiration (ET_p) values for 1992 were 0.5 mm on May 31 and 6.8 mm on June 15, respectively. In 1993, a minimum ET_P of 0.5 mm was recorded on September 3, whereas a maximum of 7.4 mm occurred on both 16 and 17 July. Potential ET ranged from a minimum of 1.0 mm on 1 May, 1994, to a maximum of 7.6 mm on 22 June is not understood. Potential evapotranspiration is a weather-dependent variable estimated strictly from atmospheric variables. Predicted cumulative $ET_{p,}$ and $ET_{t,}$ for all treatments (Table 7.4) ranked 1993 > 1994 >1992. The order for ET_a was 1993 > 1994 > 1992.

Table 7.3. Seasonal rainfall totals, daily seasonal means and maximum rainfall events; seasonal lowest, highest and mean maximum temperatures; seasonal lowest, highest and mean minimum temperatures for 1992, 1993, and 1994.

Weather Factor	Year		
	1992	1993	1994
		mm	
Rainfall			
Maximum	38.9	52.6	70.0
Mean & SD	2.7 ± 6.6	3.2 ± 8.1	3.7 ± 10.1
Total	421	493	565
Max. Temperature		°C	
Maximum	34.4	33.9	38.0
Minimum	9.4	10.0	10.4
Mean & SD	23.1 ± 4.6	24.0 ± 5.2	24.8 ± 5.7
Range	25.0	23.9	27.6
Min. Temperature		°C	
Minimum	-1.7	0.6	-0.1
Maximum	20.6	23.9	22.1
Mean & SD	9.8 ± 5.7	11.9 ± 5.4	11.6 ± 5.7
Range	22.2	23.3	22.2

Adjusted ET (ET_a) values for the stress treatment were substantially lower in 1992 than for the irrigated treatments but not in 1993 and 1994. This indicates that the stress treatment supplied less than adequate amounts of water to turfs in 1992 which had the lower rainfall (Table 7.4). The ET_t values were remarkably consistent within years for all treatments. With the exception of the stress treatment in 1994, ET_t was consistent for all irrigation treatments for each year. Variation in evapotranspiration from year to year may thus be attributed more to weather factors other than temperature since year to year variations in temperature were not statistically significant.

A weakness of ET models is that they fail to include the soil water status or soil water dynamics. This underscores the importance of incorporating soil moisture data into efficient irrigation scheduling practices. Rainfall and irrigation amounts and simulated available water content (AWC) for 1992, 1993 and 1994 are presented in Figs. 7.1, 7.2 and 7.3, respectively. The figures show the variation in AWC with time in relation to the drained upper limit (DUL) and the management allowable depletion (MAD).

Rainfall and irrigation amounts and available water content for the 2.5 mm daily, field capacity, and stress treatments for 1992 are presented in Fig. 7.1. Rainfall amounts and frequencies were highly variable from year to year. The variability of rainfall amounts and frequencies, as evident in the available water graphs for the field capacity and stress treatments, dictated the irrigation requirement. Available water content for the irrigated treatments was above the MAD for the entire season. This indicates that both irrigated treatments supplied adequate or more than adequate amounts of water for plant needs.

The field capacity treatment deviated slightly from the 0.28 cm^3 cm^{-3} average field capacity value during days with successively high ET. There were four distinct dry-down periods when AWC for the stress treatment fell below the MAD limit in 1992 (around day 140, 163, 170 to 180 and 235 in 1992). Quality ratings for the stress treatment were

Table 7.4. Seasonal cumulative potential (ET_p), turf (ET_t), and adjusted seasonal ET (ET_a), by year and irrigation treatment as predicted by the SCHEDULER model.

Irrigation Treatment		Year		
		1992	1993	1994
	ET_p	526	716	696
Field Capacity	ET_t	328	452	436
	ET_a	324	448	436
	ET_p	520	716	696
2.5 mm Daily	ET_t	326	457	439
	ET_a	324	452	439
	ET_o	526	714	696
Stress	ET_t	328	456	429
	ET_a	269	334	418

significantly lower than for the irrigated treatments (see Chapter 4). With the increase in rainfall amounts and frequency in the second half of the season, the AWC for STR stayed between the MAD and the drained upper limit (DUL) most of the time. Occasionally, the water content exceeded the 105% AWC limit, with the excess water lost as drainage or as runoff. The available water content for the 2.5 mm daily treatment in 1992 (Fig. 7.1) shows that VMC was at or above field capacity from July 10 to the end of the 1992 season. Compared to the stress treatment, the 2.5 mm daily treatment had two distinct dry-down periods at about days 160 to 170 and 180 to 195 but AWC fell never fell below MAD.

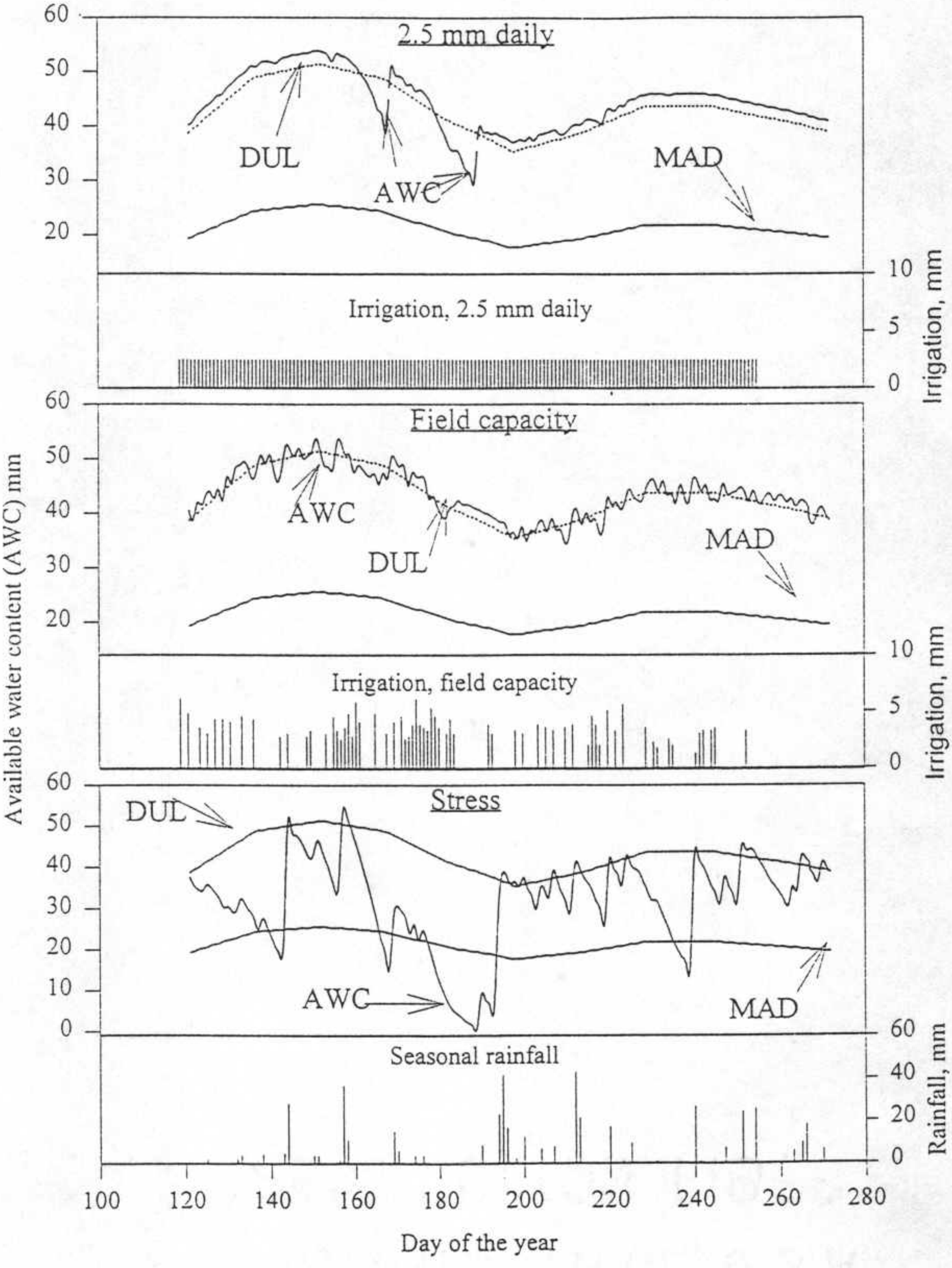

Figure 7.1. Available water content (AWC), irrigation and rainfall for the 2.5 mm daily, field capacity and stress treatments in relation to the drained upper limit (DUL) and management allowable depletion (MAD), 1992.

The field capacity treatment maintained the soil moisture level at about field capacity more consistently than DLY and received less seasonal irrigation. The amounts of water applied per irrigation for the field capacity treatment were greater than for the 2.5 mm daily treatment but irrigation was applied less frequently. This indicates that DLY supplied more water than FC and hence more than adequate water for turf growth.

In 1993 (Figure 7.2), the 2.5 mm daily treatment supplied more than adequate water for turf growth early in the season and toward the end of the season. Mid-season application of 2.5 mm daily was lower than the evaporative demand. In no instance, however, was the AWC below the MAD for this treatment. The deviation of the AWC from the DUL for the field capacity treatment was less than for the 2.5 mm daily treatment. The field capacity treatment maintained AWC at or near field capacity, as expected. There were several days in 1993 when the AWC was below the MAD for the stress treatment. When AWC is less than the MAD, there is a potential for plants to be subjected to moisture stress, particularly on days with high ET. Actual turf evapotranspiration (ET_a) is adjusted accordingly to reflect the potential for moisture stress. Poor rainfall distribution thus causes a need for supplemental irrigation to maintain quality turf as stated by Aronson et al., (1987) even when seasonal rainfall exceeded cumulative turf ET.

The figures showing rainfall, irrigation, and available water content for 1994 are presented in Fig. 7.3. The 1994 season began with a dry period from day 130 to 163. The heaviest rainfall (70 mm) for the entire study occurred on day 163. Rainfall was more evenly spread from day 163 through the rest of the season. Soil water content for both irrigated treatments oscillated about the DUL line depending on rainfall or irrigation. Soil water content for the stress treatment was below the DUL line between day 140 to 162, 207 to 217, and 245 to 258.

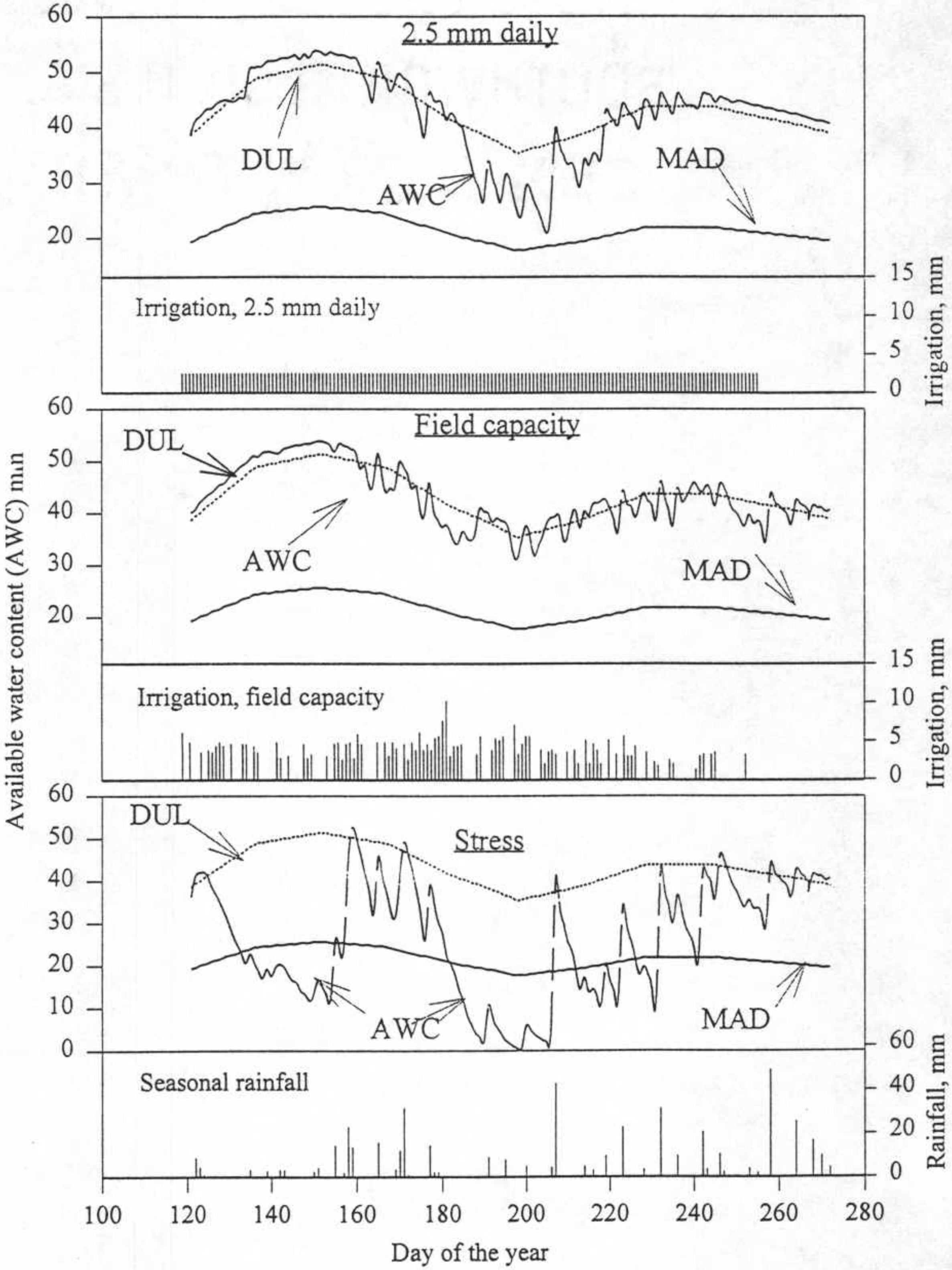

Figure 7.2. Available water content (AWC), irrigation and rainfall for the 2.5 mm daily, field capacity and stress treatments in relation to the drained upper limit (DUL) and management allowable depletion (MAD), 1993.

For the last third of the season, AWC by irrigation treatment ranked DLY > FC > STR for all years due to frequent rainfall (Figs. 7.1 through 7.3). In a dry year, one would expect the trend to be FC > DLY > STR. In terms of irrigation scheduling, the results showed that during wet periods, the field capacity and 2.5 mm daily treatments both supplied more than adequate water for quality turf maintenance. Turf quality ratings for both species for the stress treatment were significantly lower than for the irrigated treatments (Chapter 4).

Excess water by year for three irrigation treatments are given in Table 7.5. Excess water lost as drainage or runoff reduces water use efficiency, having environmental and economic implications. Excess water resulted from applied irrigation and/or rainfall when AWC is near or above the field capacity. Excess water trends were highly variable from year to year between irrigated and stress treatments due to variation in rainfall. Rainfall accounted for all the excess water from the stress and most of the excess water from the field capacity treatments. The amount of water applied per application for the field capacity treatment varied from day to day, as expected. By contrast, the 2.5 mm daily treatment was obviously constant. As expected, the least amount of excess water was from the stress treatment for all years. Although considerable water savings were evident from the stress treatment, this treatment subjects turfgrass to cycles of stress, with potential reduction in turf quality.

Because excess water lost from the stress treatment was due to rainfall, the amounts were much lower than for the irrigated treatments (Table 7.5). Excess water from irrigation for DLY ranged from 29 to 47, times that for FC, while the combined excess from rainfall and irrigation ranged from 1.2 to 1.3 times that for FC. For the stress treatment excess water from rainfall ranged from 0.1 in 1992 to a peak of 0.34 times that of FC in 1993. The excess rainfall amounts ranked DLY > FC > STR. This indicates a rather low efficiency with respect to water-resource capture for shallow-rooted, cool-season turfs. However, some of

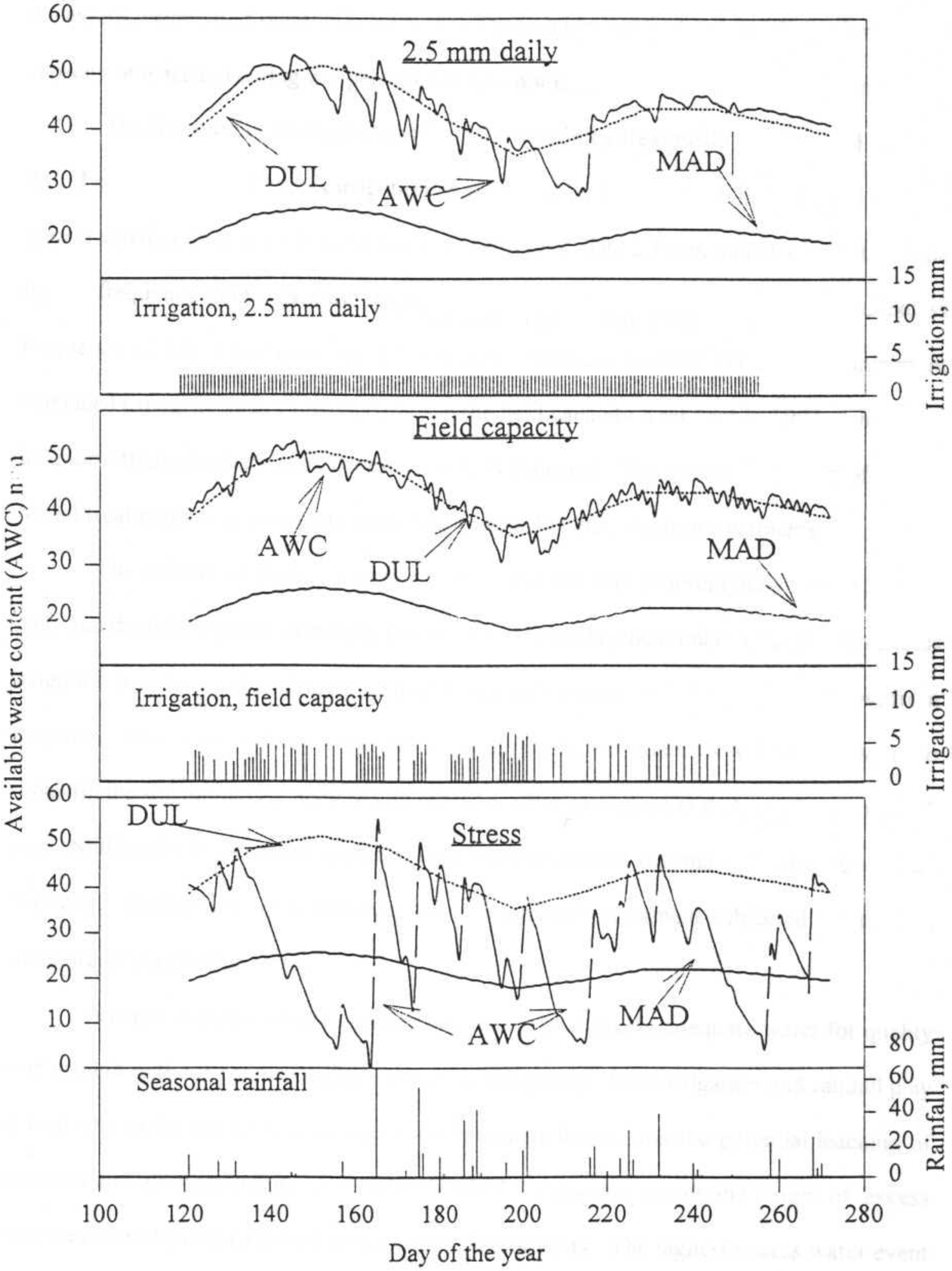

Figure 7.3. Available water content (AWC), irrigation and rainfall for the 2.5 mm daily, field capacity and stress treatments in relation to the drained upper limit (DUL) and management allowable depletion (MAD), 1994.

the excess water could reenter the root zone through upward water flow. Irrigation to field capacity or irrigation during wet periods are thus not efficient water management strategies.

The frequencies of excess rainfall and irrigation by treatment are presented in Table 7.6. The frequency of excess irrigation as predicted by the SCHEDULER model showed greater variation than that of excess rainfall for all years. The 2.5 mm daily treatment had the highest frequency of excess water applied for all three years. A maximum combined excess frequency of 104 occurred in the 2.5 mm daily treatment in 1992, whereas the minimum combined excess frequency (26) occurred in the field capacity treatment in 1994. The stress irrigation treatment had fewer excess events, as expected. The excess frequency of rainfall for all treatments was consistent from year to year for the irrigation treatments.

The number of days with excess rainfall was not very different between the 2.5 mm daily and the field capacity treatments (Table 7.6). However, the number of days with excess irrigation was drastically different. The 2.5 mm daily treatment had excess water loss from irrigation. This suggests that for wet years, the application of adequate amounts of water to replenish the soil to field capacity would result in water savings over daily application of 2.5 mm. Still losses from rainfall remained high because the soil was maintained at about field capacity. During dry years, however, the 2.5 mm daily treatment subjected the turfs to moisture stress (Saffel, 1994).

A major objective of turf irrigation scheduling is to supply adequate water for quality turf growth without compromising environmental quality. Both irrigation and rainfall play a vital role in the amounts of excess water (drainage losses) and the potential leaching of nutrients and other agricultural chemicals. Table 7.7 shows the means and ranges of excess water amounts by irrigation treatment for the different years. The highest excess water event of about 64 mm of water occurred on June 14, 1994, after 70 mm of rainfall. Up to 91% of

Table 7.5. Seasonal excess rainfall and irrigation, by year and by irrigation treatment as predicted by the SCS SCHEDULER model.

Excess Rain and Irrigation	Year	Irrigation Treatment		
		Field Capacity	2.5 mm Daily	Stress
		mm		
Rainfall	1992	363	386	28
Irrigation		2.6	123	0
Total excess		395	509	28
Rainfall		318	292	108
Irrigation	1993	1.8	86	0
Total excess		320	378	108
Rainfall		419	396	135
Irrigation	1994	3.1	90	0
Total excess		419	486	135

the rainfall was not stored in the root zone for both irrigated treatments. A minimum leaching amount of 0.3 mm was recorded for the stress and field capacity treatments in all years but only in 1992 and 1993 for the field capacity treatment. A distinct advantage of the SCS-SCHEDULER is that it partitions rainfall and irrigation amounts into the fraction stored in the soil depth of interest, the amount lost by evapotranspiration, and the excess water loss by runoff and percolation. Although leaching is not estimated by the model, the solubility of various agricultural chemicals, in the excess water, could provide useful estimates of the leaching potential of various chemicals of interest.

Table 7.6. Frequency of excess rainfall and irrigation, by irrigation treatment as predicted by the SCS-SCHEDULER model.

Year	Type	Irrigation Treatment		
		Field Capacity	2.55 mm Daily	Stress
1992	Rainfall	26	27	13
	Irrigation	0	77	0
	Combined	26	104	13
1993	Rainfall	27	22	11
	Irrigation	1	46	0
	Combined	28	68	11
1994	Rainfall	26	24	12
	Irrigation	0	55	0
	Combined	26	79	12

The high frequencies of excess water from the 2.5 mm daily and field capacity treatments suggest that irrigation scheduling should utilize a more conservative approach than returning the soil to field capacity daily, or applying 2.5 mm daily and when possible should include soil moisture monitoring as a feed back system.

Table 7.7. Means and ranges of excess water amounts by irrigation treatment as predicted by the SCS-SCHEDULER model.

Year	Excess	Irrigation Treatment		
		Field Capacity	2.5 mm Daily	Stress
		mm		
	Maximum	39.1	44.2	31.9
1992	Minimum	0.3	0.3	0.3
	Mean	2.6	3.3	1.2
	Maximum	41.4	50.3	34.8
1993	Minimum	0.3	0.3	0.3
	Mean	1.5	2.5	0.7
	Maximum	64.0	60.2	34.4
1994	Minimum	0.8	0.3	3.0
	Mean	2.7	3.2	0.9

Conclusions

Evapotranspiration estimates from the model were within the ranges of ET for the location. The available water content measured by TDR did not agree with simulated values. This may be due to faulty assumptions in adapting the model for turfgrass. More research would be needed to improve agreement between model prediction and field data.

Moisture depletion estimates from the SCS-SCHEDULER account for seasonal variations in rooting depth. This is important because rooting patterns of cool-season grasses are affected by root senescence during periods of high temperatures and other weather conditions in response to differential partitioning of assimilates.The model provides information on water use that would otherwise be unavailable or require time to calculate. Most important, it provides a method for site-specific irrigation scheduling and evaluation.

Benefits from simulations in terms of time, money, and labor savings have been documented (Hanks and Hill, 1980; Ritchie, 1991). Good simulation models serve as a useful basis for irrigation management and decision making. A method of irrigation scheduling that is accurate, site- and crop-specific, rapid, and dependable can be used to rapidly build a data base for model validation purposes. At this time the data base for turf modeling is not as extensive as in conventional agriculture. Model development calls for an extensive data base with quantitative information on the development of turfgrasses.

Although much research has been done in turf, the results are not reported in a form that can be readily applied in simulations. Information on parameters such as leaf area index, root length density, leaf extension rate and turf coefficients for different locations are not readily available. The collection of such data requires several years of research. To compensate for these shortcomings, assumptions are made which quite often oversimplify various processes and at the same time introduce errors in the analysis. In this study, a crop irrigation simulation model (the SCS SCHEDULER) was adapted for use in turfgrass research. Conventionally, rooting depths for row crops exceed those for cool season turfs. Turf coefficients for row crops are different from those encountered in fine turf management. These may lead to higher drainage amounts and higher than normal moisture depletion rates under turf ecosystems than with other crops. Hopefully, this study will generate interest in further development of turf specific models that could serve as useful tools for research and decision making in turf irrigation.

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