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SIMULATING IRRIGATION REQUIREMENTS OF AN ORNAMENTAL FERN

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Abstract. **A numerical simulation model was developed to estimate irrigation requirements (IRREQ) of an ornamental fern [*Rumohra adiantiformis* (Forst.) Ching] for soil and climate conditions of central Florida. The model was based on a daily water budget of the crop root zone for 22 to 25 years of climate record. Inputs required by the model include crop, soil, and irrigation management factors which affect crop water use. The model outputs statistical characteristics of IRREQ simulated. A sensitivity analysis was conducted to determine the relative effects of changes or errors in model inputs. IRREQ was demonstrated to be very sensitive to crop water use coefficients, time of year, and irrigation efficiency. IRREQ was less sensitive to irrigated root depth, soil water-holding capacity, and changes in allowable soil water depletion.**

Leatherleaf fern is a shallow-rooted perennial crop that is grown under shade on well-drained sandy soils in central Florida (Stamps and Conover, 1986). Shade is provided by oak tree canopies or by shadehouses constructed of polypropylene fabric. Of the approximately 5,000 acres of commercial production, 64% use shadehouses and 36% are grown under oak hammocks (Stamps et al., 1991).

Recommended fern production practices were published by Henley et al. (1980). They recommended irrigating to apply 1 inch of water every 3 days during the summer and 0.5 inches every 4 to 7 days during the winter, with adjustments for rainfall. Stamps et al. (1991) surveyed the Florida ornamental fern industry and reported that average intervals between irrigations in shadehouses was 3.9 days and 6.8 days during the dry and wet seasons, respectively. They reported average water application depths of 0.60 inches and 0.46 inches, respectively.

An irrigation requirement numerical simulation model (FERN-H2O) was developed in this research. The irrigation requirement (IRREQ) is the amount of water which must be applied by irrigation, in addition to rainfall, to meet a crop's water use requirements for growth and production without reduction in yield due to water stress. In this work, the definition of irrigation requirement is limited to irrigation applied to meet the evapotranspiration (ET) needs of a crop. Water applications for freeze protection, fertigation, leaching of salts or other beneficial uses are dependent on factors other than those which determine crop ET, thus they were not considered in this research.

The FERN-H2O model was based on a water budget of the crop root zone and on the estimation of fern ET from climate factors and crop water use coefficients. The water budget method used in this work is well-documented (Fickel, 1983; Hanks and Hill, 1980; Pair, 1983) and has been demonstrated to be applicable to irrigation scheduling in Florida (Allen et al., 1978; Jones et al., 1984; Koo, 1969; SCS, 1982; Shih et al., 1983). The estimation of ET from climate factors and crop water use coefficients is likewise well-documented (Allen et al., 1978; Doorenbos and Pruitt, 1977; Fickel, 1983; Pair, 1983; SCS, 1970). This approach has been widely used for Florida crop and climate conditions. The Florida Soil Conservation Service (SCS, 1982) used it to estimate IRREQ of major agricultural crops throughout the state. Jones et al. (1984) demonstrated that ET was accurately estimated for several crops using this approach, and that the Penman (1948) equation accurately estimated ET for Florida climate conditions. Smajstrla and Zazueta (1987a,b) used the water budget approach to stimulate IRREQ for Florida container nurseries and agronomic crops.

Because irrigation requirements vary as a function of climatic conditions and management practices such as use of shadehouses, and because both long-term average and extreme values are required for irrigation system design, management, and water use permitting, the objective of this research was to develop a numerical model to simulate fern ET based on these factors. This approach also permitted the relative effect of each of the factors affecting fern IRREQ to be evaluated using a sensitivity analysis. Thus, the relative effectiveness of various management practices was evaluated, and data limitations and needs for future research efforts were identified.

Materials and Methods

The water budget method of analysis requires that all water inflows to and outflows from the fern root zone be known. Equation 1 lists the components of the water budget used in this work.

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$$\Delta S = R + I - D - R - ET \quad (1)$$

where ΔS = change in soil water storage (inches),
R = rainfall (inches),
I = irrigation (inches),
D = drainage (inches),
R = runoff (inches), and
ET = evapotranspiration (inches).

The FERN-H2O model was developed as a daily water budget model. The soil water storage on any day was calculated from the previous day's water storage, plus the rain and irrigation, and minus the drainage, runoff, and ET that occurred since the previous day.

ET was calculated as the multiple of Penman reference ET (ETo) and a daily crop water use coefficient for fern. Crop water use coefficients were estimated from ongoing research studies of leatherleaf fern ET in shadehouses in central Florida. ETo was calculated from daily solar radiation, temperatures, and wind speeds using the form of the Penman equation reported by Jones et al. (1984). Climate data were obtained from the National Weather Service (NWS) SOLMET data base for 22 to 25 years of record at Orlando, Daytona Beach, Jacksonville, and Tampa. Rainfall data were obtained from the NWS HISARS data base for the same locations and periods of record.

Water storage in the fern root zone was calculated as the multiple of the available water-holding capacity of the soil times the depth of the fern effective root zone. Soils data were obtained from the Soil Conservation Service (SCS) mapped soil series of Florida. Under typical Florida conditions root depths range up to 12 inches (Harrison and Conover, 1970) for leatherleaf and plumosus fern in Florida.

The combination of runoff and drainage was calculated as the depth of rain in excess of that which could be stored in the fern root zone following each rain. This assumed that runoff did not occur until after the soil water content was restored to field capacity in the root zone. This assumption was valid for the high infiltration rate sandy soils and shallow root zones typical of these fern production systems.

Irrigations were scheduled on those days when the soil water depletions in the fern root zone exceeded the allowable water depletion. To avoid water stress, Harrison and Conover (1970) and the SCS (1982) recommended that water depletions not exceed 50 to 60 percent of the available soil water in the root zone.

Inputs required by the FERN-H2O model include monthly crop water use coefficients and allowable soil water depletions, from which daily values are interpolated for each day of the year. Soil type and effective root depths must also be input. The model contains default values for each of these factors, however, these can readily be changed by the model user based on site-specific conditions.

The FERN-H2O model computes seasonal, monthly, bi-weekly, and weekly statistical characteristics of IRREQ. The mean, median, standard deviation, maximum and minimum values for the period of analysis, and fraction of years with no irrigation are computed. These outputs permit the variability and the long-term average IRREQ to be used for irrigation system design, water use permitting, or other purposes.

The accuracy of the water budget in the FERN-H2O model was verified by maintaining a mass balance throughout each simulation. This procedure verified that all water additions to and extractions from the crop root zone were accounted for at the limits of computer accuracy.

The sensitivity of simulated IRREQ to various model inputs was studied to determine the effects of changes in each input and to determine the accuracy with which each input must be known to accurately simulate fern IRREQ. The sensitivity analysis was conducted by varying each input parameter over its expected range, while other parameters were maintained constant at standard values. This analysis permitted the effects of changes or errors in measuring factors which affect IRREQ to be determined on a relative basis. The standard values used in these sensitivity analyses were: climate data base location = Orlando, crop water use coefficient = 0.4, irrigated root zone = 8 inches, soil water-holding capacity (volumetric) = 0.07, allowable soil water depletion = 0.50, and irrigation application efficiency = 0.75.

Results and Discussion

The effect of geographical location on annual fern IRREQ is shown in Fig. 1. Four locations where sufficient long-term climate data were available were studied: Jacksonville, Daytona Beach, Orlando, and Tampa. These locations were selected to bracket the fern-growing region of Florida. From Fig. 1, IRREQ increased from northern to southern locations. However, there was little difference in the Daytona Beach and Orlando values which are nearest the principle fern-growing region.

The effect of time of year is shown in Fig.2 by graphing simulated monthly IRREQ for the Daytona Beach and Orlando locations. This figure demonstrates that fern IRREQ is very sensitive to time of year. Peak values occurred in Apr. and May when climate demand is high and rainfall is low. Lowest values occurred during the winter months. Monthly distributions were in close agreement at both locations from Dec. through June. Orlando values were lower in summer and higher in fall because of differences in long-term rainfall patterns between Orlando and Daytona Beach.

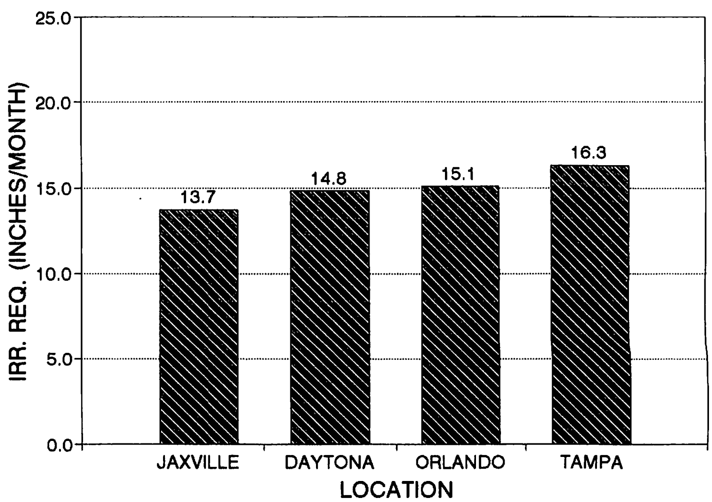

Fig. 1. Long-term average annual irrigation requirements for locations from north to central Florida.

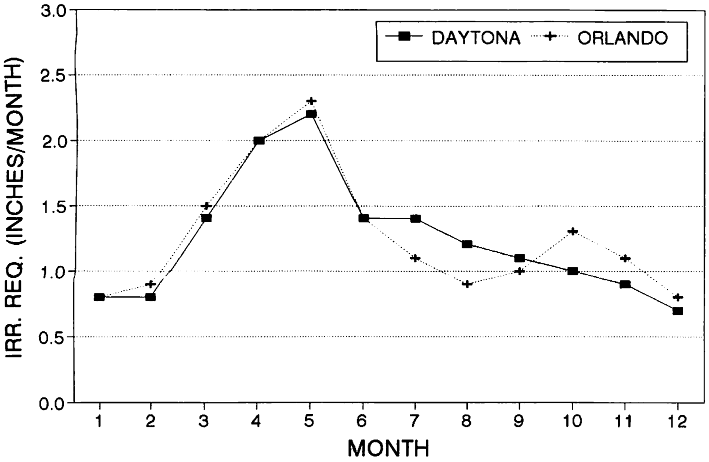

Fig. 2. Effect of time of year on irrigation requirements using Daytona Beach and Orlando climate data.

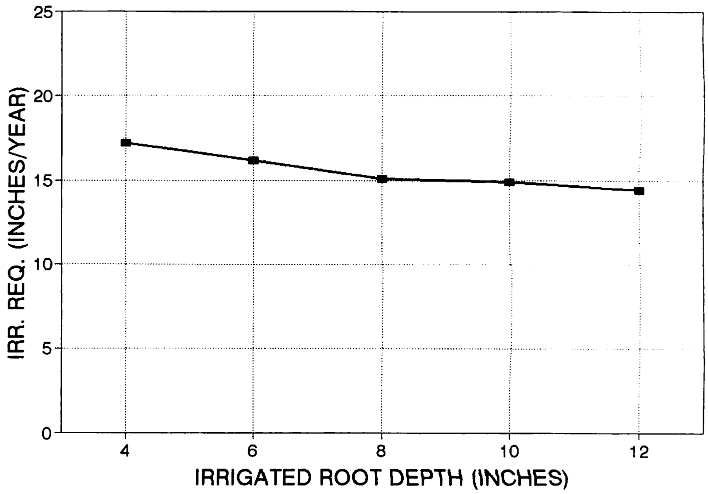

Fig. 4. Effect of irrigation root depth on simulated irrigation requirements.

Fern IRREQ were found to be very sensitive to crop water use coefficients as shown in Fig. 3. This figure demonstrates that crop coefficients must be precisely known to accurately estimate IRREQ. Crop coefficients used in this work were determined from lysimeter studies of fern ET currently being conducted at the Central Florida Research and Education Center - Apopka. Monthly values of 0.4 were used in this project. Those values reflect the reduced climate demand that results from growing fern in shadehouses.

The effects of increasing root depth (Fig. 4) and increasing soil water-holding capacity (Fig.5) are similar. Increases in either of these will increase the soil water available to the plants. In a humid area like Florida, increasing the available soil water increases the effectiveness of rain, thus reducing IRREQ. Ornamental fern is shallow-rooted, with root zone depths typically in the range of 4 to 12 inches.

Figure 4 demonstrates that IRREQ was relatively insensitive to irrigated root depths in the range of 4 to 12 inches. IRREQ decreased from about 17 inches for a 4-inch root depth to 14 inches for a 12-inch root depth. This low sensitivity demonstrates that it is not necessary to precisely determine fern root depth to accurately estimate IRREQ unless the root depth is greatly different from the 8-inch standard value used in this analysis.

Figure 5 demonstrates that IRREQ was also relatively insensitive to soil water-holding capacities over the range typical of Florida sandy soils. IRREQ decreased from about 19 inches to 13 inches as the volumetric soil water-holding capacity increased five-fold from 0.02 to 0.10. This suggests that soil water-holding capacities obtained from soil survey data would be sufficient to accurately estimate fern IRREQ.

The effect of soil water depletion allowed between irrigations is shown in Fig. 6. Allowable soil water depletions typically range from 0.3 to 0.7, with 0.5 most commonly used. Over this range, IRREQ was shown to be relatively insensitive to changes in allowable soil water depletion for all three soil water-holding capacities studied. These results demonstrate that IRREQ is relatively insensitive to irrigation scheduling practices commonly used.

Figure 7 shows the effects of irrigation system water application efficiency on IRREQ. IRREQ was less sensitive to application efficiencies when efficiency was above the

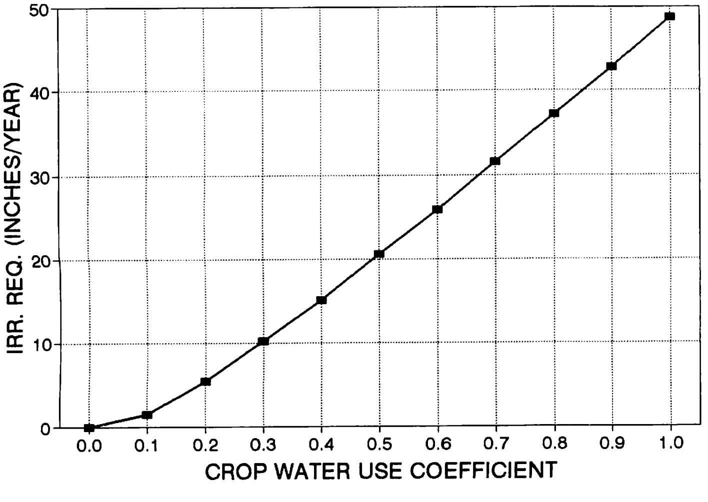

Fig. 3. Sensitivity of irrigation requirements to changes in the crop water use coefficient.

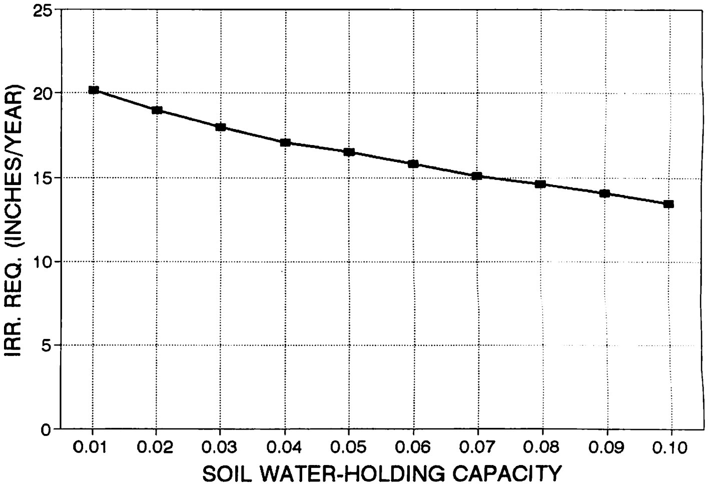

Fig. 5. Effect of volumetric soil water-holding capacity on simulated irrigation requirements.

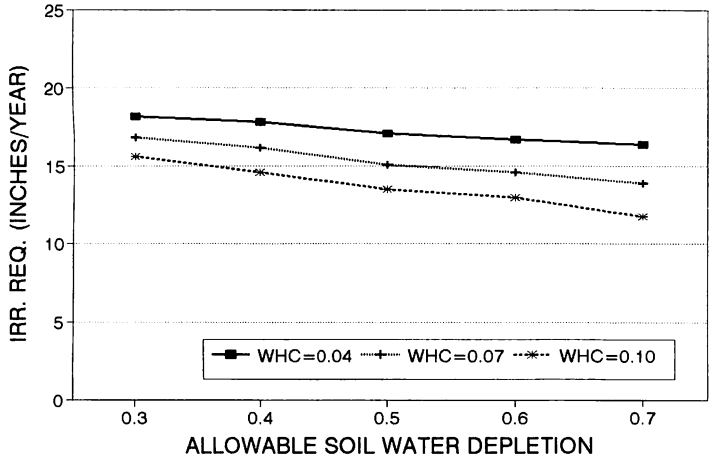

Fig. 6. Effect of allowable soil water depletion on simulated irrigation requirements for three soil water-holding capacities.

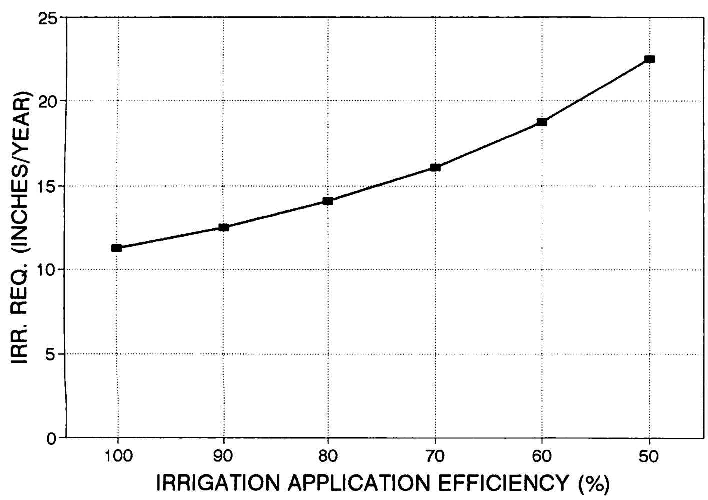

Fig. 7. Effect of irrigation application efficiency on simulated irrigation requirements.

standard value of 75%, but sensitivity increased with lower efficiencies. These results demonstrate the need for proper irrigation system design, installation, and maintenance to minimize irrigation requirements.

From the sensitivity analyses conducted, IRREQ was demonstrated to be very sensitive to crop water use coefficients, time of year, and irrigation system efficiency for low-efficiency systems. IRREQ was demonstrated to be less sensitive to location within the primary fern-producing region of the state. However, because rainfall is much more variable than ETo, site-specific rainfall records are required. IRREQ was also demonstrated to be less sensitive to depth of root zone, soil water-holding capacity, and allowable soil water depletion for typical ranges of values.

These results suggest that research directed toward decreasing fern irrigation requirements should first consider the highest-sensitivity factors. The lower sensitivity to other factors demonstrates that those factors do not need to be precisely known in order to accurately simulate irrigation requirements.

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