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Estimating Crop Irrigation Requirements for Irrigation System Design and Consumptive Use Permitting [1]

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INTRODUCTION

The irrigation requirement (IRR) for crop production is the amount of water, in addition to rainfall, that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield. Evapotranspiration (ET) includes water that is needed for both evaporation and transpiration. Evaporation is the change of water from liquid to vapor form. Evaporation occurs from all moist or wet surfaces, including soil, water, plant, and other surfaces. Transpiration is evaporation from plant leaves through small openings in the leaves called stomata.

Both evaporation and transpiration occur in response to climate demand. ET is greatest on hot, dry days and lowest on cool, humid days.

ET must occur to avoid plant water stress. Plant water stress will occur if ET is limited because water is not available to plants. Water stress will occur quickest on high climate demand days. Water stress is avoided by rainfall or by irrigating to provide a crop with the water needed for evaporation and transpiration.

CALCULATING IRRIGATION REQUIREMENTS

To avoid water crop water stress, rainfall and irrigation must be sufficient to meet the crop's ET requirement. This means that for any period of time during the crop growing season, the net irrigation requirement (NIR) is the amount of water which is not effectively provided by rainfall:

$$NIR = ET - ERAIN \quad (1)$$

where

NIR= net irrigation requirement,

ET= evapotranspiration, and

ERAIN = effective rainfall.

NIR is irrigation water which is delivered to the field and available for the crop to use. This is primarily water which is stored in soil in the crop root zone, although some of the water which is evaporated from water, soil, and plant surfaces during application also effectively reduces climate demand.

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Some water is lost while transporting it from its source to the crop root zone. Losses occur due to such causes as leakage from pipelines, seepage and evaporation from open channels, and evaporation from droplets sprayed through the air. Because of these losses, more water must be pumped than that required to be stored in the crop root zone. The gross irrigation requirement (IRR) is the amount that must be pumped. IRR is greater than NIR by a factor which depends on the irrigation efficiency (EFF):

IRR = NIR / EFF(2)

where

IRR = gross irrigation requirement (inches),

NIR = net irrigation requirement (inches), and

EFF = irrigation efficiency (decimal fraction).

ERAIN is that portion of rainfall which can be effectively used by a crop, that is, rain which is stored in the crop root zone. Therefore, ERAIN is less than total rainfall due to interception, runoff and deep percolation (or drainage) losses.

From the above definition, a crop's irrigation requirement does not include water applied for leaching of salts, freeze protection, crop cooling, or other purposes, even though water for these purposes is required for crop production and is applied through an irrigation system. Total crop water requirements would be determined by adding water needed for these uses to the irrigation requirement calculated from equation (1).

From Equation (1), the irrigation requirement may be calculated for any time period; however, for water (consumptive) use permitting purposes, it is normally calculated for monthly and seasonal or annual time periods.

ESTIMATING IRRIGATION REQUIREMENTS

Estimates of irrigation requirements can be made from 1) historical observations, or 2) numerical models. Numerical models may be based on statistical methods or on physical laws which govern crop water uptake and use.

Historical Observations

If a crop has been repeatedly grown at a given location, and if a long-term record has been kept of irrigation water applied, this record can be used to estimate future uses. Both long-term average as well as extreme values can be estimated using the historical record. The problem is that few such long-term data bases exist. It is desirable to have 20 to 30 years of record to estimate extreme values with sufficient accuracy.

Another problem with the use of the historical data method is that its use may be limited to the specific location where the data were obtained. The effects of differences in climate, soil, location, time of year during which the crop is grown, as well as other factors on irrigation requirements cannot be determined from the available data. Thus, although this method may be accurate for the continuous production of a given crop at one location, the data may not be useful for other crops at other locations.

Historical data may be found in crop production guides or obtained from growers or irrigation system managers who have considerable field experience with a given crop and irrigation system.

Numerical Models

Numerical models may be based on statistical methods or on physical laws which govern crop water uptake and use. The Soil Conservation Service (SCS, 1970) procedure is a statistical regression method. The Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) model (Smajstrla, 1990) is a numerical simulation model based on the water budget of the crop root zone.

Equation (1) may be applied by estimating monthly ET and ERAIN or by calculating daily water budgets and adding them for the required time periods. The first approach is used in the SCS method. The second was used in the AFSIRS model. There are advantages and limitations to both methods, as discussed in the following sections of this report.

SCS Method

The SCS method is a statistical regression method that allows monthly crop irrigation requirements to be estimated based on three factors: monthly crop ET, monthly rainfall, and soil water-holding characteristics, data that are readily available at most locations. The method is given in SCS Technical Release 21 (SCS, 1970). The model has the following characteristics:

- It estimates irrigation requirements for monthly or longer time periods only. This is a limitation of the statistical regression approach used.
- It estimates either mean or extreme values of irrigation requirements, based on rainfall drought frequency data used. To estimate mean values, long-term average values of monthly rainfall and ET are used in the regression model. To estimate extreme irrigation requirement values, extreme values of rainfall are used. A procedure is included to estimate extreme rainfall values from long-term average values for locations with widely-ranging rainfall characteristics.
- It estimates irrigation requirements for crops grown on deep soils with no shallow water table present. This limits the application of this model to sprinkler and surface irrigation systems where the typical irrigation practice is to periodically irrigate the entire crop root zone to field capacity. It also limits the model application to deep soil types which freely drain excess rainfall. These were limitations of the data used to develop the regression model.
- It estimates irrigation requirements for systems that irrigate the entire soil surface. This prohibits this model from being used with microirrigation systems because the effective rainfall model was developed assuming that the entire soil surface is irrigated.
- It requires monthly rain and ET estimates or measurements. These may be either long-term values or specific monthly values, depending on whether the user is estimating long-term or specific monthly irrigation requirements.
- It requires soil water storage data. Soil water storage data are input to the model as the typical depth of water applied per irrigation. It is assumed that the depth of water applied is appropriate for the soil water-holding characteristics and the crop water requirements.

AFSIRS Model

The AFSIRS model is a water budget model that was developed by the authors of this publication. AFSIRS is an acronym for Agricultural Field Scale Numerical Simulation Model. It is a computer simulation model based on a daily water budget of the crop root zone. The AFSIRS model has the following characteristics:

- It estimates irrigation requirements for daily, weekly, two-week, monthly, seasonal, and annual time periods. Because it is based on daily water budgets, irrigation requirements can be calculated for shorter periods of time than with the SCS model. However, estimates for very short (daily) time periods are often not very meaningful because these data are highly variable.
- It requires long-term historical climate data bases of daily ET and rain to calculate daily water budgets of the crop root zone. These calculations require a long-term climate record of daily reference ET and rainfall for the location being studied. Ideally, 20 to 30 years of climate record should be used in order to be able to accurately estimate extreme values of irrigation requirements.
- It estimates both mean and extreme values of irrigation requirements, based on probabilities calculated from daily irrigation requirements simulated. The year-to-year distributions are used to calculate extreme values by fitting a theoretical function to the actual annual data. A coefficient is calculated which indicates how well the data fit the theoretical distribution so the user can determine whether the data base is sufficiently long to accurately estimate the desired extreme values.

- It estimates irrigation requirements for common Florida irrigation systems, including sprinkler, surface, micro and seepage systems. All four types of systems are included in the model by simulating the effects of periodic irrigations of the entire soil surface with sprinkler and surface irrigation systems, high water tables in seepage irrigation systems, and partial root zone irrigation in microirrigation systems.
- It requires many inputs which describe crop, soil, irrigation system, and management factors which affect irrigation requirements. The user is prompted for each of these inputs; however, default values are given for each input, based on typical Florida conditions.
- It is limited by few available data for some Florida crops and production systems. Because of the great diversity of Florida's agriculture, not all crops and production systems have been extensively studied. However, the AFSIRS model contains actual crop data when available and the author's best estimates for coefficients and data that can be extrapolated from other locations. In all cases, the user can change the model input data as required to customize the model for a specific application or based on the most recent research results.

SUMMARY AND CONCLUSIONS

The irrigation requirement (IRR) for crop production is the amount of water, in addition to rainfall, that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield. Estimates of irrigation requirements can be made from 1) long-term historical observations, or 2) numerical models.

Few long-term historical data bases exist. Also, these data bases may not be readily extrapolated to other sites, thus they may have limited use for estimating irrigation requirements for irrigation system design or consumptive use permitting purposes. For these reasons, numerical models have been developed and are used to estimate irrigation requirements for a wide range of crop and production conditions.

Numerical models may be based on statistical methods or on physical laws which govern crop water uptake and use. Two models are available for use in Florida: the SCS statistical regression model and the AFSIRS water budget model. The use of the SCS model is limited to monthly or seasonal calculations of irrigation requirements of surface or sprinkler irrigated crops on deep, well-drained soils.

The AFSIRS model is more flexible: it can be used for all Florida soils and irrigation systems. However, because it requires much more input data than the SCS model, the data required for all crops and production systems may not be readily available.

REFERENCES

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