IRRIGATION SCHEDULING IN HUMID AREAS

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Irrigation of humid areas of the U.S. was very sporadic until the middle to late seventies. Farmers irrigated only when moderate to severe drought occurred except for horticultural or specialty crops. The need for reliability of crop yield, cash flow income to insure annual net profits, and increased emphasis on national production has increased the emphasis on southeastern agriculture, and renewed interest in irrigation. For example, total irrigated acreage in Georgia has increased from 58,500 ha in 1970 to an estimated 340,000 in 1979.

Climatic variability is typified by nonirrigated corn yields which varied from 0 kg/ha in 1954 to 8,230 kg/ha (131 bu/ac) in 1950 in an irrigation experiment in South Carolina. Yield was 2,000 kg/ha (32 bu/ac) or below for 6 years and 6,000 kg/ha (96 bu/ac) or above for 6 years out of the 19 years. Such variability plays havoc with a farmer's cash flow, and usually with the overall profitability of his farm. As the cost-price squeeze has tightened during the last few years, and as low-labor requiring systems have become available, many farmers in the humid areas of this country have installed irrigation systems. This has been particularly true in the southern areas where plentiful water, abundant radiation, longer growing seasons, and higher temperatures are conducive to increased production of a wide variety of crops.

Irrigation in humid areas is often economical even though annual rainfall exceeds evapotranspiration. Three factors necessitate irrigation of humid areas: (1) the annual rainfall distribution does not coincide with the evapotranspiration distribution, (2) water holding capacity generally is not sufficient to provide adequate water for crops during the deficit rainfall periods and (3) frequently restricted rooting limits soil water availability to plants.

Average monthly rainfall and evaporation at 4 representative locations in the eastern U.S. are shown in Fig. 1. These locations typify the widespread humid areas where deficit rainfall occurs throughout the entire growing season. Rainfall is much more erratic than evaporation. Less than 5 cm of rain may fall during any month of the growing season (Fig. 1). Evaporation rates near 15 cm/mo cause very serious deficits.

Most soils in the southeastern U.S. are of relatively low water-holding capacity and the crop root systems are often shallow due to physical impedance, chemical toxicity or poor aeration. Little water is held at water potentials less than -1 bar (Bruce et al. 1980). Campbell et al. (1974) found that the Ap horizon, or surface layer, of typical Paleudults of the South Carolina

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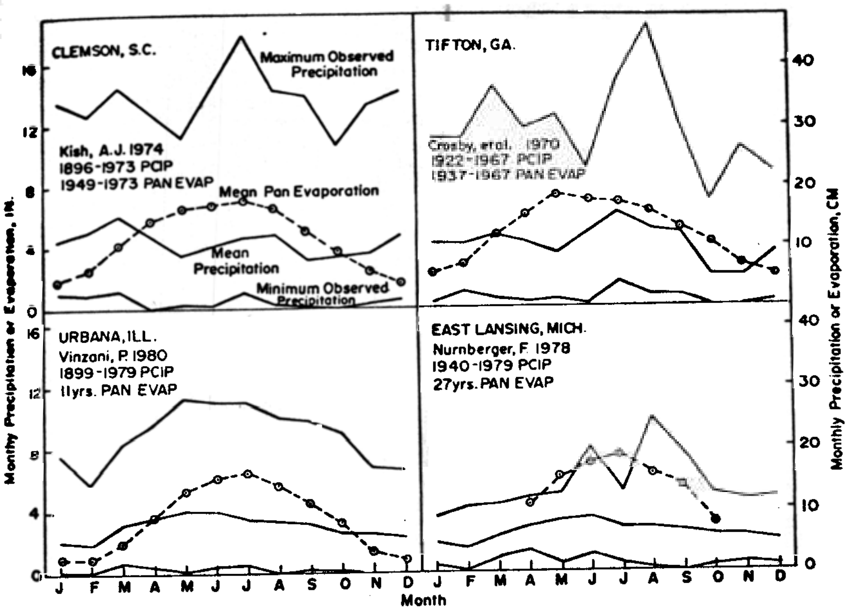

Fig. 1. Monthly Rainfall Distribution and Average Pan Evaporation for 4 Humid Locations.

Coastal Plains drains 42% of its pore volume between -0.1 and -1.0 bars. Soil water retention between -0.05 and -1.0 bar ranges from 0.05 to 0.13 cm/cm for both Piedmont and Coastal Plain soils (Bruce et al. 1980). For 70-cm rooting depth, 9.1 cm is the maximum water holding capacity available in most of these soils. Typically used values are 5 to 8 cm. With peak evapotranspiration rates of 0.6 to 0.8 cm/day usual irrigation intervals are 5 to 7 days.

The purpose of this paper is to describe four methods now being tested for scheduling irrigation and to discuss experiences related to their use. This study has been partially funded by USDA-AR at Florence, South Carolina, and influenced by previous work by Jensen et al. in the West. Modifications and additional studies have been necessary because of differences in water-holding capacities of the soils, lack of validation of evapotranspiration models, and interspersed rainfall.

SCHEDULING VIA PERSONAL COMPUTER AND WATER BUDGET

Increased irrigation, especially by inexperienced persons, has led to renewed interest in scheduling methods. Low-cost personal computers that are available to individual farmers, extension agents, and consultants have influenced a study to determine the feasibility of using these computers and the water budget approach on individual fields to reduce water and energy consumption, improve economic yields, and develop a tool that individual farmers or consultants can use. Such a practice must be kept relatively simple. The philosophy of this study is that the practitioner will run the program on his own computer using data he acquired by observing his fields or from National Weather Service information.

Approach

Water budgets are calculated semi-weekly using historical data for the previous 3 or 4 days on daily maximum and minimum temperatures, incoming solar radiation, effective rainfall or irrigation applied, and root-zone depth. The practitioner also states daily the allowable depletion as a percentage of total available soil water, based on crop growth stage, experience, and any other available subjective input. Initialization includes a one-dimensional description of soil horizon depths, water holding capacities, and initial water contents.

Daily evapotranspiration is calculated by the Jensen and Haise (1963) method and modified for canopy cover and soil moisture content. A water budget is maintained for the root zone, and reported in both inches and percent (Fig. 2).

IRRIGATION SCHEDULING FOR EDISS

07/31/80 11:45:15

BACK RECORDS:

DATE	TMAX	TMIN	RAIN	IRRG	WIND	RAD	PEVP	ETP	AETP	RD	AD(%)	AWC(%)	AWC(IN)	DPL(IN)
07/28	94	68			19	379	.216	.201	.178	42.0	50	72.0	3.64	1.42
07/29	94	68			24	391	.215	.207	.179	42.0	50	68.4	3.46	1.60
07/30	95	68			24	403	.215	.215	.183	42.0	50	64.8	3.28	1.78

FORECAST:

DATE	TMAX	TMIN	RAD	ETP	AETP	RD	AWC(%)	AWC(IN)	DPL(IN)	
07/31	91	67	391	.201	.167	42.0	61.5	3.11	1.95	
08/01	94	68	437	.231	.188	42.0	57.8	2.92	2.14	
08/02	95	70	415	.225	.178	42.0	54.3	2.75	2.31	
08/03	97	73	440	.247	.190	42.0	50.5	2.56	2.50	
08/04	92	72	400	.215	.161	42.0	47.3	2.40	2.66	IRRIGATION NEEDED.

Fig. 2. Typical Output from Water Budget Program for Personal Computer Used for Irrigation Scheduling.

A Radio Shack* TRS-80/I computer was programmed to interactively request the user to input daily TMAX and TMIN (deg F), any effective RAIN or IRRiGation (in), WIND (mi), incoming solar RADiation (ly), observed Rooting Depth (in), and Allowable Depletion (%) from the date of previous analysis (28 July) until "yesterday" (30 July), the last day for which data are available. The program is very user oriented, with error trapping, safeguards, and explanatory comments. From the input data, Potential daily EVaPotranspiration (in), EvapoTransPiration (in) considering canopy cover, and Actual EvapoTransPiration (in) considering both canopy cover and soil moisture Content, Available Water Content (% and in) and DePLetion (in) are calculated. If the analysis indicates that the depletion exceeded the stated allowable depletion on a previous day, the corresponding line is flagged during output. A field named EDISS had a depletion of 4.52 cm (1.78 in, 35.2%) in a 107-cm (42-in) root zone on 30 July 1980 (Fig. 2).

Similar calculations are made for a future 5-day period, using quantitative 5-day forecasts of maximum and minimum temperatures and radiation furnished for six locations throughout the Southeast by the Columbia, South Carolina

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* Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agric. or the S.C. Agri. Exp. Sta. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

National Weather Service. Rainfall is precluded from the 5-day projected budget. The resulting budget predicts depletion for the 5-day future assuming no rain. The first day during which depletion is forecast to exceed the stated allowable depletion is flagged to indicate that irrigation will be needed near that date (4 August). If no irrigation need during the next five days is forecast, a straight-line extrapolation of depletion is made and the date of anticipated irrigation need is stated on the printout.

If rain does fall during the forecast period, the budget may be adjusted manually or mentally, or the program may be rerun to determine if any forecasted irrigation is needed. Reinitialization of water content profiles may be done at any time data are available.

Experience

Cooperating researchers at five locations in four southeastern states have irrigated corn and soybeans during 1979, 1980 and 1981 by the personal computer/water-budget approach. Budgets were calculated on Monday and Thursday mornings, typically, based on temperatures, radiation, and rainfall observed at the field site.

Mechanical and quantitative operation of the hardware and approach have been satisfactory. Comparison of predicted and measured soil water content data indicates the real need to periodically obtain field data for reinitialization. Whenever 3- to 4-week reinitializations are made, and whenever field scheduling of irrigations follows the analysis results closely, agreement of field-measured and computer-based soil water content has been acceptable.

Some underestimates of water needs were apparent, especially on sandier soils, but in most cases needs were adequately met. We obviously don't know enough about how to estimate available water in a profile; how to account for dry conditions in the upper, more densely rooted portions of the root zone while the lower portions are still wet; how to calculate evapotranspiration, especially under limited soil water contents; or how to manage the allowable depletion parameter to optimize crop behavior.

Results

Trials during a very dry 1980 at five locations resulted in 6 to 12 irrigations of 11.4 to 36.9 cm total applied water. Corn yields ranged from approximately 1,380 to 4,760 kg/ha (22 to 76 bu/ac) for no irrigation and 4,140 to 8,410 kg/ha (66 to 134 bu/ac) for irrigation by the water budget method. Field results from this project have been limited to areas that can be irrigated in one day.

SCHEDULING VIA SCREENED PAN EVAPORATION

The evaporation pan provides a way to physically simulate a water balance in the soil profile and schedule irrigations, using a specially equipped evaporation pan. Campbell and Phene (1976) showed that in the Southeast the amount of evaporation from a screened standard Class A pan is equal to Potential EvapoTranspiration (PET) as calculated by the Penman (1948) equation. By using screened pan evaporaton as PET, and a crop coefficient, Doty (1980) showed that the storage in the soil profile could be closely approximated. Based on these findings, the screened evaporation pan was modified to schedule irrigations and tell the farmer how much water to apply and when to irrigate. The assumption must be made when using the screened evaporation pan to schedule irrigation that water evaporates from the screened evaporation pan at the same rate as PET.

How Much to Apply Each Irrigation

To determine the amount of irrigation water to apply at each irrigation the following equation is used: (1)

$$I = (A \times La) / E$$

I = Depth of irrigation water to apply
A = Available water in the rooting depth (determined from SCS, National Cooperative Soil Survey, Blue Sheets of Soil Series description and Crop rooting depth)
La = The percent of available water to be used by evapotranspiration before irrigation is needed (Loss Allowable)
E = Efficiency of irrigation system.

When to Irrigate

The evaporation pan automatically indicates when to irrigate. The pan is modified with an overflow to discharge excess water analogous to runoff or deep percolation when the soil profile becomes full (Fig. 3). A movable stainless steel scale is also added. The amount of pan evaporation that must occur before irrigation is needed can be determined by the following equation: (2)

$$Ad = (A \times La) / C$$

Ad = Pan evaporation to occur before irrigation is needed (allowable depletion)
C = Ratio of actual evapotranspiration to screened pan evaporation. This is known as crop coefficient. Normally we use C = 0.6 until the corn is above knee high. After that, we use C = 1.0. However, C can be changed more often if necessary.

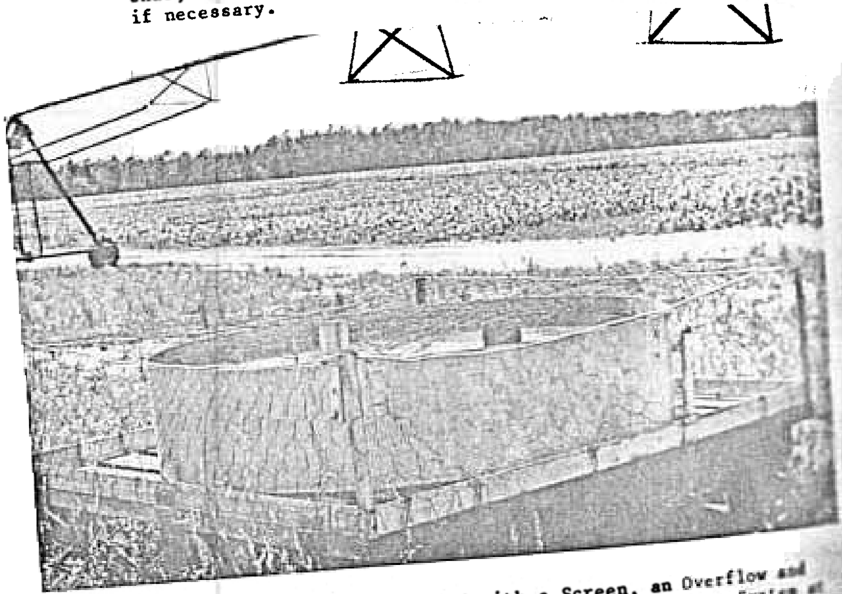

Figure 3. Evaporation Pan Modified with a Screen, an Overflow and Scale to Schedule Irrigation for a Center Pivot System at Florence, SC.

To avoid estimating the amount of water stored in the profile when the schedule is started, the soil profile should be full. This can be accomplished by (1) setting up the evaporation pan the day after a rain that fills the soil profile, or (2) filling the soil profile by irrigating at the beginning of the irrigation season. The pan is leveled and filled to overflowing. A scale is then placed on the side of the pan and inserted into the water the depth of the allowable depletion (Ad in Eq. 2) and clamped to the side of the evaporation pan. The screened pan is observed as required, and when the water level of the evaporation pan drops to the end of the scale, the allowable water has been depleted by evapotranspiration and I depth of water (Eq. 1) must be applied by irrigation.

The evaporation pan will automatically adjust to the water balance throughout the season. If rainfall occurs, the pan catches it and excess water is removed from the pan by the overflow. However, if the evaporation pan is not placed under the irrigation system, the pan must be filled to the overflow point after each irrigation.

This scheduling technique requires that a separate pan be used for each crop being grown. The technique is not exact but is as accurate as most systems are able to apply water. Since only a portion of the available water is allowed to be depleted, this scheduling technique should call for water before the crop suffers.

Experience and Results

The screened evaporation pan was used to control a center pivot system for three years. In 1978 irrigation was scheduled by the screened evaporation pan for early and late soybeans. Even though at least one irrigation was missed because of malfunction of the irrigation equipment, five irrigations resulted in 10.3 cm of irrigation water being applied. Rainfall was 21.2 cm. Nonirrigated soybeans produced 1,660 kg/ha (26 bu/ac) for the early-planted soybeans and 1,190 kg/ha (19 bu/ac) for the late-planted soybeans, while the irrigated soybeans produced 2,430 kg/ha (39 b/ac) for the early-planted and 1,820 kg/ha (29 bu/ac) for the late-planted beans.

In 1979 (a near average rainfall year) corn required 5 irrigations, totaling 19.4 cm. Rainfall amounted to 47 cm during the corn growing season and 73 cm during the soybean growing season. The soybeans were irrigated 5 times with 19.8 cm of irrigation applied. Corn yields of 6,460 kg/ha (103 bu/ac) and soybean yields of 1,400 kg/ha (21 bu/ac) were harvested from the nonirrigated area. Irrigated yields under the center pivot system with applications scheduled by the screened evaporation pan were 10,900 kg/ha (174 bu/ac) corn and 2,450 kg/ha (36 bu/ac) soybeans. In 1980, a dry year, 29.7 cm of rainfall on corn and 43.3 cm on soybeans resulted in 6 irrigations on corn, totaling 25.6 cm; 12 irrigations on soybeans, totaling 34.9 cm of irrigation. Nonirrigated yields were 2,990 kg/ha (48 bu/ac) corn and 1,380 kg/ha (21 bu/ac) soybeans, while the evaporation pan scheduled irrigated area produced 6,050 kg/ha (96 bu/ac) corn and 2,400 kg/ha (36 bu/ac) soybeans.

SCHEDULING VIA TENSIOMETERS

For either the computer-based water-budget or the pan method to be used accurately, selected parameters must be specified: available soil water as a function of depth, rooting depth, and evapotranspiration rates throughout the growing season. However, in soils with similarly shaped soil water characteristic curves, a simple measure of the soil water tension will indicate the soil water status, eliminating the need for any other input.

Figure 4 shows desorption curves for three soil series found in the Piedmont and Coastal Plains of the Southeast. While the absolute values of the soil water contents differ greatly for given tensions, the general shapes of the curves are similar. The upper limit of available water in these soils is generally between -0.04 and -0.06 bars potential regardless of the horizon or texture. Little available soil water is held between potentials of -0.2 and -1.0 bars. Thus most of the available soil water is held between -0.05 and -0.2 bars. The only other information needed to use tensiometers to schedule irrigation is the soil depth over which the soil water potential is to be maintained at values greater than -0.2 bars. In this study, the soil water potential was kept above -0.2 bars throughout the 60 cm soil depth.

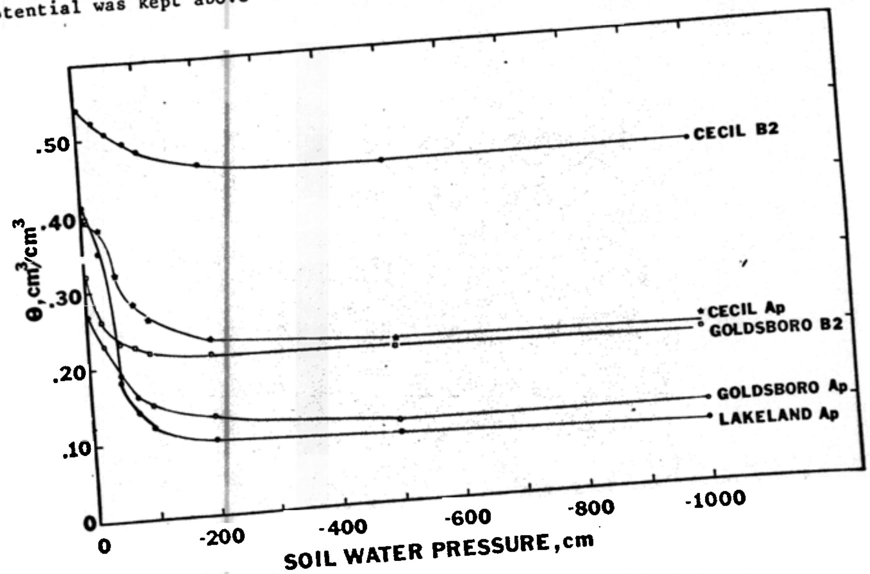

Fig. 4. Soil Moisture Characteristic Curves for Three Typical Southeastern Soils.

Experience and Results

During the past two years, experiments have been conducted at Blackville, South Carolina on a Wagram sand to compare the use of the computer-based water-budget method to tensiometers for scheduling irrigation of corn. A summary of the water use data for a period from June 10 to July 15, 1980, is presented in Table 1. Evapotranspiration was measured from tensiometers which were placed in 15-cm increments through 121.9 cm. During this 35-day period average daily ET was 0.33, 0.47 and 0.67 cm/day for the nonirrigated treatments, the water-budget treatment, and the -0.2 bar treatment, respectively. The water-budget consistently called for water 3 to 4 days after the need for irrigation was indicated from tensiometer readings. Often the water-budget corn showed severe stress symptoms before irrigation. With this type of information the water-budget and screened pan evaporation methods can be improved to meet the actual water needs.

There is no doubt but that some of the soil physical properties used in the water-budget were incorrectly used. In particular, a rooting zone depth of 137 cm was used throughout the period with an allowable depletion of 50%. There is also no doubt that the pyranometer has given low radiation readings, perhaps by 35 percent. Root samples taken frequently during this period showed rooting densities of approximately 0.4 cm/cm at the lower depth. Soil water potentials frequently decreased below -0.6 bars in the surface 60 cm before 50% of the available water through 137 cm had been used.

Table 1. Water Use Data from June 15 to July 10, 1980, for Corn Grown on a Wagram Sand.

Method	Rainfall	Irr.	Total	OO	Ave. ET	Ave. OP	% OP
	cm				cm/day		
0.2 bar	8.97	14.61	23.58	0	0.67	0.66	102
Budget	8.97	7.49	16.46	0	0.47	0.66	71
No-Irr	8.97		8.97	2.54	0.33	0.66	50

Another question regarding the water budget concerns the maximum ET estimated. Soil water use rates for corn during late vegetative and reproductive stages show that ET is approximately equal to open pan evaporation when the soil water potentials are maintained above -0.2 bars. As shown in Table 1, corn in the -0.2 bar treatment used approximately 100% of the amount of open-pan evaporation during this period. The water-budget treatment utilized 71% of open pan evaporation and the nonirrigated treatment used 50% of open-pan evaporation. Yield data show that the water-budget treatment was periodically stressed. Yields for the -0.2 bar, water-budget and nonirrigated treatments were 11,180, 6,670 and 4,780 kg/ha (166, 99 and 71 bu/ac), respectively. Based on these results soil water potentials must be maintained above -0.2 bars in the surface 60 cm for optimum corn growth to occur. ET must be maintained at about 90% of open pan evaporation during late vegetative and reproductive stages for maximum yields. Campbell and Phene (1976) showed that evaporation from the screened evaporation pan was about 90% of open pan.

Tensiometers provide an easy way to properly maintain soil water potentials within the desired limits for optimum crop growth. This is especially true for a crop such as corn for which just a few stressed days can result in substantially reduced yields.

COMPARISON OF THREE METHODS

Several plots under a center-pivot irrigation system at Florence, SC were controlled by three methods: water-budget, screened evaporation pan, and tensiometers. Table 2 shows the water applied and the yield for each scheduling technique. The screened pan required 2 applications (7.1 cm) more water than the water budget and 1 application (5.9 cm) more than the tensiometers in 1979. Corn yields in 1979 were 10,900, 10,170, and 8,370 kg/ha (174, 162 and 133 bu/ac) for the screened pan, tensiometer, and water-udget methods, respectively. However, factors such as poor estimation of rooting depth and allowable depletion and poor communications were problems with use of the water budget in 1979. In 1980 the water-budget and the tensiometer methods required 9 applications totaling 29.4 and 29.0 cm, respectively, while the screened pan method required 8 applications totaling 25.6 cm of water. Yields were 6,050, 7,730 and 7,770 kg/ha (96, 123 and 124 bu/ac) for the pan evaporation, water-budget and tensiometer methods, respectively. The pan evaporation method of scheduling irrigation increased yield compared to nonirrigated yields by 69 and 103 percent in 1979 and 1980, respectively; the water budget method increased yields by 30 and 159 percent; and the tensiometer method increased yields by 57 and 160 percent over nonirrigated corn.

The differences in water applied in 1980 (3.8 cm), the fact that there was only one application difference and the fact that the two-year average yield was similar (Table 2) indicate that all three methods of scheduling irriga- tion are feasible in the Southeast. However, there are several relations that still must be determined for more efficient irrigation scheduling by the water-budget and screened-pan evaporation methods. The relation of rooting depth to days after planting by soil type, system irrigation efficiencies, allowable depletions of soil water, and crop coefficients would assist these scheduling techniques to provide crop water needs, conserve water and energy, and increase irrigation production. When these are developed for each crop, the farmer can choose the method that best suits his needs for scheduling irrigation in the Southeast.

Table 2. Results from Three Irrigation Scheduling Methods on Corn that Was Under-row Subsoiled at Florence, SC

Year	Irrigation: No. of Applications	Irrigation: Yearly Amount (cm)	Rainfall (cm)	Total Water (cm)	Yield[1/] kg/ha	Yield[1/] % increase over nonirrig.
Personalized Computer Model						
1979	3	12.1	47.4	59.5	8,365b	29.5
1980	9	29.4	29.7	59.1	7,730d	158.9
Mean	6	20.7	38.5	59.3	8,049	70.4
Screened Pan Evaporation Method						
1979	5	19.2	47.4	66.6	10,895a	68.6
1980	8	25.6	29.7	55.3	6,048e	102.5
Mean	6.5	22.4	38.5	60.9	8,472	79.3
Tensiometer Method						
1979	4	13.3	47.4	60.7	10,167a	57.3
1980	9	29.0	29.7	58.7	7,767d	160.1
Mean	6.5	21.1	38.5	59.7	8,967	89.8
Nonirrigated						
1979	-	-	47.4	47.4	6,463c	-
1980	-	-	29.7	29.7	2,986f	-
Mean			38.5	38.5	4,724	

1/ Yields with the same letter within the same year are not significantly different at the 5% level.

SCHEDULING VIA CALCULATED RISK

The impetus for any farmer to irrigate, in a humid or non-humid area, is to increase the net return from a crop. Guessing, feeling the soil, measuring the soil water potential, and estimating the soil water budget are indirect approaches to decision making relative to the economic benefit of a particular irrigation.

Employing the principle of calculated risk (Thompson 1963) to make irrigation decisions involves calculation of an expected loss and comparing it with the cost that would be necessary to prevent the loss. The expected loss may be calculated by taking the product of the loss due to moisture deficiency that would be incurred, should no rain occur and no irrigation be applied, and the probability that no rain will fall. The cost of preventing the expected loss is the cost of the irrigation (Allen and Lambert 1971a).

The actual criterion involved, based on the calculated risk principle and applied to irrigation, may be stated as:

	>	irrigate
P	= C/L	either course
	<	do not irrigate

where P = probability of the loss occurring (no rainfall); C = cost of protective measures (irrigation) required to prevent the would-be loss; L = loss that would be incurred should no precipitation occur and no protective measures be taken. The loss (L) would be the decrease from potential in the final dollar value of the crop caused by non-optimum moisture conditions during a prescribed loss period subsequent to the decision. The attainable potential will vary throughout the season because of the residual effect of moisture during the earlier portion of the season and all other factors affecting final yield. Dynamic simulation models of crop growth and yield are used to estimate final crop yield under irrigation or no-irrigation scenarios (Lambert 1978).

Application of the calculated risk principle to daily decisions of irrigation has been shown to reduce the number of irrigations required, to reduce the total water added, and thus the total energy required, and to reduce the occurrence of 13 mm of rainfall within 24 hours after an irrigation, compared to a criterion of irrigation at 50% depletion of available soil moisture. Net economic return from tobacco also was improved (Allen and Lambert 1971b).

Field testing on corn has indicated the calculated-risk/crop-simulation method of scheduling irrigation in humid areas to have potential, especially now that marginal cost of irrigation has decreased significantly with the advent of automatically moving systems. Results of 4 years of experience with tobacco and corn indicate savings of water and energy compared to use of the 50% criterion for irrigation.

During the 1981 growing season we used the calculated risk method to schedule irrigation of corn at Tifton, Georgia. The program was a Fortran program written for the IBM 370, modified to run on the TRS-80/I.

SUMMARY

Poor rainfall distribution with respect to evapotranspiration distribution and low water-holding capacities of most soils cause irrigation to be needed in many humid areas, particularly in intensive agriculture. Rainfall occurs sporadically during the growing season and disrupts any preplanned schedule.

A consortium of researchers is evaluating techniques for scheduling irrigation in the Southeast. A personal computer has been programmed to calculate water budgets from data supplied by the user and to forecast the date of the next irrigation. The results are no better than the data supplied and evapotranspiration rates for southeastern U.S. conditions are not well known.

Addition of wire screen and an overflow to a Class A evaporation pan causes the evaporation to approximate the evapotranspiration from a nonstressed crop with full canopy cover. Such a pan can therefore be used to physically simulate the water budget of a profile and to indicate the need for irrigation when a preset depletion has been reached.

Tensiometers may also be used to determine the need for irrigation. Data indicate that soil water potentials maintained above -0.2 bar in the upper 60 cm produced maximum yields in these studies. Net economics of irrigation application is the basis for using the calculated-risk method for scheduling irrigation, including forecast probabilities of rain.

Based on initial tests, the pan method is the simplest and easiest to use, but is limited by the assumption of fixed rooting depth and gives little advance information for scheduling or planning purposes. The computer-based water-budget method is powerful for planning, but relies on soil physical parameters and evapotranspiration rates which we don't know how to determine well. Tensiometer methods apparently result in increased yields for the conditions tested, but require considerable attention and a decision on how many to use and where to locate them in the field and give little advance information. Inclusion of direct economic benefits and rainfall probabilities for scheduling irrigation is fundamentally more sound, but relies heavily on dynamic crop growth simulators which are still being developed.

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