CHAPTER 6

Adaptation of a New Water Balance Model for Turfgrass Under Variable Irrigation Regimes

Abstract

The water balance routine of the System Approach to Land Use Sustainability (SALUS) model was modified to simulate water balance in fairway turfs under three irrigation regimes at the Hancock Turf Research Center at Michigan State University. The irrigation treatments were: i) apply 2.5 mm daily; ii) maintain soil at field capacity; and iii) apply 2.5 mm only upon the appearance of wilting stress. Model components included subroutines for estimating infiltration, drainage, soil evaporation, transpiration, evapotranspiration, and soil volumetric moisture content (VMC) from soil, plant, and weather input files. Model modifications included the assumption of a fixed leaf area index and root length density through the growing season. Field measurements of VMC by depth were obtained for up to 60 days each year using time domain reflectometry (TDR) during the summers of 1992 through 1994. Evapotranspiration estimates were within the expected ranges for the site. The TDR measurements fell within the range of simulated VMC values. However, agreement between model simulations and field observations ranged from $0.12 < R^2 > 0.29$ for the irrigated treatments. The best agreement between observed and simulated VMC was with the stress

treatment for all depths ($0.39 < R^2 > 0.47$) suggesting that poor application uniformity may account for some of the variability. More turf-specific data would be needed to improve agreement between field VMC observations and model output.

Introduction

Turfgrasses continually are subjected to biochemical and physical adjustments in response to changing environmental conditions or managerial inputs. These changes result either from natural inputs such as rainfall, solar radiation, wind speed, temperature, and relative humidity or from managerial inputs such as traffic, irrigation, fertilizers, pesticides, mowing, and other cultural practices. For example, turfgrasses grown on sandy soils can lose most of the available soil water over a very short period.

Available water content (AWC) is widely used as the basis for scheduling irrigation, yet inexpensive, rapid, accurate, repetitive, and noninvasive methods of soil moisture determination are still lacking. Accurate VMC measurements are needed to improve irrigation scheduling for quality turf maintenance without compromising environmental quality.

Improvements in water balance models and computer simulation techniques can be used to improve water management strategies in urban agriculture. The need for predictive models such as the System Approach to Sustainable Land Use (SALUS) for soil water balance studies (Ritchie, 1991) stems from the lack of fast, safe, accurate, and affordable methods for determining volumetric moisture content (VMC). Such models are invaluable in estimating soil moisture status within the root zone for irrigation scheduling and for reducing the leaching of agricultural chemicals into ground water.

The SALUS model integrates soil, plant, and climatological inputs using either physically based or empirically derived relationships between system components to calculate the desired outputs. This study focuses mainly on water inputs, storage, and outputs as influenced by environmental conditions, plant factors, and managerial inputs, conveniently described by the hydrologic balance equation (Ritchie, 1981):

$$VMC_t = VMC_{t-1} + P_t + I_t - R_t - D_t - ET_t$$

where VMC_t is the volumetric moisture content at time t, $\mathbf{P_t}$ is precipitation, $\mathbf{I_t}$ is irrigation, $\mathbf{R_t}$ is runoff, $\mathbf{D_t}$ is drainage, and $\mathbf{ET_t}$ is evapotranspiration for a given time interval.

Operational estimates of the range of AWC are based on laboratory determination of soil water content. Ritchie and Amato (1990) summarized some of the criticisms of this approach: i) drainage water may be available to plants; ii) 1500 kPa may not represent the lowest potential of moisture extraction by plants; iii) moisture extraction is highly dependent on root density; and iv) the effects of spatial and temporal variability of soil moisture are largely ignored.

The water balance models of Richardson and Ritchie (1973) and Skaggs (1978) were among the earliest dynamic water balance models. Innovations in computer technology have increased the number of user-friendly models. Despite widespread applications of water balance models in crop studies, their use in the study of turfgrass ecosystems has been limited. Ritchie et al. (1991) cited the lack of accommodation for spatial and temporal variability in the factors used to predict plant performance as a deficiency in the usefulness of such models for agrotechnology transfer.

Time domain reflectometry provides the convenience of rapid and accurate moisture determination in space and time (Topp and Davis, 1980; Dalton, 1992). Carrow (1991) and Saffel (1994) demonstrated the successful use of TDR for VMC determination within turfgrass root zones. This could provide a database for the verification of water balance models in turfgrass ecosystems.

The objectives of this study were: i) to simulate the water balance components of a turfgrass ecosystem, using the new water balance subroutine of the SALUS model; ii) to compare volumetric moisture content under different irrigation regimes; and iii) to compare modeled volumetric soil moisture content to TDR data measured in the field.

Materials and Methods

This study was conducted at the Hancock Turfgrass Research Center at Michigan State University. Three irrigation treatments provided contrasting moisture inputs for established annual bluegrass (*Poa annua*, L. var. reptans) and Penncross creeping bentgrass (*Agrostis palustris* Huds. L.) fairway turfs mowed three times a week at a cutting height of 16 mm. Irrigation treatments were: i) return the soil to field capacity (FC); ii) apply 2.5 mm daily (DLY) (Vargas, 1994); and iii) apply 25 mm only upon the appearance of wilting stress (STR). There were three replications for each treatment. A fourth irrigation management scenario, the effects of applying 2.5 mm every other day (EOD), also was simulated. There were no corresponding field observations for this treatment.

Irrigation plots had a slope of about 1.5%, with dimensions 11 m x 11 m. Each plot was split (11 x 5.5) and randomly seeded to annual bluegrass or creeping bentgrass. Four pop-up Rainbird irrigation heads were located at each corner of the plots, with average flow rate of

21.5 L per minute. Irrigation clocks were set to apply water at 0300 h under the assumption that low wind velocities at that time would be less likely to reduce application uniformity.

Table 6.1. Soil physical properties for SALUS model.

Depth (cm)	LL	DUL	SAT	INISW	RWCON	KSMAC	KSMTX
	$cm^3\ cm^{-3}$					cm day^{-1}	
2.0	0.12	0.33	0.38	0.33	0.25	40.0	3.1
5.0	0.11	0.29	0.32	0.29	0.25	53.0	3.0
8.0	0.11	0.28	0.32	0.28	0.25	55.0	2.9
11.0	0.10	0.27	0.32	0.27	0.25	57.5	2.8
14.0	0.10	0.27	0.32	0.27	0.15	75.5	2.5
17.0	0.10	0.27	0.32	0.27	0.12	74.1	2.3
20.0	0.10	0.27	0.32	0.27	0.11	80.0	2.0
23.0	0.10	0.27	0.32	0.27	0.11	80.0	1.8

LL is drained lower limit, DUL is drained upper limit, SAT is moisture content at saturation, INISW is initial soil moisture content, RWCON is root constant, KSMAC is saturated macropore hydraulic conductivity, and KSMTX is matrix hydraulic conductivity.

Field volumetric soil moisture was determined by time domain reflectometry (TDR). Pairs of stainless steel probes, 3.2 mm in diameter and 20 cm long, were placed horizontally at 2.5, 7.5, and 12.5 cm for the first three pairs of sensors and at 17.5 and 22.5 cm for the fourth pair of sensors. These represent depths of 0-5, 5-10,10-15 and 15-25 cm. The depths did not correspond to the soil-depth increments in the SALUS model as shown in Table 6.1. Weighted VMC averages from the water balance simulations were calculated to correspond to the field installations and were used in validating the model.

The soil type was a modified Owosso sandy loam (Fine mixed mesic Typic Hapludalf). Initial soil hydraulic properties were taken from taxonomic properties of an Owosso sandy loam, as described in the Ingham County Soil Survey. Weighted means of the volumetric soil moisture content by depth from the model were calculated to yield VMC values that correspond to the depth increments of the TDR installations. The soil file included the wilting point or drained lower limit (LL), the drained upper limit (DUL) or field capacity, moisture content at saturation (SAT), and the macropore (KSMAC) and soil matrix (KSMTX) hydraulic conductivities for the different soil depths, as shown in Table 6.1. The drained upper limit (DUL, 0.28 $cm^3 cm^{-3}$) was determined from TDR field observations 48 h following a soaking rain. Hall and Heaven (1970) used similar procedure to estimate field capacity, in-situ, in early spring using a neutron probe. This value agreed with the gravimetrically determined value of 0.281 cm^3 cm^{-3} (Saffel, 1994).

Model Description

Functional models like SALUS have modest input requirements, minimum computational time, making them more user-friendly. The model contains subroutines for estimating infiltration, drainage, upward-flow, moisture redistribution, potential soil evaporation, transpiration and evapotranspiration, and root water uptake. The model requires a weather file, a soil file, and a plant data file. A detailed outline of the input files was provided by Ritchie and Baer (1994, personal communication).

Infiltration amounts were assumed equivalent to irrigation and/or rainfall assuming negligible runoff. The model assumes that drainage occurs only when soil moisture content in a given depth exceeds the DUL. Daily drainage amounts were estimated from the equation (Ritchie, 1981):

$$drainage = SWON\ (VMC_I - DUL_I) * DLAYR_I$$

where **SWON** is a unitless drainage coefficient that varies between 0 and 1; $\mathbf{VMC_i}$ and $\mathbf{DUL_I}$ are daily volumetric moisture content and the drained upper limit, respectively; and $\mathbf{DLAYR_I}$ is depth of the soil layer.

Potential evapotranspiration was calculated according to the equation of (Ritchie, 1994 personal communications). This equation differs from the Penman equation in that it does not include a wind function or vapor pressure deficit term. An advantage of the SALUS model is that it partitions evapotranspiration ($\mathbf{E_o}$) into soil evaporation ($\mathbf{E_s}$) and transpiration ($\mathbf{E_p}$) on the basis of the leaf area index. Potential soil evaporation ($\mathbf{E_s}$) was estimated from potential evapotranspiration as a function of the leaf area index (LAI) according to the equation (Ritchie, 1972):

$$E_s = E_p^{-(0.4\ LAI)}$$

Upward water flow was calculated using Richards (1931) equation. The new water balance model was written in FORTRAN. Modifications in the FORTRAN code were made by J. L. Ritchie (personal communication).

Model Inputs

Weather data from a Rainbird weather station 2 m high and 30 m from the plots were used in soil-water-balance simulations. Weather data sets for these simulations included daily solar radiation (MJ m^{-2} day^{-1}), maximum and minimum temperatures (°C), and rainfall (mm). For the irrigated treatments, irrigation amounts were added to rainfall. These data were used to estimate infiltration, drainage, soil evaporation and turf transpiration. Data files were set in arrays specified for the SALUS model (Ritchie, Personal communication).

Plant Properties

Plant variables used for simulations were LAI and root length density (RLD) for the four depth increments. An effective root length density of 5 cm cm^{-1} was assumed for the 0-5 cm depth. Root length density for the 5-10, 10-15, and 15-25 cm depths were calculated based on the percent root mass distribution by depth (1.1 cm cm^{-1}, 0.55 cm cm^{-1} and 0.45 cm cm^{-1} respectively). These percentages were derived from average root mass ratios for four depths from three sampling dates presented in Chapter 4. These estimates fell within the range of values observed by Murphy et al. (1994) in minirhizotron studies.

Leaf area index is needed in practically all ET models (Ritchie and Amato, 1990). Instruments for accurate leaf area determination for closely mowed turf are not yet practical. Leaf area indices for fairway turfs are not easy to measure because of the small leaf area for closely mowed turfs and the folding habits of some species such as annual bluegrass. For a fairway turf mowed three times a week at a cutting height of 16 mm, a constant LAI of 3.5 was assumed (Ritchie personal communications)

Model Modifications

Simulations began on May 1 each year and ended on September 30 (152 days annually). The model was modified by; i) setting a fixed leaf area index, and ii) allowing for user defined root length density. This provides greater flexibility in simulation options. Output files were also modified to generate only data relevant for the water balance study. Descriptive statistics was used to analyze the output data. Volumetric moisture content as measured by TDR were compared to simulated VMC by regression analysis.

The SALUS model assumes homogeneity of each soil depth. Water movement from irrigation or rainfall into lower depths occurs only after the previous depth is saturated. The model also uses a two-domain saturated hydraulic conductivity: matrix and macropore hydraulic conductivities.

Results and Discussion

Weather for the 1992, 1993 and 1994 seasons are presented in the appendix. In 1992, rainfall was spread more evenly than in 1993 or 1994. In 1993, most of the rainfall occurred in the latter half of the season. In 1994, heavy and frequent rains occurred between days 163 and 235, coinciding with the peak of hot summer conditions.

Model output of interest include infiltration, drainage, VMC, and ET components. Infiltration amounts generated by the model were the sum of rainfall and/or irrigation for the different treatments. The 2.5 mm daily treatment had the highest total water input as irrigation was applied daily regardless of rainfall. As a result, cumulative seasonal infiltration was also highest in the 2.5 mm daily treatment for all years. The water input per application tended to be highest for the FC which had lower irrigation frequency than the DLY treatment but had higher amounts of applied water per irrigation event. The stress treatment had the lowest mean seasonal infiltration, as expected.

Mean seasonal infiltration ranked DLY > FC > EOD > STR (Table 6.2). Seasonal water application for the FC, EOD and STR treatments were 0.80, 0.75 and 0.50 of the amounts for the DLY treatment in 1992. Similar results were observed for other years (1993; 0.89, 0.76, 0.51 and 1994; 0.91, 0.73, and 0.53 respectively for the FC, EOD and STR). This suggest that during wet years application of 2.5 mm daily supplies more water than is required to maintain the soil at field capacity. Futhermore, maintaining soil moisture levels at field capacity fails to accommodate potential moisture gains from rainfall, hence increasing water losses.

Cumulative infiltration by irrigation treatment for 1992 is given in Fig. 6.2a. The data for all years are shown in Table 6.2. Cumulative infiltration of more than 700 mm for the DLY treatment was nearly double that for STR (357 mm) in 1992 but only 1.3 times compared to FC and EOD. Cumulative infiltration ranked DLY > FC > EOD > STR for all years.

Daily drainage for 1992 are presented in Fig. 6.1. Seasonal values for all years and treatments are presented in Table 6.3. Drainage from the stress treatment was minimal compared to the irrigated treatments. Overall daily and seasonal drainage by irrigation treatment also ranked DLY > FC > EOD >STR. Variation in drainage losses was also dependent on rainfall amounts and distribution. For a water balance model in which the depth of interest is only 25 cm, drainage losses are expected to be high due to low storage capacity of the shallow soil depth under consideration.

This was particularly true when 2.5 mm of irrigation is applied daily or when the soil is returned to field capacity daily in years with above average rainfall. Drainage in this modelwas estimated below the 100 cm depth hence the low drainage values reported in Table 6.3 Daily application of 2.5 mm of irrigation resulted in 1.4 times more drainage losses than

Table 6.2. Seasonal water application by irrigation treatment and by year based on 152 day season.

Year	Irrigation Treatment			
	2.5 mm Daily	2.5 mm Alternate Days	Field Capacity	Stress
	mm			
<u>1992</u>				
Mean	4.7 ± 5.2	3.5 ± 5.6	3.8 ± 6.5	2.3 ± 5.5
Total	717.4	536.1	573.6	357
<u>1993</u>				
Mean	4.8 ± 5.0	3.7 ± 5.4	4.3 ± 6.7	2.5 ± 5.4
Sum	740.9	563.9	658.7	384.3
<u>1994</u>				
Mean	5 ± 5.9	3.7 ± 6.7	4.4 ± 6.0	2.6 ± 6.3
Sum	757.9	556.2	689.3	404.2

EOD, 1.2 to 1.3 more drainage loses than FC and more than 2 times more drainage compared to STR.

Cumulative drainage for the different treatments for 1992 are presented in Fig. 6.2b. Drainage amounts were low because drainage was estimated below the 1 m depth, four times deeper than the sphere of influence of TDR installations. Estimates for the 25 cm depth are expected to be much higher suggesting poor resource capture by shallow rooted cool season turfs. Maintaining the soil at or near field capacity does not allow maximum utilization of rainfall.However, there was evidence of upward capillary presented in Chapter 5.

Table 6.3. Seasonal drainage by irrigation treatment and by year based on 152 day season as predicted by SALUS.

Year	Irrigation Treatment			
	2.5 mm Daily	2.5 mm Alternate Days	Field Capacity	Stress
	mm			
1992				
Mean	0.4 ± 0.3	0.3 ± 0.3	0.3 ± 0.5	0.2 ± 0.3
Range	2.8	2.7	3.5	2.6
Total	64.9	47.0	50.9	29.3
1993				
Mean	0.4 ± 0.3	0.3 ± 0.3	0.4 ± 0.6	0.2 ± 0.3
Range	2.3	2.1	3.5	1.8
Sum	67.4	49.3	58.3	31.6
1994				
Mean	0.5 ± 0.4	0.3 ± 0.3	0.4 ± 0.5	0.2 ± 0.3
Range	2.6	2.5	3.4	2.3
Total	68.5	49.2	57.8	33.4

Daily soil evaporation, (E_s) and plant transpiration (E_t) for 1992 are presented in Fig. 6.3a. Daily E_s soil as predicted by the SALUS model ranged from 0.02 to 1.4 mm but seasonal E_s means ranged from 0.8 to 1.0 mm for all years as presented in Table 6.4. It is worth noting that E_s was strictly a function of the leaf area index. Based on an assumed fixed leaf area index of 3.5, assumed in the calculation of E_s the more or less constant value is expected. This implies that soil evaporation is independent of soil moisture conditions, once

Table 6.4. Seasonal soil evaporation by irrigation treatment and by year based on 152 day season as predicted by SALUS.

Year	Irrigation Treatment			
	2.5 mm Daily	2.5 mm Alternate Days	Field Capacity	Stress
	mm			
1992				
Mean	0.9 ± 0.3	0.9 ± 0.3	0.9 ±0.3	0.8 ± 0.3
Range	1.3	1.3	1.9	1.3
Sum	129.4	129.3	126.4	126.4
1993				
Mean	0.8 ± 0.3	0.8 ± 0.3	0.9 ± 0.5	0.8 ± 0.3
Range	1.4	1.3	2	1.3
Total	125.2	125.2	141	123.3
1994				
Mean	0.9 ±0.3	0.8 ±0.4	1 ± 0.3	0.9 ± 0.3
Range	1.3	1.8	1.6	1.3
Sum	136.7	120.3	156.6	132.4

again emphasizing the need for soil moisture-based irrigation scheduling. Further research would be needed to obtain accurate seasonal variation of LAI for closely mowed turf. This may improve predicted values of the different hydrologic components.

Cumulative seasonal values for soil evaporation, plant transpiration and potential evapotranspiration (E_p) are presented in figure 6.3b. The highest and lowest transpiration and soil evaporation values were recorded between day of the year (DOY) 140 and 160. Overall, soil evaporation contributed up to 20% of daily potential ET. It must be noted that the

Table 6.5. Seasonal transpiration by irrigation treatment and by year based on 152 day season as predicted by SALUS.

Year	Irrigation Treatment			
	2.5 mm Daily	2.5 mm Alternate Days	Field Capacity	Stress
	mm			
1992				
Mean	3.4 ± 1.3	3.3 ± 1.2	3.5 ± 1.2	3.3 ± 1.3
Range	5.1	5.1	7.3	5.3
Total	511.2	509.5	531	514.2
1993				
Mean	3.2 ± 1.3	3.2 ± 1.3	3.6 ± 2.0	3.3 ± 1.6
Range	6	5.4	9	5.7
Total	494.1	494.4	554.4	495.9
1994				
Mean	3.6 ± 1.3	3.1 ± 1.6	4.1 ± 1.2	3.6 ± 1.3
Range	5.4	7.7	6.1	5.5
Total	540.2	474.3	617.9	544.3

quantification of E_s was based on an assumed rather than measured leaf area index (LAI) given the difficulties involved in measuring LAI for closely mowed turfs.

Mean seasonal transpiration values for all years and treatments are shown in Table 6.5. Mean transpiration values among irrigation treatments were fairly constant in 1992 and 1993, but not in 1994. The highest mean seasonal transpiration values from the simulations were for the field capacity treatment, whereas those from the 2.5 mm daily and the stress treatment

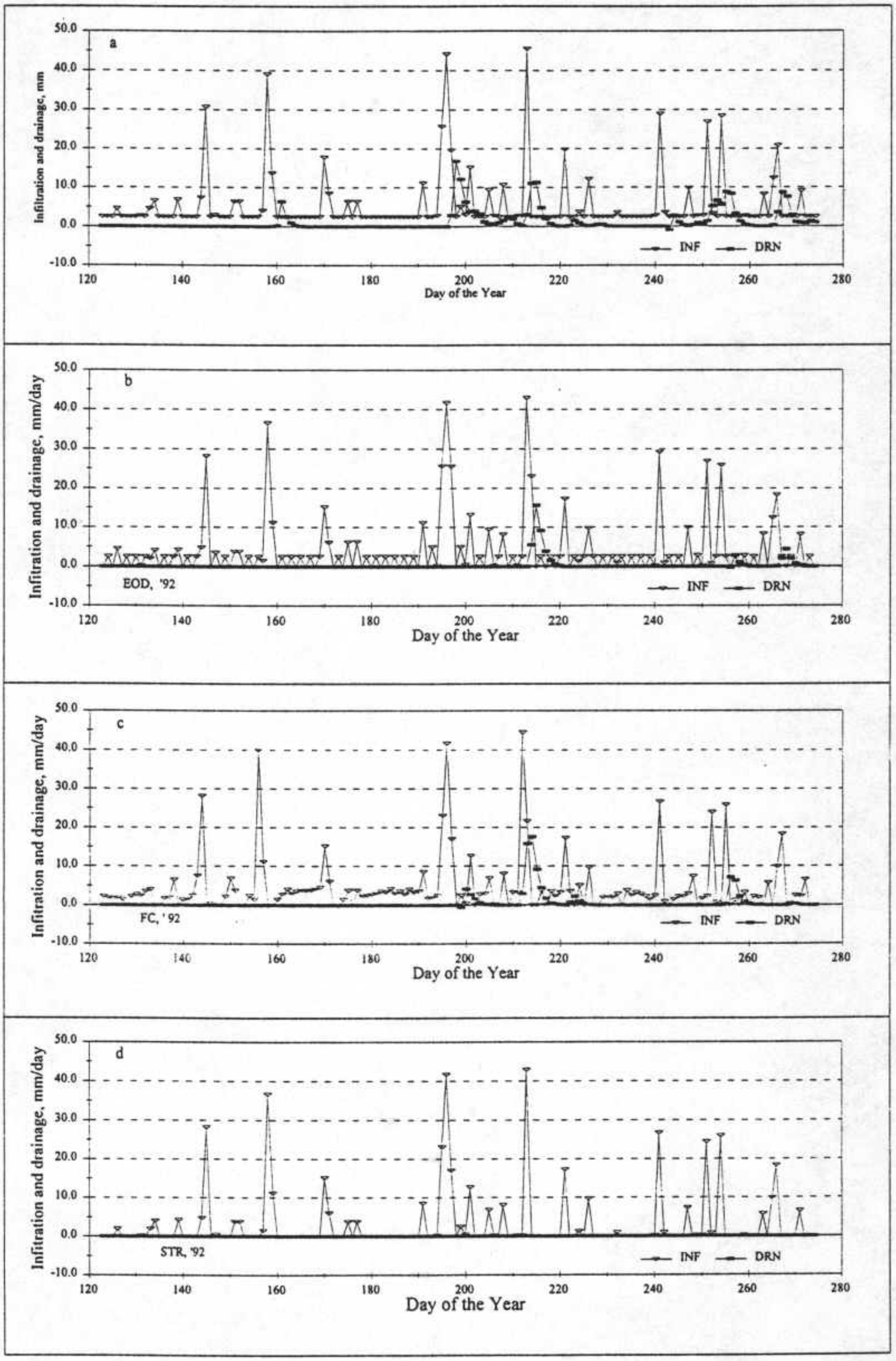

Fig. 6.1 Seasonal infiltration and drainage for the 2.5 mm daily (DLY); 2.5 mm every other day (EOD); Field capacity (FC); and Stress treatments (STR) for 1992.

were about the same.

Transpiration estimates were based on weather data at the site. Mean transpiration rates were about the same, regardless of irrigation treatment, for all years. Because the stress plots received no irrigation, one would expect less moisture depletion from this treatment and hence lower transpiration values. This provides a good argument for conjunctive use of soil moisture monitoring and conventional ET methods for irrigation scheduling.

Cumulative transpiration was similar for all irrigation treatments for 1992 (Fig. 6.3c). The lack of separation of the different treatments in the cumulative transpiration plots from year to year is evidence that irrigation treatments did not significantly affect transpiration in this model. This is again obvious because unlike rainfall, the effect of irrigation on ET is not accounted for in weather data used in ET calculations.

Volumetric moisture content was the most important variable in this study because TDR observations in the field could be compared to simulated VMC. Simulation outputs for VMC for the different depths for the 2.5 mm daily treatment and TDR measurements are presented in Fig. 6.4. Both measured and simulated VMC ranked 0-5 > 5-10 $\geq$ 10-15 > 15-25 cm depths with values ranging from 0.24 cm^3 cm^{-3} for the 15-25 cm depth to a high of 0.33 cm^3 cm^{-3} for the 0-5 cm depth. Although the 5-10 cm depth was consistently higher in VMC than the 10-15 cm depth, the differences were not always significant. Measured VMC values were often lower than simulated values with increasing depth.

Measured and simulated VMC response to rainfall and irrigation for the field capacity treatment are presented in Fig. 6.5 The field capacity treatment showed higher variability than the 2.5 mm daily treatment in all years. Both the predicted and measured VMC show

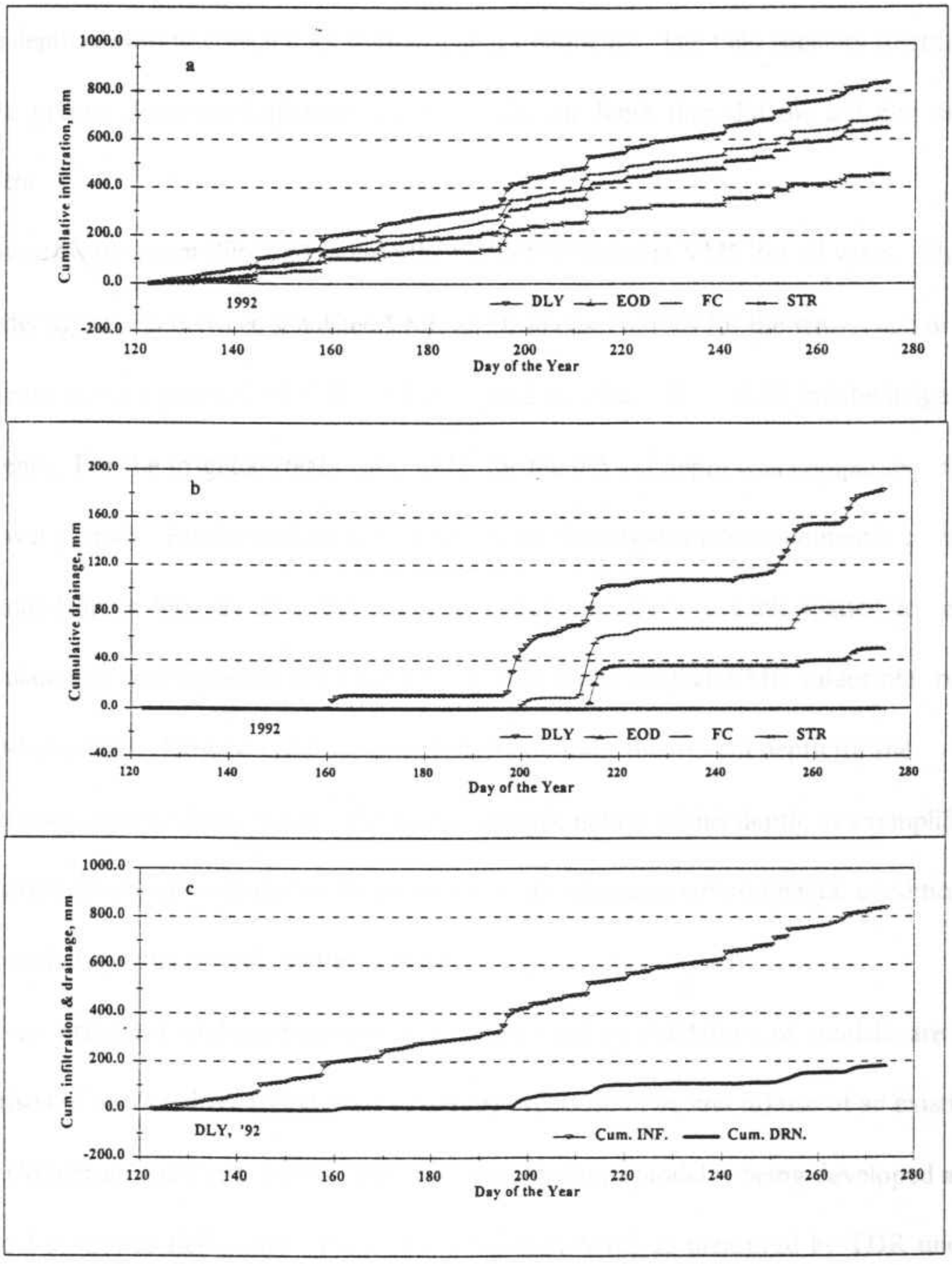

Fig. 6.2. Cumulative infiltration (a), and cumulative drainage (b) for the daily (DLY), 2.5 mm every other day (EOD), field capacity (FC), and stress (STR) treatments and cumulative infiltration and drainage (c) for the daily treatment , 1992.

a very narrow range over time. Volumetric moisture content, by depth, followed the pattern observed in the 2.5 mm daily treatment. Maximum VMC values during rainy periods for the 0-5 cm depth seemed to coincide for both irrigated treatments. The field capacity treatment showed greater moisture depletions for the 15-25 cm depth than did the 2.5 mm daily treatment.

The stress treatment (Fig. 6.6) showed the highest variation in VMC for all years. There was better agreement between simulated VMC and field observations for the stress than other treatments in both years, $0.39 < R^2 < 47$ compared to $0.12 < R^2 < 0.29$ for the irrigated treatments. For the irrigated treatments, VMC for the 0-5 cm depth was comparably high during wet periods. Ritchie and Amato (1990) stated that organic matter content increases the drained upper limit by 23% for each percentage increase in organic matter content. Accumulation of organic matter at the surface may thus explain higher VMC values observed in the 0-5 cm depth. However, during extended dry periods, the 0-5 cm depth for the stress treatment was also the driest depth. The highly dynamic nature of this depth, as exemplified in the stress treatment, was due to its proximity to the changing environmental conditions, high root density, and organic matter content.

Three prevalent philosophies that have been used in validation of models are: i) comparison of measured versus modeled values; ii) expert opinion, and iii) use of an existing model (Manetsch and Park, 1993). This new water balance model is being developed and verified for various field crops. Field observations of VMC as measured by TDR under fairway turfs for 1992 were compared to model predictions. Field measurements using TDR fell with the range of the SALUS model VMC for all treatments and for all years. However, R^2 values (up to 0.29 for the irrigated treatments and 0.47 for the stress indicate that much

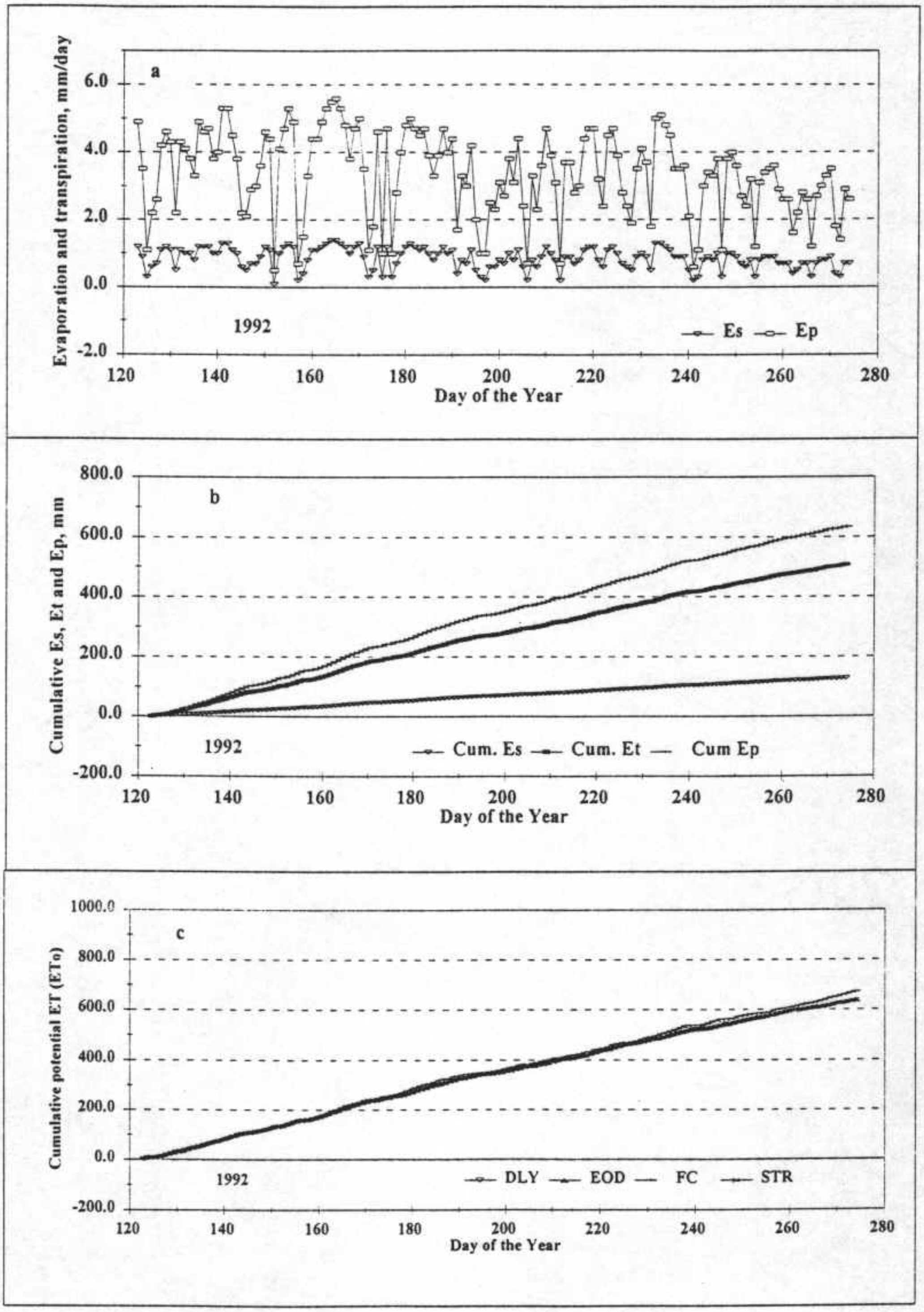

Fig.6.3. Daily soil evaporation (Es) and transpiration (Es) (a); cumulative soil evaporation (Cum Es), transpiration (Cum. Et), and evapotranspiration (Cum. Ep) (b); and cumulative potential evapotranspiration (ET_o) for the daily (DLY) 2.5 mm every other day (EOD), field capacity (FC) and stress (STR) treatments (c), 1992.

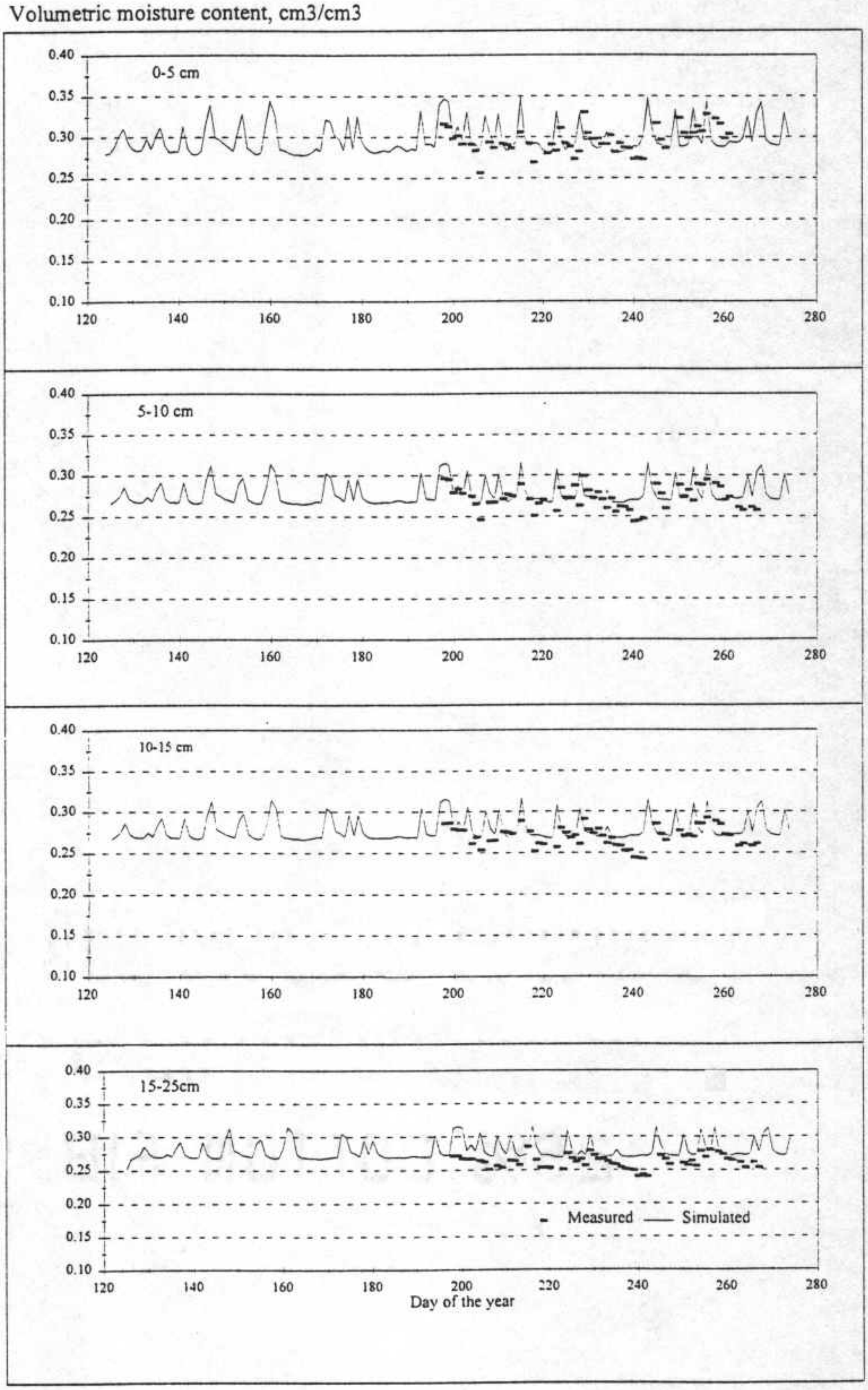

Fig. 6.4. Measured and simulated volumetric moisture content by depth for 2.5 mm daily treatment (DLY), 1992.

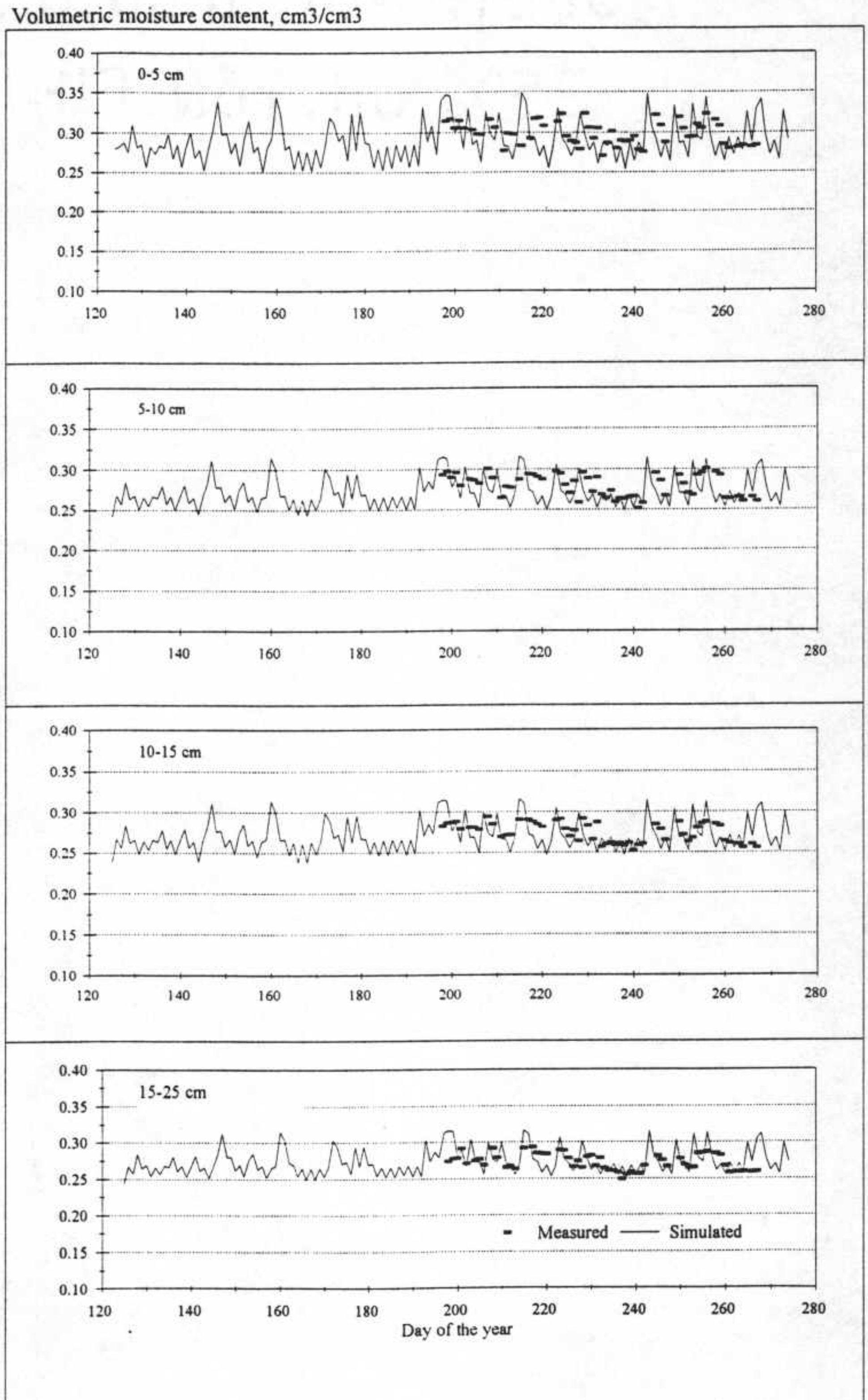

Fig. 6.5. Measured and simulated volumetric moisture content by depth for the field capacity treatment (FC), 1992.

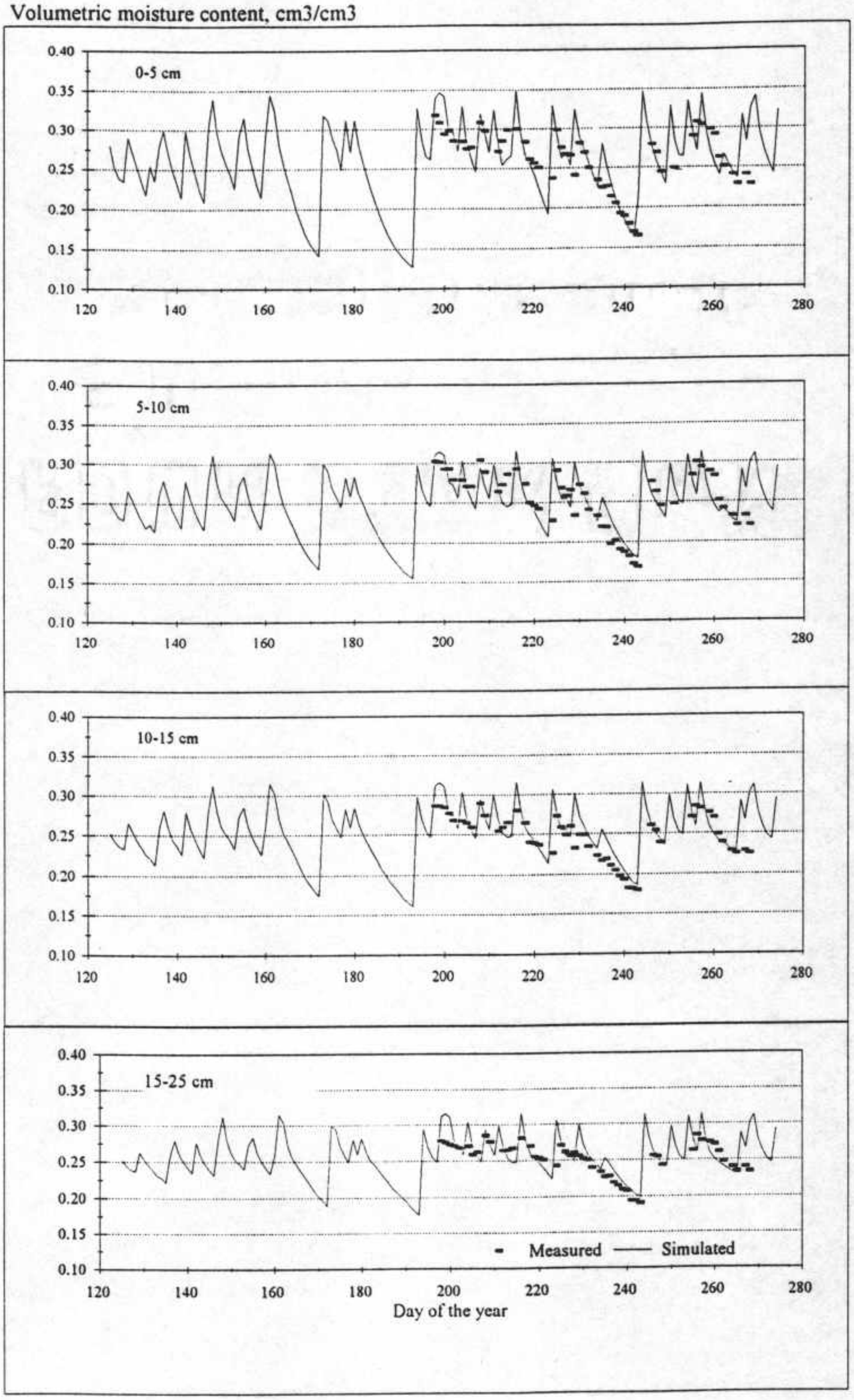

Fig. 6.6. Measured and simulated volumetric moisture content by depth for the stress (STR) treatment, 1992.

of the variation in soil moisture content is not explained by the model. This low correlation for the irrigated treatments could explained in terms of poor irrigation application uniformity, and the spatial variability of VMC in the field.

Simulated VMC and TDR measurements showed reversals in VMC trends above and below the 0.20 to 0.25 $cm^3\ cm^{-3}$ range for this soil type. Over this range all soil depths showed only minor differences in VMC for the stress treatment and it is reasonable to assume that there is no net moisture flux among depths in spite of evapotranspiration losses. From an environmental standpoint, this could be an ideal level to maintain soil moisture content if soil moisture based irrigation scheduling is employed. Two advantages of this are: i) the above moisture level guarantees at least the minimum acceptable turf quality rating (6); ii) potential water savings could result from lower irrigation rates, with greater accommodation for water inputs from rainfall.

Simulated versus the measured VMC for 1992 are presented in Figs. 6.4, 6.5, and 6.6. Volumetric moisture content for the irrigation treatments at four different depths were compared to the simulated values for 1992 and 1993. For the 5-10, 10-15, and 15-25 cm depths, the model overpredicted soil moisture levels for all treatments in turfgrass ecosystems.

The assumption of constant soil hydraulic properties for both years, when soil hydraulic properties are indeed dynamic may also account for differences between the model and field data. In addition, poor irrigation application efficiency may contribute to the observed differences. Model predictions of volumetric moisture content were based on the instantaneous VMC following rainfall or irrigation. The time lag between irrigation application (0300 h) and TDR measurements (0700 to 0900 h) may explain some of the variability between predicted VMC and TDR readings.

Conclusions

The modified water balance routine of the SALUS model provided reasonable estimates of hydrologic components for turf ecosystems. Time domain reflectometry data fell within the range of simulated VMC. The best agreement was with the 0-5 cm depths and the stress treatment. The highest R^2 values between simulated and TDR VMC were for the stress treatment and the 0-5 cm depths for all years. Model estimates for the 0-5 cm depth provided the best approximation of field conditions for all treatments in all years. Although simulated VMC were within the range of TDR measurements, R^2 values were low. More turf specific data would be needed to improve correlations between field observations and simulation output.

Mean seasonal infiltration and drainage ranked DLY > FC > EOD > STR. The low drainage amounts may not imply less leaching from the 25 cm depth as drainage was calculated below the 100 m depth as for field crops. Daily soil evaporation contributed about 20% of total ET based on assumed leaf area index of 3.5. Transpiration values were within the expected range for East Lansing MI. Contrary to expectation, seasonal cumulative transpiration was not different for the various irrigation.

The stress treatment showed the greatest variation in VMC for all years. While changes in VMC for the irrigated treatments were over a very narrow margin, volumetric moisture content by depth ranked 0-5 > 5-10 >10-15 >15-25 cm at all times for the irrigated treatments. This trend was also true for the stress treatment during wet periods but during dry periods, the trend was reversed (15 -25 > 10-15 > 5-10 > 0-5 cm). These reversals were evident in both the simulated and measured VMC. For a model based on limited weather input the SALUS model provides accurate ET estimates and VMC estimates by depth for a turfgrass ecosystem. Once all the data is arranged, it takes less than 5 seconds to execute. This is a high level of efficiency with respect to computation time.

Because the model was initially designed for crops the model structure did not allow for adjustments in the soil data input by depth. Future modifications in programming may hopefully resolve this weakness. With technological advancement more accurate leaf area indices for closely mowed turf will improve the partitioning of soil evaporation and transpiration. Overall this model could serve as a management tool for improving turf irrigation management.

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