Table 4. Characteristics of 13 nurseries in Jefferson and Leon counties classified as large, medium, and small based on average number of employees per nursery.

Nursery category	No. of employees	Percent of nursery as: Field area	Container area	Greenhouse area	Percent of sales to: Retailers	Wholesalers	Landscapers
Largest 1/3 (n = 4)[z]	35.9	63.2	35.0	1.8	36.7	31.7	23.3
Middle 1/3 (n = 5)	4.1	59.4	39.8	0.8	36.2	51.2	12.5
Smallest 1/3 (n = 4)	1.4	0.0	70.0	30.0	53.2	46.0	0.5

[z]Number of nurseries in category.

in this survey started their operations before container production became widespread in the 1950's and 60's. Their acreage of field production area may reflect the method of production that was dominant at the nurseries' inception.

Results of this survey will be helpful in determining information and training needs of nursery growers that could be provided by the Cooperative Extension Service. However, the combination of diversity in size and type of plants produced indicates that a more widespread survey and further research on labor, sources of income, and market locations would be very helpful for determining successful strategies for new nurseries.

As a result of the survey, we are in the process of organizing a directory of nurseries and their products in Jefferson and Leon Counties. Industry response to the survey and the directory has been favorable. A similar effort is likely to be made in Columbia and Suwannee Counties.

Proc. Fla. State Hort. Soc. 100:343-348. 1987.

ESTIMATING IRRIGATION REQUIREMENTS OF SPRINKLER IRRIGATED CONTAINER NURSERIES

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Additional index words. evapotranspiration, potential evapotranspiration, crop water use, computers, numerical modeling, numerical simulation.

Abstract. **An irrigation requirements (IRREQ) numerical simulation model was developed in this research. The model was based on a water budget of the crop root zone and the concept that crop evapotranspiration (ET) can be estimated from historical climatic records and crop water use coefficients (Kc). Inputs required by the model include crop, soil, irrigation system, and irrigation management factors which affect crop water use. The model outputs statistical characteristics of IRREQ simulated for the periods of climatic record used. A sensitivity analysis was conducted to determine the relative effect of changes or errors in model inputs on IRREQ. IRREQ was demonstrated to be very sensitive to Kc, time of year, irrigation system efficiency, fraction of ET extracted from the containers, and fraction of the surface area covered with containers. IRREQ was less sensitive to geographical location, while it was relatively insensitive to container media water-holding capacities, container depths, and allowable soil water depletions for typical ranges of these factors. Data limitations and needs for future research efforts were identified.**

An irrigation requirement (IRREQ) numerical simulation model was developed in this research. IRREQ is the amount of water which must be applied by irrigation, in addition to rainfall and antecedent soil water storage, to meet a crop's water use requirements for growth and production without significant reduction in yield due to water stress. In this paper the definition of IRREQ is limited to irrigation applied to meet the evapotranspiration (ET) requirements of a crop. Other uses such as freeze protection, crop cooling, and leaching of salts are legitimate irrigation uses, but their magnitudes are dependent upon factors other than those which determine ET requirements of crops. Thus, they were not considered in this research.

The net irrigation requirement (NIR) is the amount of irrigation which must be applied to a crop if no losses of water occur during application. However, because irrigation systems are not capable of applying water without losses, the gross irrigation requirement (IRREQ), which includes irrigation application efficiency losses, is a more meaningful term. IRREQ rather than NIR must be known by irrigation system managers in order to apply the correct amount of water during irrigation, and by water management personnel so that the correct amount of water can be

Florida Agricultural Experiment Station Journal Series No. 8511. This research was partially funded by the South Florida, the Southwest Florida, the St. John's River, and the Suwannee River Water Management Districts.

permitted for crop production. For these reasons, the irrigation requirement estimated in this work was the gross irrigation requirement (IRREQ).

The IRREQ model was based on a water budget of the crop root zone and the concept that ET can be estimated from potential evapotranspiration (ETp) and crop water use coefficients. ETp is an index of climatic demand and can be calculated from historical climatic records. A water budget is a mass balance for water in the crop production system.

The water budget method used in this research is a well-documented (7, 10, 12, 13, 16) method of irrigation scheduling which has been shown to be applicable to irrigation scheduling in Florida (1, 3, 15, 18, 20, 21). The concept of estimating ET from ETp and crop water use coefficients is likewise well-documented (5, 7, 13, 16, 19). This approach has been widely used for Florida crop, soil, and climatic conditions. The Florida Soil Conservation Service (20) used it to provide estimates of irrigation requirements for major agricultural crops throughout the state. Jones et al. (14) demonstrated that ET was accurately estimated for several crops using this approach and that the Penman (17) equation estimated ETp best for Florida conditions.

Stanley and Harbaugh (23, 24) demonstrated that ET requirements of certain container ornamental plants could be estimated by using pan evaporation as an index of climatic demand, and using plant height as an index of plant size. Fitzpatrick (8, 9) demonstrated that water use varied widely as a function of plant species and size. Barrett and Nell (2) showed that water requirements varied as a function of plant species and drought stress.

Harrison (11) reported that irrigation applications to sprinkler-irrigated container nurseries were much greater than amounts required for ET. Amounts observed ranged from 73 to 111 inches per year. This large difference between water applied and ET of container grown plants is believed to be due to relatively low irrigation system efficiencies which caused much of the water applied to be ineffective.

Because IRREQ varies as a function of climatic conditions, irrigation system type, and other factors, and because both long term average and extreme values of IRREQ are required for container nursery irrigation system design, management, and water use permitting, the objective of this research was to develop a method of estimating irrigation requirements for Florida container nurseries which would incorporate these factors. Also, because of the various factors which affect irrigation requirements, and the climatic variability from year-to-year, the approach chosen was that of the development of a numerical simulation model. This approach also permitted the relative effect of each of the factors affecting IRREQ to be evaluated using a sensitivity analysis. Thus, the relative effectiveness of various management practices were evaluated, and data limitations and needs for future research efforts were identified.

Model Development

The Water Budget. The water budget approach to simulation of IRREQ is ideally suited to the study of container nursery plants because the root zones of container grown plants are well-defined. The water budget method of analysis required that all water inflows to and outflows from the root zone be known. Figure 1 shows the components of the water budget for the root zone of container grown plants. Water is stored in the plant root zone in the containers. The amount potentially stored depends on the container size and the hydraulic properties of the potting media. Excess water from large rainfalls or large irrigation events is lost to drainage. Other losses from soil water storage are due to transpiration from the plants and direct evaporation from the potting media, combined as ET. Inputs to soil water storage occur from rainfall and irrigation. Both rainfall and sprinkler irrigation effectiveness may be affected by shedding of water from the containers due to the plant canopy, depending on the types of plants being irrigated.

The water budget was mathematically defined as

$$\Delta S = R + I - D - ET \tag{1}$$

where ΔS = change in container water storage (inches),
R = rainfall (inches),
I = irrigation (inches),
D = drainage (inches),
ET = evapotranspiration (inches)

The model was developed as a daily water budget model. This frequency was used because it was appropriate to the irrigation scheduling problem studied, and climatic data required to estimate daily ET were available. Then the container water storage on any day (i) was calculated in terms of the previous day's (i-1) water storage plus the rain and irrigation and minus the drainage and ET that occurred since the previous day as

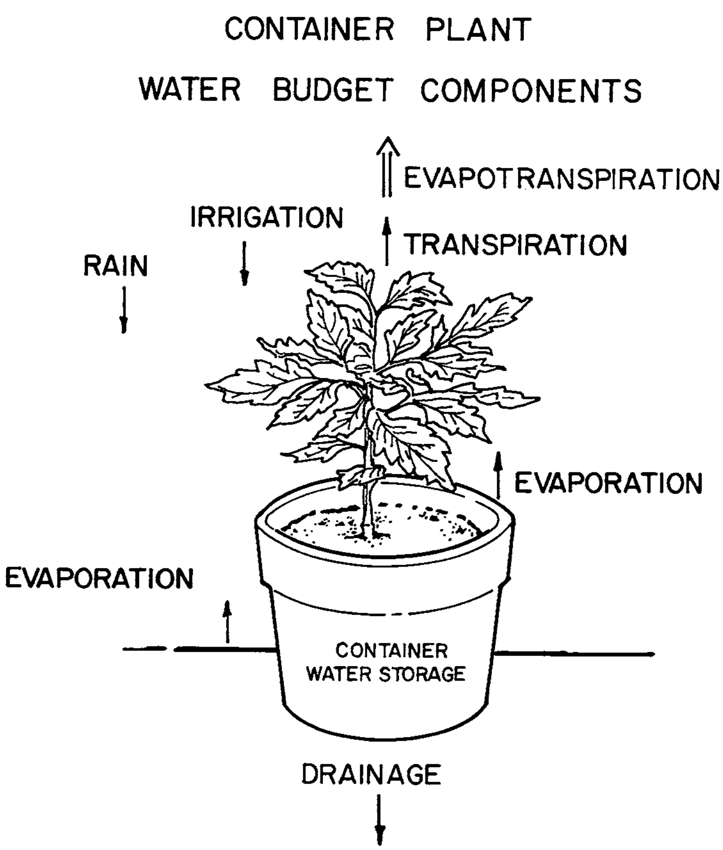

Fig. 1. Water budget components for container nursery plants.

$$S(i) = S(i-1) + R + I - D - ET \quad (2)$$

ET was calculated as a multiple of ETp and daily crop water use coefficients for nursery crops (5). ETp was calculated using the Penman (17) equation as modified and recommended for Florida conditions by a study committee of IFAS research scientists (14). Details of the application of this method in the development of an ETp data base were reported by Smajstrla et al. (22).

Data required for the ETp data base were daily values of solar radiation, maximum and minimum temperatures, and wind run. These climatic data were obtained from the National Weather Service (NWS) SOLMET data base. This data base was limited to a maximum of 25 years of record (1952-1976) for eight Florida locations. Mobile, Alabama data were used as a ninth location to help describe ETp in northwest Florida.

Rainfall data were obtained from the National Weather Service HISARS data base. Daily values were obtained for the same 25-year periods and locations as the ETp data base.

Water storage in the crop root zone was readily defined because the root zone was assumed to be confined to the containers and to permeate throughout the containers. The maximum amount of water that could be stored in the containers (container capacity) was calculated as the multiple of the available water-holding capacity of the potting media (on a volumetric basis) and the depth of media in the containers. Likewise, the container water content at any time was calculated as the multiple of the water content of the potting media at that time and the depth of potting media. The depth in inches per unit of nursery land area was obtained by multiplying the depth of water in the containers by the fraction of the nursery land area covered by containers. This produced units consistent with those of rainfall and ET.

Drainage from the containers was calculated as the depth of rainfall which exceeded that which could be stored in the containers when rain occurred. This included rain which fell between containers as well as that which exceeded the container capacities and thus drained through the containers. Irrigation was assumed to be applied in amounts sufficient only to restore the containers to capacity, but still produced drainage because of that which fell between the containers.

From equation (2), the container water content on a given day was calculated as yesterday's water content, plus rainfall and irrigation, and minus ET and drainage since yesterday. To begin each simulation, the water stored in the containers was assumed to be at 80% of container capacity.

Irrigations were scheduled when the water depletions from the containers exceeded the allowable water depletion. Irrigation depths applied were calculated as the amounts required to restore the containers to capacity, including application efficiency losses.

Model Inputs. Inputs required by the IRREQ model include crop water use coefficients and allowable water depletions on a monthly basis. From these, daily values are interpolated. The irrigation season must be specified. For container nurseries, it is normally all year, but it may be specified as only a portion of the year. The climate data base location must be selected from one of the nine model-supplied locations. This selection specifies the ETp and rainfall data bases used. The irrigation system application efficiency must be specified so that IRREQ can be calculated from NIR.

The container depth and fraction of the land area which is covered by containers must be specified. The container depth limits the crop root depth, and with the land area covered by containers, defines the crop root volume. The water-holding capacity of the potting media must be specified, and with the crop root volume, defines the available water in the crop root zone.

Model Outputs. The model computes statistical characteristics of IRREQ simulated for the periods of climatic record used. The mean, median, standard deviation, maximum and minimum values for the period of record, and proportion of years with no IRREQ are computed. These outputs permit the variability as well as the long term average IRREQ to be considered for irrigation system design, water use permitting, or other purposes.

Results and Discussion

Model Verification. The accuracy of the model developed was verified by maintaining a mass balance throughout each simulation. This procedure verified that all water additions to and deletions from the system were accounted for at the limits of computer accuracy.

The accuracy of the simulation model was also tested by comparing the model results with measured water usages by container nurseries reported in the literature. However, only very few data were available for this comparison. Harrison (11) reported a range in irrigation pumpage from 73 to 111 inches per year for sites he metered. Duerr and Trommer (6) reported a range from 105 to 240 inches per year for farms included in the Southwest Fla. Water Mgt. Dist. Benchmark Farm Program. Neither of the above papers reported other data required for a direct comparison with the IRREQ model results. However, the model was observed to simulate IRREQ in the range of those reported in the above papers.

Sensitivity Analysis. The sensitivity of irrigation requirements simulated to various model inputs was studied to determine the effects of changes in inputs on IRREQ and to determine the accuracy with which each input must be known to accurately simulate IRREQ. The sensitivity analysis was conducted by varying each input parameter over its expected range, while other parameters were maintained constant at their expected values, and observing the effect on IRREQ simulated. This analysis permitted the effects of changes or errors in measuring factors which affect IRREQ to be determined on a relative basis.

The effect of the geographical location of nurseries on IRREQ is demonstrated in Fig. 2 for the nine climate data bases in and near Florida. This figure demonstrates that nursery geographical location was important as IRREQ was greater in south and central as compared to north Florida. This occurred because ETp was less in north Florida, but rainfall was greater in south as compared to central Florida.

The effect of time of year is shown in Fig. 3 by graphing monthly IRREQ values for locations in north, central and south Florida. This figure demonstrates that IRREQ was very sensitive to time of year. This occurred because

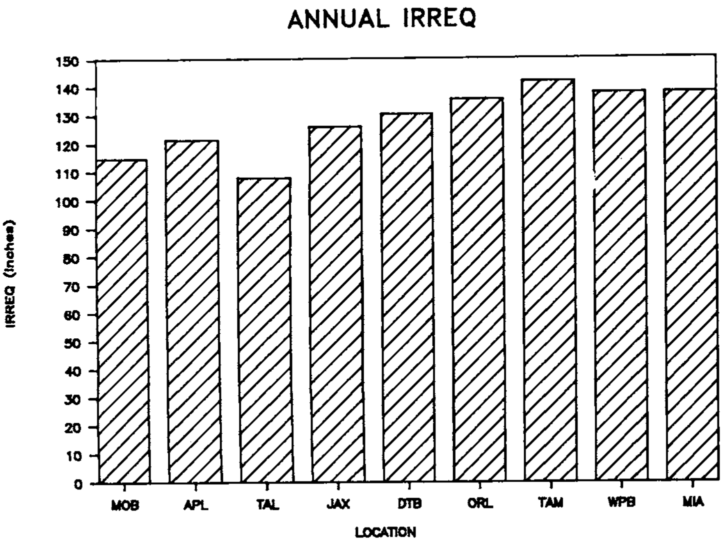

Fig. 2. Long-term average annual container nursery irrigation requirements simulated for nine locations in and near Florida.

IRREQ is a function of both rainfall and ETp. Thus the greatest IRREQ occurred during the dry, high ETp month of May throughout much of Florida, while the lowest values occurred during the winter months.

IRREQ was found to be very sensitive to crop water use coefficients (Kc) at all locations studied. Fig. 4 shows effects of crop coefficients ranging from 0.5 to 1.5 on IRREQ. This figure demonstrates that IRREQ increased with increasing values of Kc, but that it increased more rapidly at larger values of Kc. This occurred because rainfall provided a greater portion of ET when ET rates were small than when ET rates were large.

For Florida container grown ornamental plants, container water-holding capacities typically range from 0.10 to 0.50 (4). IRREQ was found to vary only about 5% when the water-holding capacity of the potting media in the nursery containers was varied over this range (Fig. 5). This insensitivity to water-holding capacity occurred because the relatively small container sizes (with respect to the soil

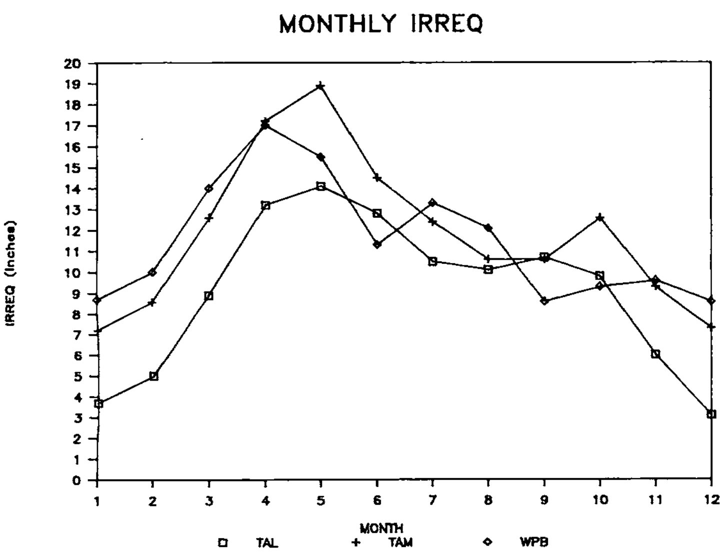

Fig. 3. Monthly distribution of simulated container nursery irrigation requirements for Tallahassee, Tampa, and West Palm Beach, Florida.

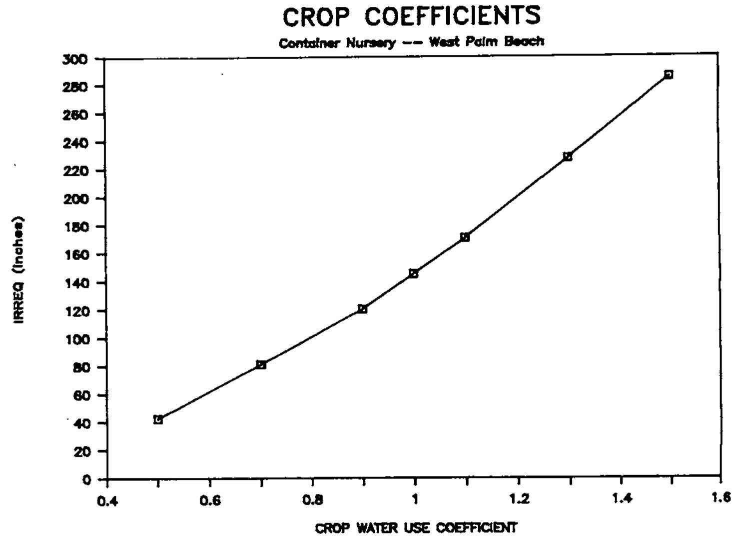

Fig. 4. Effects of crop coefficients on irrigation requirements simulated for container nurseries.

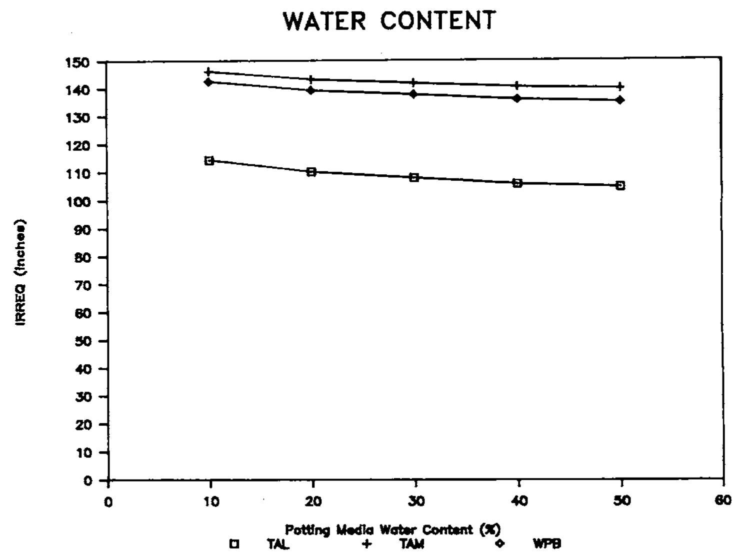

Fig. 5. Effects of potting media water holding capacity on simulated irrigation requirements for Tallahassee, Tampa, and West Palm Beach, Florida.

volume available to field-grown palants) contained relatively little water. Thus, rainfall was relatively ineffective and most of the crop's water requirements were provided by irrigation.

The depths of containers had little effect on IRREQ as shown in Fig. 6. This occurred for the same reason that IRREQ was relatively insensitive to container water-holding capacity; that is, rainfall was relatively ineffective for the limited soil volumes available, even for container depths of up to 36 inches.

IRREQ was very insensitive to allowable soil water depletions between irrigations (Fig. 7) for the same reasons that it was insensitive to the water-holding capacity of the container media and container depths; that is, because of the very limited water-holding capacity of the container media and the resulting ineffectiveness of rainfall.

IRREQ was very sensitive to the efficiency (EFF) of sprinkler irrigation systems in applying water to the containers (Fig. 8). Also, the sensitivity was greater when the

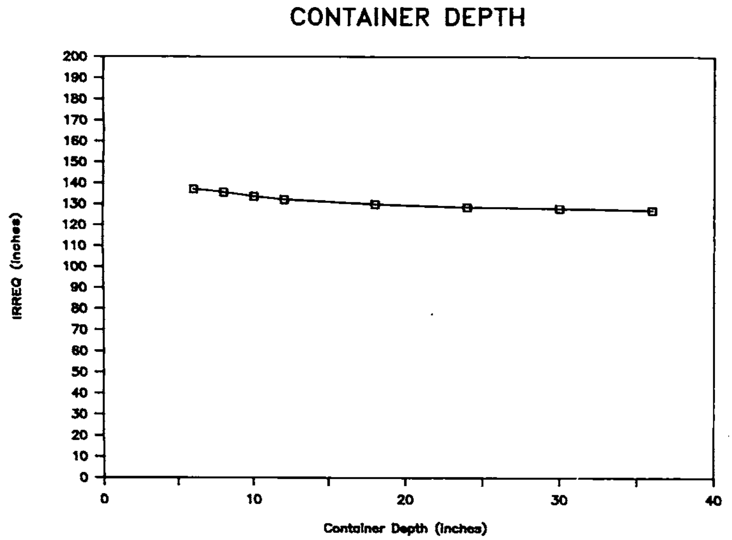

Fig. 6. Effects of container depth on simulated irrigation requirements of container nurseries.

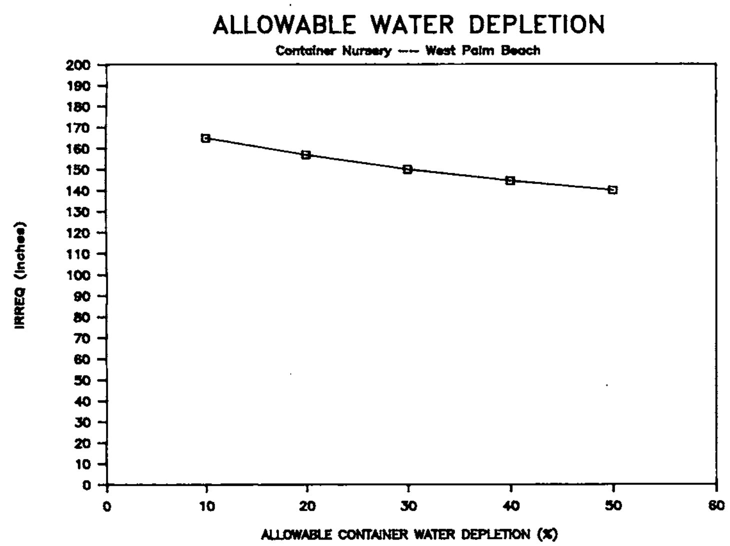

Fig. 7. Effects of allowable container water depletion on simulated irrigation requirements of container nurseries.

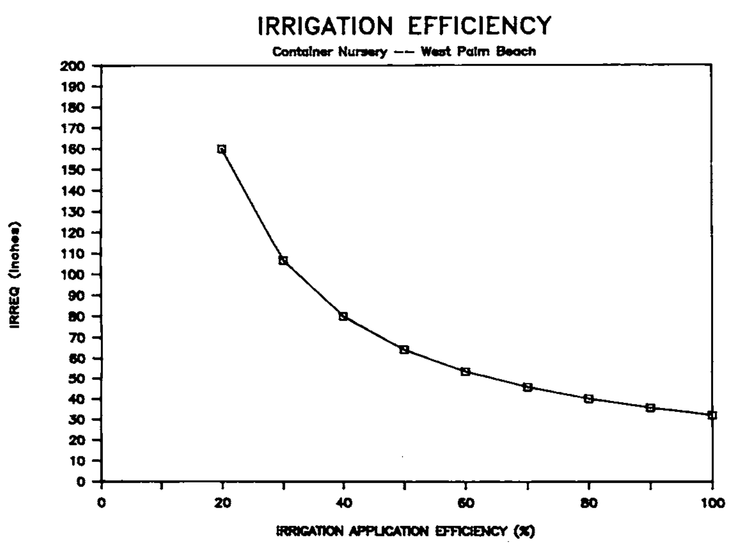

Fig. 8. Effects of irrigation system application efficiency on irrigation requirements simulated for container nurseries.

efficiency was lower, because IRREQ was calculated by dividing NIR by the efficiency. This demonstrates the need for more accurately determining the efficiency of low efficiency systems than high efficiency *systems.*

In a container nursery, the majority of the ET occurs as transpiration from the container plants and evaporation from the container media. Some however, is direct evaporation from foliage wetted by the sprinklers, and some is evaporation from the soil and other areas between the container plants. Fig. 9 demonstrates the importance of contributions to ET from sources other than ET from the container media. IRREQ was very sensitive to the fraction of ET which was contributed from the containers as compared to the total ET requirement. This figure demonstrates the need for accurately measuring ET losses from container plants under the nursery conditions that they will experience during irrigation. The amount of plant foliage and the condition of the ground surface between containers would both be expected to greatly influence IRREQ because of the potential contributions to ET from these surfaces.

IRREQ was sensitive to the fraction of the surface covered with containers (Fig. 10) because the rainfall effectiveness is directly influenced by the catchment area described by the surface area covered. Fig. 10 demonstrates that for plants having the same ET rates (plants of the same size and species) those in larger diameter containers will intercept more rainfall and irrigation, thus reducing IRREQ.

Research Needs. From the sensitivity analyses conducted, IRREQ was demonstrated to be very sensitive to crop water use coefficients, time of year, irrigation system efficiency, fraction of ET extracted from the containers, and fraction of the surface area covered with containers. Research studies are required to quantify these factors if IRREQ is to be accurately estimated using the model developed in this work.

IRREQ was shown to be sensitive to geographical location, demonstrating the need to use climatic data in the region of the nursery for which IRREO is to be estimated. Also, because rainfall is much more variable than ETp, site-specific rainfall data records are required.

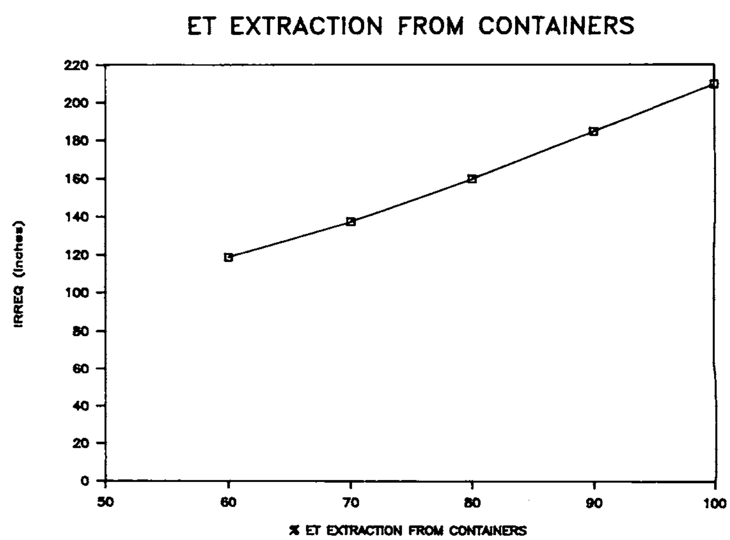

Fig. 9. Effects of ET extraction from water stored in containers of nursery plants on simulated irrigation requirements.

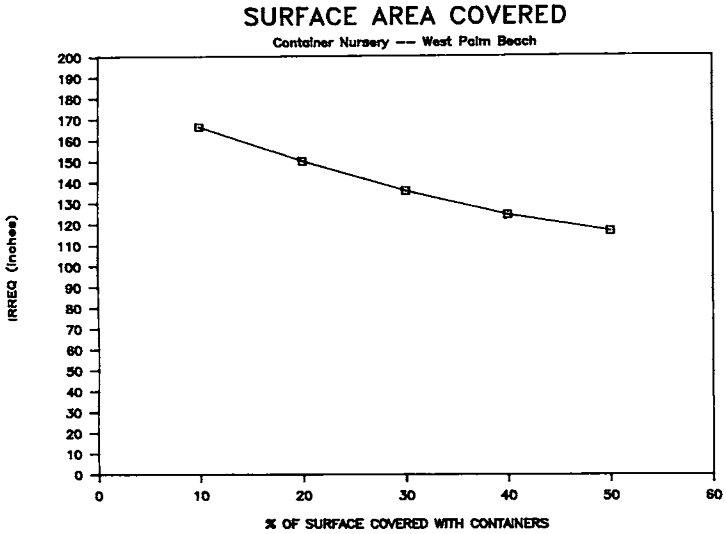

Fig. 10. Effects of land surface area covered with containers on irrigation requirements of container nurseries.

IRREQ was shown to be relatively insensitive to container media water-holding capacities, container depths, and allowable soil water depletions, for typical ranges of these parameters. This indicates that research directed toward decreasing IRREQ should not concentrate on these factors, but rather should be directed toward those factors to which IRREQ is very sensitive.

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Proc. Fla. State Hort. Soc. 100:348-350. 1987.

THE CENTER FOR ARTHROPOD SYSTEMATICS AND THE CENTER FOR SYSTEMATIC ENTOMOLOGY, INC.

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Abstract. **The Bureau of Entomology of the Division of Plant Industry, Florida Department of Agriculture and Consumer Services located in Gainesville, Florida, provides an arthropod identification service for the state of Florida. Much of the work concerns identification of insect pests found in and around nurseries and an increasing number of identifications for home owners. Their basic tools are the Division's extensive entomological library and the Florida State Collection of Arthropods (FSCA). The Center for Arthropod Systematics, initially involving an institutional agreement between the University of Florida and the Florida Department of Agriculture and Consumer Services, was established in 1983. Its primary purpose is to encouraoge research on the diversity, systema-**