COMPUTER-BASED IRRIGATION SCHEDULING IN THE SOUTHEASTERN COASTAL PLAINS[1]

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ABSTRACT

Two irrigation scheduling methods were evaluated in field experiments for corn at 6 locations in 5 states during a three-year period (1979-81). A computer-based water balance procedure used measured and forecast weather values to estimate irrigation water requirements for up to 5 days ahead. A second method required a decision by the operator based on measured soil water potential values obtained using conventional tensiometers. Difference in irrigation water required by the two methods were generally small, and there was no significant difference in corn yield between the two methods. Both irrigation scheduling methods performed satisfactorily, so the choice depends primarily upon personal preference. The CBWB generally underestimated the irrigation requirement, but can be used in its present form if periodic recalibration or correction is performed during the growing season. Further refinement in the CBWB will reduce the frequency, but probably will not eliminate the need for recalibration. The CBWB offers the advantage of planning irrigation applications up to 5 days ahead which should improve effective and efficient use of resources.

INTRODUCTION

Annual rainfall in the Southeastern Coastal Plain normally equals or exceeds evapotranspiration (ET). However, rainfall is often poorly distributed during the crop growing season, and total rainfall during the growing season often does not satisfy ET requirements. More importantly, drought periods can occur that are of sufficient duration and intensity to reduce crop yield. Sheridan et al. (1979) showed that 22 consecutive days with less than 6 mm of rainfall on any day could be expected every other year on average. Most soils of the region are coarse textured and have low water-holding capacities, and many have compacted layers. Consequently, crops suffer from plant water stress after 3 to 7 days without rainfall because of the low soil water-holding capacity and limited soil volume explored by plant roots.

Corn is important to the region, but generally does not rank high as a cash crop because it is utilized primarily as an intermediate product for meat production. The need for irrigation on corn in the

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region is well documented (Van Bavel and Carreker, 1957; Van Bavel et al., 1957; Van Bavel and Lillard, 1957; Sheridan et al., 1979). Because of the relatively short growing season required for corn in this region, some farmers produce other crops before or after corn to increase land and equipment utilization and enhance economic return. With the rapid expansion of irrigated corn land area and the soil, climate, and cultural problems associated with crop production in the region, there is a critical need for crop water requirement information and irrigation management technologies that will efficiently and effectively satisfy crop water needs.

Several irrigation management methods have been suggested for humid regions, but few have been accepted by irrigation managers in the southeastern U.S. The use of soil water potential (tensiometers) to manage irrigation is widely recognized and recommended (Bruce et al., 1980; Rhoads, 1982), but is not being widely used (Lambert, 1980). Evaporation from containers such as National Weather Service Class A evaporation pans and other metal containers of various sizes have been used to either physically simulate a soil-water balance or to estimate potential ET for use in other water balance procedures (Westesen and Hansen, 1981; Doty et al., 1982).

Various adaptations of the water balance technique have been developed, but are restricted to specific crops, soils, or climatic regions and require tedious recordkeeping or interpretation of charts and figures (Lambert, 1980; Doty et al., 1982; Gregory and Schottman, 1982). Also, all water balance methods require knowledge of plant-available water, measured or estimated daily ET, measured rainfall and irrigation amounts, and initial soil-water storage.

Computers have been widely used for several years in arid regions to eliminate tedious recordkeeping associated with water balance methods and to estimate daily ET based upon daily meteorological inputs (Jensen et al., 1970; Kincaid and Heermann, 1974). Although efforts have been made to adapt this technology to humid regions and to incorporate rainfall predictions into the decision-making process, the use of computers in scheduling irrigation is neither widely recommended nor practiced by irrigation managers (Rochester and Busch, 1972; Lambert, 1980). Development of water balance methods for programmable calculators (Kincaid and Heermann, 1974) and personal computers (Lambert, 1980) and increased availability of these machines provide a method of scheduling irrigation that offers the capability for a single computer to manage several irrigation systems for a wide range of soil, crop, and climate conditions.

Little data is available in the southeastern United States comparing irrigation scheduling methods, comparing methods for estimating daily ET, or in determining crop water requirements. A critical need exists to evaluate irrigation scheduling methods and to assemble a data base quantifying water use by crops in the region. Consequently, a group of interested research personnel organized a regional work group to accomplish some of this needed research. A general description of the regional research project and results based upon preliminary analyses will be provided in this report.

REGIONAL RESEARCH PROJECT

This research was initiated and funded in part by the Agricultural Research Service, U. S. Department of Agriculture and was coordinated by the Coastal Plains Soil and Water Conservation Research Center. Cooperators and respective participating locations included D. K. Cassel, North Carolina Agricultural Research Service; G. D. Christenbury, V. L. Quisenberry, J. R. Lambert, and I. Israeli, South Carolina Agricultural Experiment Station; J. E. Hook and E. D. Threadgill, Georgia Agricultural Experiment Station; and L. C. Hammond and J. M. Bennett, University of Florida Institute of Food and Agricultural Sciences. Field research was conducted at Clayton, North Carolina; Florence, South Carolina; Blackville, South Carolina; Tifton, Georgia; and Gainesville, Florida, during 1979, 1980, and 1981 (Fig. 1). Results for 1980 and 1981 only will be summarized in this report.

Objectives of this research were (1) to evaluate a computer-based water balance (CBWB) irrigation scheduling technique for the region, (2) to compare corn growth and yield and water requirements when irrigation was scheduled by CBWB versus tensiometers (TENS), (3) to assemble crop water use data in relation to meteorological data for the region, and (4) to evaluate the CBWB procedure as a user, particularly with respect to input parameter selection and interpretation of output guidance.

These research objectives were often incorporated with other objectives specific to individual locations. In some cases, additional irrigation scheduling methods, additional crops, and tillage variables were included in the experimental design. Individual researchers also selected management criteria for the tensiometer method that were most appropriate for their soils and locations.

The CBWB procedure was developed and operated by J. R. Lambert at Clemson, South Carolina (Fig. 1). Weather forecasts were provided to Dr. Lambert for each location twice weekly during the growing season by M. E. Brown, National Weather Service Office in Columbia, South Carolina. Irrigation schedules and data were communicated directly between Dr. Lambert and individual locations.

The three irrigation management treatments included at all locations were (1) CBWB, (2) TENS, and (3) rainfall only (no irrigation). In the TENS treatment, typically, irrigation was initiated when soil water tension at the 30-to-45-cm (12-to 18-inch) depth reached 20-35 kPa (cbar), but the initiating value varied among locations and soils. The corn hybrid Pioneer 3369A was planted at all locations for all years. Daily measurements of maximum and minimum temperature, solar radiation, irrigation, and rainfall were made at or near each experimental site. Soil water content was measured several times during the season at most locations using gravimetric samples or neutron probe equipment. These data were used to initialize the CBWB procedure and to update it during the season. Soil water potential measurements were made throughout the season at most locations using tensiometers at various locations and depths.

Unknown to this work group, similar research was being conducted at Suffolk, Virginia (1980-82), by N. L. Powell, Virginia Agricultural Experiment Station, and F. S. Wright, USDA-ARS at Suffolk (Fig. 1). The computer based scheduling procedure used at this location was different from that used by the regional work group and a tensiometer-controlled treatment was not included. Results for this location, are included in this report because of many similarities.

COMPUTER-BASED WATER BALANCE

The CBWB procedure used in the regional study consisted of a computer program to compute a daily water balance for that portion of the soil profile in which plant roots were actively growing. The program was written in BASIC for the Radio Shack TRS-80[3] Models 1 and 3 microcomputers. The CBWB was operable in either of two modes. In the "historical" mode, measured daily meteorological data for the past few days was used to calculate evapotranspiration (ET) and the water balance. In the "forecast" mode, the CBWB used forecast meteorological data to calculate ET and the water balance for the immediate future (up to 5 days) beginning with the current day. If forecast data were not available, the CBWB used a historical weather file to estimate the meteorological data. The modified Jensen-Haise equation (Jensen et al., 1970) was used to estimate daily ET in both modes and required maximum and minimum daily temperature and daily solar radiation in addition to several site-dependent parameters. In the daily water balance, rainfall and irrigation were positive (additive) factors while ET (or crop water use) was a negative (subtractive) factor. Two final daily inputs required were crop rooting depth and allowable depletion. Allowable depletion was that fraction (expressed as a percentage) of the plant available water stored in the soil profile that could be depleted (or used) before irrigation was applied. Typically for the coarse-textured soils, this value was about 50%. The CBWB daily output included calculated ET, water stored in soil profile, water depleted from storage, and a flag to indicate the need for irrigation.

At the beginning of the growing season, the CBWB was initialized by entering information requested by the computer program regarding crop planting/emergence dates, time to crop maturity, soil physical properties and initial soil water content. The soil was described with up to 6 layers of variable thickness. The upper and lower limits of available water expressed as a volumetric percentage were measured or estimated for each layer. Likewise, the initial water content was estimated or measured for each layer. If the soil profile was completely filled by rainfall or irrigation, the upper limit of available water was considered a reasonable estimate of initial water content for that date if measured values were not available. For measuring soil water content, the gravimetric method is probably the most reliable and practical method available to most users because it is the

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

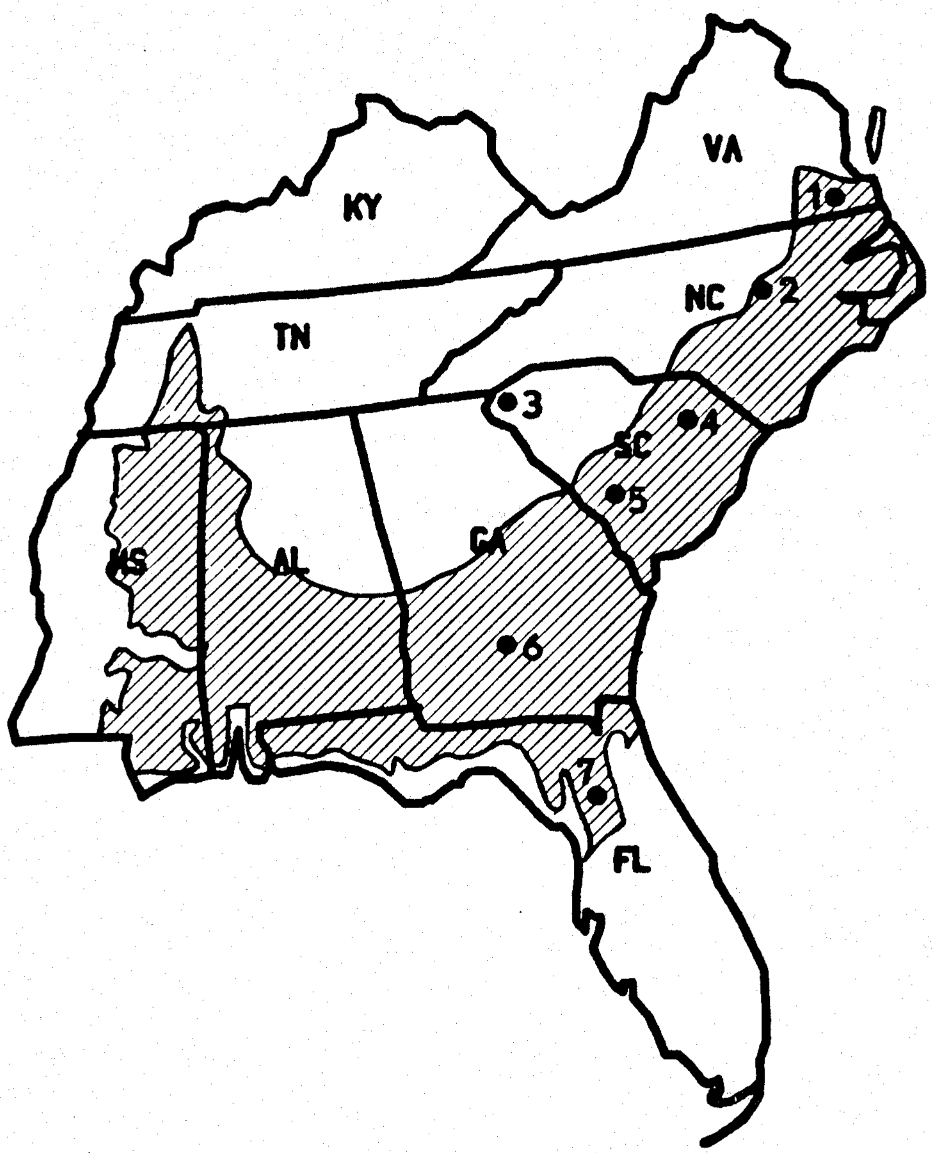

Fig. 1. Field research sites for a regional irrigation scheduling research project include 1, Suffolk, VA; 2, Clayton, NC; 4, Florence, SC; 5, Blackville, SC; 6, Tifton, GA; and 7, Gainesville, FL. The computer-based water balance (CBWB) computations for all locations except Suffolk, VA, were performed at 3, Clemson, SC. The Coastal Plain physiographic region is indicated by the shaded area.

standard for calibrating most other methods and it requires only an accurate weighing device and a drying oven. The CBWB accuracy was evaluated and improved by determining soil water content by layer several times during the growing season. In this study, the CBWB was operated twice each week, normally on Monday and Thursday; however, if desired, it can be run on a daily basis.

RESULTS AND DISCUSSION

Seasonal rainfall and irrigation amounts for all locations during the 1980 growing season are shown in Table 1. Rainfall amounts varied considerably among the various locations from a low of 213 mm at Suffolk to a high of 429 mm at Tifton. Irrigation amounts also varied considerably among the locations, but did not necessarily vary with rainfall amount. Differences in irrigation water required by the two scheduling methods were generally small for all locations. The largest differences between the two scheduling methods were 40 and 60%, which occurred at Tifton and Blackville, respectively.

Table 1. Seasonal rainfall and irrigation amounts for irrigated and nonirrigated treatments and all locations in 1980.

	Clayton	Florence	Blackville	Tifton	Gainesville	Suffolk
	mm					
Rainfall[1]	264	297	247	429	360	213
CBWB[2]	156	294	215	211	186	301
TENS[2]	156	290	342	286	176	---

[1] Rainfall only
[2] Irrigation only

Seasonal rainfall and irrigation for all locations during the 1981 growing season are shown in Table 2. Again, rainfall amounts varied considerably among the locations from a low of 220 mm at Clayton to a high of 435 mm at Florence. As in the previous year, there were considerable differences in irrigation amounts among the locations, but irrigation amount was not necessarily related to rainfall. Differences in irrigation water required by the two scheduling methods varied from 1 to 50%, but neither method was consistently high or low. The largest differences between the two methods occurred at Clayton and Blackville.

The operation of the CBWB can be demonstrated graphically for the Florence location using Fig. 2. Various soil water contents are shown as a function of days after planting (DAP). Daily rainfall and irrigation amounts are shown as vertical bars along the bottom of the figure. The upper and lower solid lines represent the upper and lower limits of available water stored in the soil profile. The middle solid line indicates the limit of allowable depletion before irrigation is required. The stepwise increase of the three solid lines with

Table 2. Seasonal rainfall and irrigation amounts for irrigated and nonirrigated treatments and all locations in 1981.

	Clayton	Florence	Blackville	Tifton	Gainesville	Suffolk
	mm					
Rainfall[1]	220	435	325	223-248[2]	241	354
CBWB[3]	276	214	150	339-341[2]	218	316
TENS[3]	188	269	226	243-346[2]	---	---

[1] Rainfall only
[2] Range of values for three different experiments at this location.
[3] Irrigation only.

time reflects the increasing rooting depth until a maximum is reached about 55 DAP. The dashed line is the volumetric water storage in the profile as calculated by the CBWB. Ideally, this curve would be maintained between the upper and middle solid lines in order to minimize plant drought stress. The break in the dashed line about 70 DAP reflects an adjustment in the calculated value because the soil water content was measured on this day. In this case, the CBWB had overestimated the stored water, and the water content value was adjusted

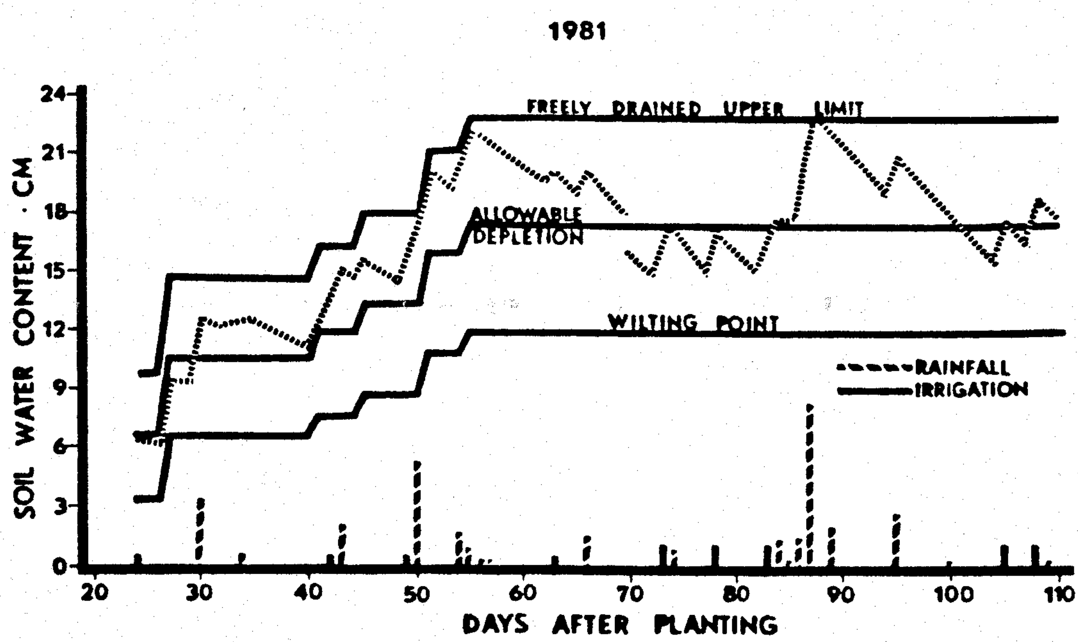

Fig. 2. Soil water storage, soil water content, and daily irrigation and rainfall amounts for the 1981 corn-growing season at Florence, SC.

downward. This adjustment caused the soil water storage value to fall below the allowable depletion level where it fluctuated for a few days until rainfall raised the soil water storage value back into the control zone. In most, but not all, cases during the study, the CBWB overestimated water stored in the profile.

There was a large variation in corn grain yields for the nonirrigated treatments among locations in 1980, primarily reflecting differences in rainfall (Table 3). Yields ranged from a low of 2.01 Mg/ha at Suffolk to a high of 8.14 Mg/ha at Clayton. Corn grain yields were similar for the two irrigation scheduling methods and for both irrigation treatments among most locations. One exception was Blackville where yield for the CBWB was much lower than for the TENS method. This is probably a reflection of the large difference in irrigation water applied for the two scheduling methods at this location. Corn grain yields for all irrigated treatments were higher than yields for the nonirrigated treatments. However, there was not a great difference between the irrigated and nonirrigated yields at Clayton.

Table 3. Corn grain yield for irrigated and nonirrigated treatments and all locations in 1980.

	Clayton	Florence	Blackville	Tifton	Gainesville	Suffolk
	Mg/ha					
Rainfall	8.14	2.69	4.77	2.20	3.99	2.01
CBWB	9.01	7.35	6.78	8.40	9.55	10.50
TENS	10.14	7.08	10.42	9.10	10.19	---

Corn grain yields for the nonirrigated treatments varied considerably among the locations again in 1981 (Table 4) from a low of 0.5 Mg/ha at one of the Tifton sites to a high of 6.41 Mg/ha at Suffolk. Rainfall amounts certainly had a major effect on these yields, but other factors also exerted a major influence. There was little difference between corn grain yield between the two irrigation scheduling methods with the exception of Blackville. Again, this was probably a result of the large difference in irrigation water applied between the two scheduling methods. Yields for the irrigated treatments ranged from a low of 5.86 Mg/ha at Gainesville to a high of 12.51 Mg/ha at Suffolk. Many of the yields for irrigated treatments in this study were not as high as can be produced when management is directed toward maximum yields which was not always the case in this study. Lower yields were probably due to the particular corn hybrid used and various cultural practices included as additional treatments at some locations. Corn grain yields as high as 15 Mg/ha were produced at Florence in a parallel experiment, in which maximum yield was one of the objectives, and a different corn hybrid was used (Camp et al., 1985).

Table 4. Corn grain yield for irrigated and nonirrigated treatments and all locations in 1981.

	Clayton	Florence	Blackville	Tifton	Gainesville	Suffolk
	Mg/ha					
Rainfall	4.87	4.46	6.27	0.5-4.7[1]	1.42	6.41
CBWB	9.01	8.78	6.90	10.9-12.1	5.86	12.51
TENS	9.37	8.24	8.74	10.1-10.5	---	---

[1] Range of values for three different experiments at this location.

One factor of major interest in most irrigation experiments is the corn yield produced per unit of water available. Although the rainfall and irrigation amounts for this study have not been corrected for losses caused by runoff and drainage, an attempt was made to establish a relationship between yield and total water available. Yield data from all locations for a two-year period were used in this analysis. This represents a rather wide range of soils, climate, locations, and cultural practices imposed as treatments at some locations. The relationship between yield and total water is shown in Fig. 3. There is a large amount of scatter in this relationship, which results in a relatively poor correlation (R^2 = 0.51). This correlation should improve with correction of the rainfall and irrigation data for runoff and drainage. However, the poor relationship may also indicate a difficulty in developing a single relationship for the entire region. These data will be refined with future analysis, and some improvement in the correlation should result.

When correction for drainage through the profile was made at one location for a two-year period, an improved relationship resulted (Fig. 4). L. C. Hammond at Gainesville partially corrected the rainfall for drainage through the soil profile. This results in an improved correlation (R^2 = 0.71). An even better correlation was obtained when results for a single year were considered. This offers promise for a better relationship across the entire region after rainfall and irrigation amounts have been corrected for runoff and drainage.

The two irrigation scheduling methods studied in this project generally produced comparable yields and required similar amounts of irrigation water. Each of the methods offer respective advantages and disadvantages. Regardless of the method used in managing irrigation, soil variability and water application variability within the management unit must be recognized and included in the decision-making process. In the case of discreet soil water potential measurements (tensiometers), the number and location of instruments in relation to spatial variability of soil physical properties must be considered in the design of the monitoring system as well as in interpretation of measurements. Likewise, a knowledge of plant available water and crop

All Locations 1980-81

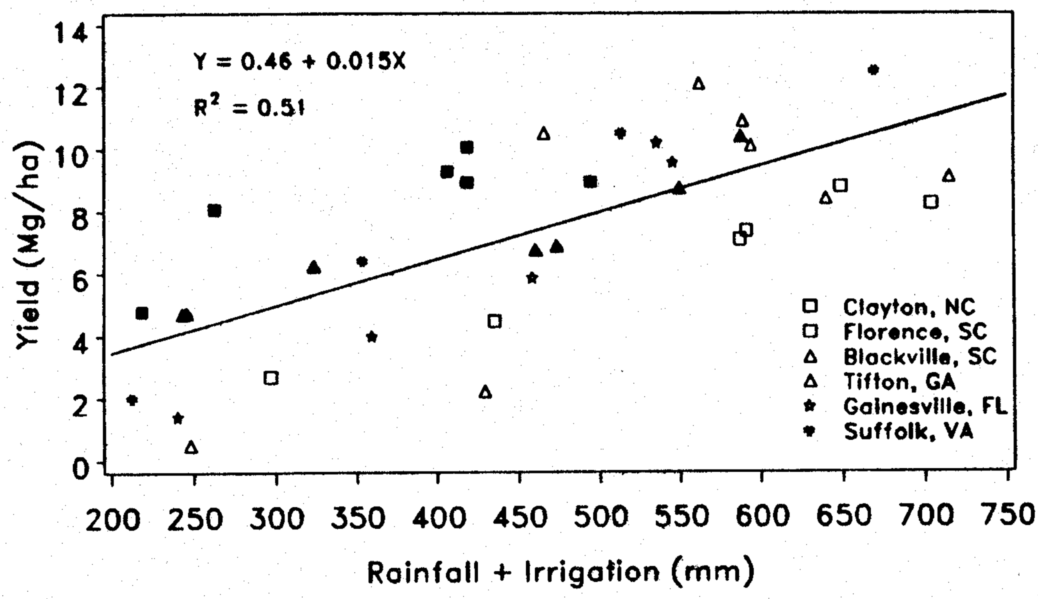

Fig. 3. Corn grain yield in relation to rainfall and irrigation water applied for all locations during 1980-81 with no correction for runoff or drainage.

Gainesville 1980-81

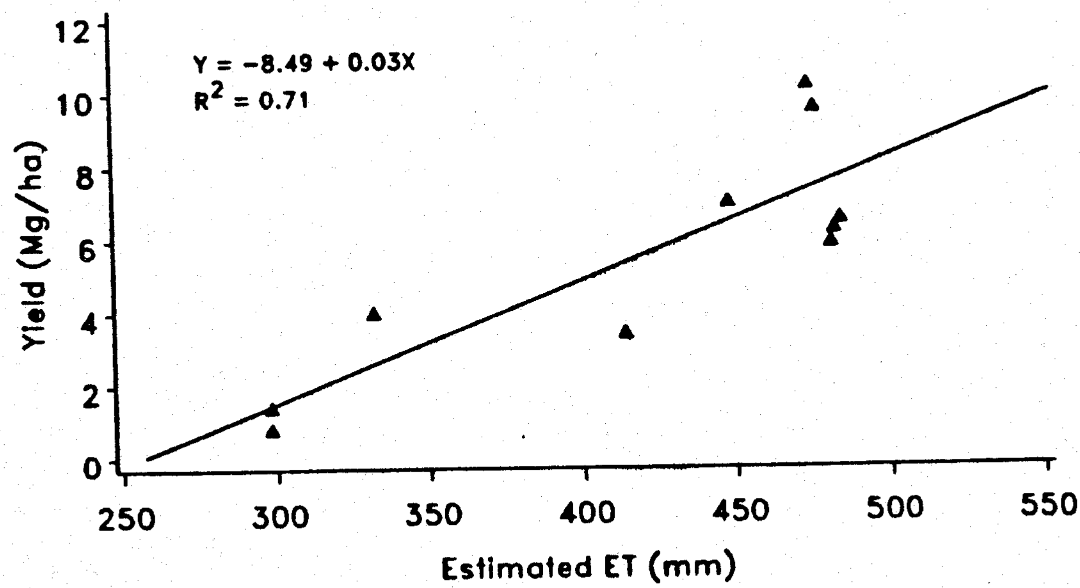

Fig. 4. Corn grain yield in relation to rainfall and irrigation water applied for the Gainesville location during 1980-81 with correction for drainage only.

rooting depths for soils in the management unit is critical for successful application of any water balance procedure whether it be computer-based, manual bookkeeping, or evaporation pan simulator. In all methods, control sites that adequately represent soil and crop conditions for the entire management unit must be selected. These control sites will then be used to determine the timing and amount of irrigation water to be applied. With the development of automated irrigation machines and suitable soil water sensors, it may be possible to vary the irrigation application to satisfy soil needs within a management unit even during a given irrigation cycle. Even in this case, some compromise will be required because soil changes will seldom coincide with the movement patterns of the irrigation machine.

CONCLUSIONS

Differences in irrigation water required by the two irrigation management methods, CBWB and TENS, were generally small. There was no significant difference in corn grain yield between the two irrigation methods, and all irrigated treatments produced higher yields than did the nonirrigated treatments. The CBWB and TENS methods both performed satisfactorily. The choice depends primarily upon personal preference. The CBWB generally underestimated the irrigation requirement (overestimated stored water) particularly for periods when high ET conditions existed. Most of the deviation between predicted and measured soil water content values in the CBWB procedure was caused by differences in soils and soil water retention values. The difference could not be explained across locations. Most of the researchers experienced difficulty in selecting or determining representative soil water storage values to be used in the CBWB procedure. However, a knowledge of these values is important for the tensiometer method, also.

In the current form of the CBWB, periodic recalibration or correction is required during the growing season if reliable results are to be expected. An improved irrigation scheduling model that includes additional features and improved parameter values derived from these results is currently under development and should provide improved performance and reduce the need for correction or recalibration.

Finally, a USDA-ARS publication reporting the complete results from this study should be published within the next year and will be available for distribution.

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