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ABSTRACT

IMPROVING IRRIGATION SCHEDULING AND WATER USE EFFICIENCY IN COTTON

Cotton (*Gossypium hirsutum* L) is an important crop in the southern United States. The crop is grown in both irrigated and rainfed situations and is seldom free from periods of water shortages at some stage during the season. In recent years the need for consistency in yields and a stable cash flow has resulted in a rapid expansion in the number of irrigated acres of cotton in the Mississippi Delta. Irrigation research has, however, not kept pace with this expansion. This project represents a start at meeting this urgent need. The influence of weather patterns necessitates that these studies be conducted over several years, and the results given here are, therefore, only preliminary observations. The early termination of irrigation has not resulted in any significant decrease in yield or lint quality on the Sharkey clay, although there was a slight detrimental trend when irrigation was terminated too early in August. These studies have helped to clarify the relationship between soil-moisture deficit and plant stress, especially as relates to yield, for cotton cropped on a Sharkey clay soil. Evaluation of crop indicators of water deficit showed that leaf water potential and the air-canopy temperature differential are reliable indicators of the onset of water stress. Leaf extension growth is also a sensitive indicator, but of no practical value in irrigation management. With further research, leaf water potential and canopy-air temperature differentials could provide useful indicators for use in conjunction with traditional methods of scheduling irrigation for cotton in the humid mid-south. A better understanding of the irrigation requirements of the crop will improve management and will have a very significant dollar reduction in the cost of production of the crop.

D.M. Oosterhuis

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Keywords -- Irrigation/Water stress/Evapotranspiration/Water use efficiency

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INTRODUCTION

Historically, cotton has been a major contributor to the economy of the mid-south United States. When indirect economic benefits are considered, billions of dollars of economic activity each year can be attributed to the production of cotton in the Mississippi Delta (Daniels, 1989). However, with falling prices and increased competition from foreign competitors, there is an urgent need for more attention to all aspects of production, including precise irrigation management. The additional efficiency necessary for cotton producers to effectively compete in world markets at current prices, without the aid of government farm programs, can be achieved by lower production costs, higher yields or combinations of the two. Improved irrigation management will contribute significantly to achieving these goals. Several additional benefits should also accrue from more efficient irrigation management and early irrigation (and crop) termination that are not easily defined in economic terms. These include less environmental contamination due to a reduction in the use of late-season pesticides, the reduced insect problems.

Water stress affects practically every aspect of plant growth and is the most important single factor limiting crop productivity and yields throughout the world. Therefore, large increases in production are possible through efficient management of available water resources. The detection of water deficits to which crops are subjected is vitally important for predicting crop responses to stress, implementing crop management decisions, and maximizing water use efficiency.

Irrigation has been used for centuries to overcome water stress in plants. In the past, irrigation timing was based mainly on soil water status and not so much on plant water. Tensiometers are popular instruments for measuring soil water potential and are used for irrigation scheduling. They do, however, have limitations associated with the narrow range of soil water potentials in which they operate. Various computer models are available for predicting irrigation requirements. The most simplistic of these use an estimate of evapotranspiration and a crop factor (Fereres et al., 1981) and others include an estimate of the soil water budget. However, the integration of plant indicators of water stress with measurements of soil water should be even more accurate and further improve irrigation scheduling.

Obviously, the earliest detection of the onset of water stress in crops is highly desirable in order to irrigate in time to offset possible deleterious effects of the stress (Bradford and Hsiao, 1982). However, a prerequisite for a useful indicator of water stress is that the response be sensitive, easily recognizable and reliable (Oosterhuis, 1988). Our understanding of plant indicators of water stress has increased with research in recent years and several could have practical value in crop water management. The most dramatic and easily recognizable indicators of water stress are changes in leaf orientation, wilting and senescence. However, senescence and wilting indicate a serious depletion of soil water, and a significant reduction in yield may have already occurred by the time these indicators are visible. Therefore, they serve no practical purpose as early indicators of water stress.

Traditionally, irrigation and the research that accompanies it, have been confined to the arid areas in the western USA. In the past decade, however, there have been dramatic increases in the area under irrigation in the humid mid-south. Furthermore, short periods of drought frequently occur in the mid-south, despite the summer rainfall, and these can have considerable detrimental influence on cotton yields and lint quality. Research on irrigation for cotton, however, has not kept pace with the increased acreage under irrigation or the demand from producers and extension personnel. Further research is obviously required to improve irrigation techniques for cotton in the humid Delta region.

A. Purpose and Objectives

This study was designed to address some of the more urgent problems concerned with improving irrigation practices and water use efficiency for cotton in the humid Delta. The research deals specifically with the relationship between soil moisture deficit and plant water stress, the value of plant indicators of water stress, and the optimum timing of the last irrigation. The results should be of immediate use to cotton producers and cooperative extension services for improving crop management. Specific objectives are:

(1) Determine the relationship between soil moisture deficit and plant water stress for cotton cropped on Sharkey clay soil.

(2) Evaluate alternative scheduling methods on cotton, including potential plant indicators of the onset of water stress.

(3) Determine the optimum timing of the last irrigation of cotton in relation to yield and lint quality.

B. Related Research and Activities

Successful crop production in temperate climates relies heavily on the early identification of plant water stress for improved water use efficiency and maximum crop yields. However, controversy exists as to when the onset of water deficiency occurs and how reliably it can be used to determine crop water requirements (Bradford and Hsiao, 1982).

Different criteria have been used for irrigation scheduling, with many techniques involving estimates of soil water status with tensiometers, gypsum blocks, and neutron probes. However, research has indicated that the most reliable indicators of crop water status for irrigation purposes are those that involve plant-related measurements (Kaufmann, 1968; Clark and Hiler, 1973;

Oosterhuis and Walker, 1987). Direct assessment of plant water status represents an integrated average for the atmospheric demand, soil-water potential, rooting density and distribution, as well as other crop characteristics (Kramer, 1969).

Many plant indicators of water deficiency have been proposed for use in irrigation scheduling. Leaf temperature as a measure of plant water deficit was used by Hiler and Clark (1971) and Hiler et al. (1974), who proposed a "stress day index" to assess crop water status. This concept used a plant-based water deficit measure, such as leaf water potential or canopy-air temperature differential, and a crop sensitivity factor to assess the severity of water stress. Although Hiler and Clark (1971) earlier proposed leaf temperature as one possible indicator of plant stress, leaf water potential was later suggested as a superior indicator of the onset of water deficit conditions (Hiler and Howell, 1983). Leaf water potential has been used as an indicator of crop water stress in wheat and soybeans (Meyer and Green, 1980) and cotton (Grimes and Yamada. 1981). However, leaf water potential exhibits considerable daily fluctuations which may diminish its usefulness for irrigation scheduling.

Idso et al. (1977) proposed canopy-air temperature differences as a stress indicator. This technique was subsequently refined (Idso et al., 1981) to incorporate vapor pressure deficit which ultimately developed into an environmentally responsive indicator of plant stress. The crop water stress index derived via this technique has progresses into a state-of-the-art tool for scheduling irrigation in the semi-arid and arid western regions of the United States (Jackson, 1982).

The usefulness of stomatal response as an indicator of the onset and development of water stress has been proposed (Oosterhuis and Walker, 1987). Since stomata play an integral part in regulating carbon dioxide uptake for photosynthesis, monitoring stomatal opening has the advantage of indicating changes in plant water status which are directly related to crop productivity (Bradford and Hsiao, 1982). However, some disagreement exists as to the usefulness of stomatal resistance as an indicator of plant water stress. Hsaio (1973) considered stomata to be relatively insensitive to mild water stress and only moderately sensitive to more severe stress. Ackerson et al. (1977) considered stomatal resistance an unreliable estimate of plant water status in cotton. In contrast, Adjei and Kirkham (1980) found stomatal resistance in wheat to be a better indicator of drought resistance that either leaf water potential or canopy temperature. Generally, methods of measuring stomatal resistance have not been very satisfactory, due in part to the nature of the early equipment used, large sampling variability, and a lack of understanding of the stomatal mechanism (Bradford and Hsaio, 1982).

Changes in leaf coloration have been identified as indicators of water stress on a limited number of crops (Jones, 1979; Oosterhuis et al., 1987). For example, wheat leaves and culms may show a slight blue appearance, while pea leaves show an increased blue-green appearance under water stress. However, visual symptoms frequently occur after much photosynthetic activity has already been lost and therefore, indicators of this type are not sufficiently sensitive to prevent yield losses in agricultural crops.

METHODS AND PROCEDURES

The study was conducted as three separate field experiments in representative areas of cotton production where irrigation has been recently introduced.

A. Soil moisture deficit and plant response

This trial was planted on May 1, 1988 at the Northeast Research and Extension Center in Keiser, Arkansas, on a Sharkey clay soil (Vertic Haplaquepts). The cotton cultivar was Stoneville 506. Treatments consisted of 1, 2, and 3 inch soil moisture deficits (SMD) and a non-irrigated (dryland treatment). Irrigation was applied using a lateral move overhead irrigation system. The soil moisture deficits were monitored using tensiometers, placed at a depth of 0.3 m in each plot, and a computer water balance model. The plots were defoliated with Dropp (thidiazuron) (N-phenyl-N′-1,2,3-thiadiazol-5-ylurea, Nor-Am Chemical Company, Wilmington, DE) and Folex (S,S,S-Tributyl-phosphorotrithiote, Rhone-Poulenc Ag Company, Research Triangle Park, NC) when 60% of the bolls were open, and harvested two weeks later with a 2-row spindle picker.

B. Plant indicators of the onset of water stress

This study was conducted at the main experiment station in Fayetteville on a Captina silt loam (Typic Fragiudults). The cotton cultivar Stoneville 506 was plant on May 17, 1989 in rows 5 m apart with approximately 10 plants m^{-1}. The plot layout consisted of a well-watered treatment and a water-stressed treatment, with 4 replications.

A variety of different crop indicators of the onset of water stress for irrigation scheduling were compared. The measurements recorded, and the instrumentation used, included:

(a) Leaf water potential (leaf pressure chamber).

(b) Leaf elongation/expansion growth (ruler).

(c) Stomatal resistance (steady state porometer).

(d) Stem red coloration (ruler and visual estimate).

(e) Canopy temperature (handheld infrared thermometer).

(f) Soil moisture tension (tensiometers).

The water deficit was initiated at peak flowering, about 15 weeks after planting, by withholding irrigation until a severe stress had developed. Measurements of plant-water status using the instruments listed above commenced a week prior to the start of the stress period and continued at two day intervals for three weeks. All measurements were taken at the same time each day between 1100h and 1300h to prevent possible diurnal variations (Parsons and Kramer, 1974).

All plant measurements were made using uppermost fully expanded leaves. Measurements of leaf water potential with the pressure chamber (PMS, Corvallis, OR) were made by first covering the leaves with a moistened plastic bag prior to excision to prevent evaporative losses. measurements were made on three leaves from each plot. Stomatal resistance was measured using LI-1600 steady state porometer (Licor Inc, Lincoln, NE) on five leaves from each plot. Canopy temperature was measured using a hand held infrared thermometer (IRT) (Everest Interscience Inc., Fullerton, CA) by taking 10 readings from each side of each plot. Leaf elongation of young expanding leaves previously marked with a black felt tip pen was recorded using a ruler to measure the length from the point where the petiole joined the leaf to the leaf tip. Stem red coloration was measured using a ruler to record the extent of the red color from the top of the stem. Tensiometers were placed at a depth of 0.3 m alongside the center row in each plot and read using a pressure transducer.

C. Optimum timing of the last irrigation

This study was conducted in 1988 and 1989 at the North East Research and Extension Center at Keiser, NW Arkansas, on a Sharkey clay (Vertic Haplaquept). The cotton (cultivar Stoneville 506) was planted during the first week of May each year in rows 1 m apart with a plant population of approximately 80,000 plants ha^{-1}. Plot size was 50 m x 6 m. Treatments consisted of four times of irrigation termination; (1) 10-days prior to first open boll, (2) at first open boll, (3) 10-days after the first open boll, and (4) 20-days after the first open boll. Treatments were defoliated when 60% of the bolls were open, and harvested three weeks late using a two-row spindle picker. One-meter row samples were taken from each plot prior to harvest to determine the components of yields (boll number and boll weight). These samples were also used for fiber quality analysis.

PRINCIPAL FINDINGS AND SIGNIFICANCE

The large year-to-year variability in weather commonly experienced in Arkansas necessitates that these studies be conducted over several years, and the results given here are, therefore, only preliminary observations.

A. <u>The relationship between soil moisture deficit and plant water stress for cotton cropped on Sharkey clay soil</u>

Two seasons of data have helped to clarify the relationship between soil-moisture deficit and plant stress, especially as relates to yield, for cotton cropped on a Sharkey clay soil. Results are presented in Table I. Emergence date was May 16,

1988. The 1988 crop was expected to be severely affected by drought. However, due to the timing of the drought and the drought tolerance properties of the cotton plant, farmers who had sufficient soil moisture to achieve an adequate stand generally obtained good yields, even without irrigation. This situation was reflected in the non-irrigated treatment which averaged 1.8 bales/acre. Average yields for the irrigated plots in the same experiment ranged from 2.1 bales/acre to 2.2 bales/acre, and did not appear to be influenced by the total amount or timing of the irrigation (within the limits of the study). The study is to be continued and compilation of data from several years may show more significant trends.

Table I

Cotton Yields as Affected by Varying Soil Moisture Deficit

Soil moisture deficit (in.)	Total applied water (in.)	Average yield (bales/acre)
1	14	2.23
2	9	2.12
3	7	2.14
N.I.	0	1.79

B. Evaluate alternative scheduling methods on cotton.

The effect of increasing water deficit on cumulative leaf extension, leaf water potential, and crop-air temperature difference is presented in Figure I. The increasing severity of the water shortage is clearly shown in the decreased leaf growth, increasingly negative water potential and the increased DT. The onset of water stress could be easily monitored in all three of these parameters by the first significant differences when compared to the unstressed control (Figure I). The relationships between leaf water potential and DT and also between leaf water potential and stomatal resistance are given in Figure II.

Leaf water potential proved to be a very good indicator of crop water status with potential for irrigation scheduling. The use of leaf water potential in irrigation scheduling is increasing in California. However, further research is needed to adapt this indicator to the humid south cotton growing areas. Stomatal resistance, on the other hand, was not a good indicator of water stress as has been reported by other researchers, probably because cotton stomates are more adapted to drought. Measurements of canopy temperature with the handheld infrared thermometer were comparable with those of leaf water potential (Figure I).

Tensiometer readings of soil moisture tension were not very satisfactory because of the limited range in which they operate and also the difficulty of getting a representative reading from a field plot. The upkeep of these instruments has been reported to be a practical problem.

Measurements of leaf elongation proved to be a sensitive indicator of water stress as would be expected (Figure II). This was to be expected because the first affect of water stress is on cell expansion (Hsiao, 1973) and this would be reflected in leaf size. However, although these measurements are of great use in water-relations research, they are of little practical value.

The red coloration of the upper main-stem internodes have often been cited by farmers as an indication of the onset of water stress. When our measurements of this were compared with the other indicators (taken at the same time) a reasonable agreement was found. The problem with this measurement is that it is so variable and subjective that it is difficult to be precise and have confidence in the measurement. Furthermore, the red coloration can also be influenced by temperature and nitrogen status. The red coloration may have some value as a "backup" or confirmatory measurement to be used along with leaf water potential or canopy temperature.

These studies have clearly shown the potential that plant indicators have for detecting the onset of water stress. With further refinement selected plant indicators could be used in conjunction with existing methods to improve irrigation management and water use efficiency.

C. <u>The optimum timing of the last irrigation of cotton in relation to yield and lint quality</u>

The timing of the last irrigation on cotton did not have any significant affect on cotton yields in 1988 and 1989 (Table 2). There was a slight trend for the early termination date to have the lowest yield, and the first open boll termination date to result in the highest yield. Seasonal rainfall patterns had a major influence on these results. This trial will need to be repeated for a few more years on other soil types in order to obtain a more meaningful conclusion.

Table II

Summary of Seed Cotton Yield as Affected by the Timing of the Last Irrigation at Keiser, Arkansas during 1988 and 1989

Time of irrigation termination	Seed cotton yield (kg/ha)	
	1988	1989
10 days prior to first open boll	2337 a[1]	2790 a
first open boll	2468 a	3004 a
first open boll +10 days	2424 a	2861 a
first open boll +20 days	2383 a	2844 a

[1]Values within a column followed by a similar letter are not significantly different at the 0.05 level of probability.

Timing of the last irrigation also had no significant effect on the components of yield (Table III).

Table III

Components of Yield for Irrigation Termination Study
Keiser, Arkansas during 1988

Time of irrigation termination	Boll number (/m2)	Number of plants (/m2)	Yield (kg/ha)
Open boll -10 days	79 a[1]	15 a	2790 a
Open boll	82 a	14 a	3004 a
Open boll +10 days	75 a	14 a	2861 a
Open boll +20 days	77 a	14 a	2844 a

[1]Values within a column followed by a similar letter are not significantly different at the 0.05 level of probability.

Lint quality in 1988 was not significantly affected by the timing of the last irrigation (Table IV). This was similar to the lack of affect on yield. As with yields, the rainfall during the season influenced the results and the trial should be repeated for a few more years in order to obtain a meaningful conclusion.

Table IV

The Affect of the Timing of the Last Irrigation on Lint Quality
Keiser, Arkansas, 1987

Treatment	Micron-aire	Length	Unifor-mity	Strength
10 days prior to 1st open boll	4.23 a[1]	1.19 a	84.3 a	26.3 a
First open boll	4.25 a	1.18 ab	83.1 b	25.4 a
10 days after 1st open boll	4.13 a	1.15 b	83.7 ab	25.9 a
20 days after 1st open boll	4.16 a	1.17 ab	84.5 a	25.8 a

[1]Values within a column followed by a similar letter are not significantly different at the 0.05 level of probability.

CONCLUSIONS

These studies have provided useful information for improved irrigation management in cotton. However, the nature of the research and the effect of seasonal weather patterns necessitates that the conclusions are only preliminary and that the research should be continued for a number of years on other soils with less clay. On the Sharkey clay soils irrigation deficits of one to three inches had no detrimental effect on cotton yield. There was, however, a significant yield decrease in the dryland treatment. Timing of the last irrigation did not have any effect on the yield or fiber quality of cotton grown on the Sharkey clay. Both these results are probably related to the high moisture holding capacity of the Sharkey clay. Production inputs during late season crop management are numerous and expensive in cotton and all these have a significant influence on maturity, quality and possible contamination of the environment. For this reason it is essential that this type of research be continued with the incorporation of more soil types.

Although water deficit stress elicits a plethora of plant responses, only a few of these are potentially useful as indicators of crop water stress for irrigation scheduling. Among the most useful of these are measurements of leaf water potential and canopy temperature. Measurements of soil water status in conjunction with plant indicators of water stress should provide the most reliable means of monitoring crop water status and determining crop water requirements.

Successful irrigation practices require the integration of sound management techniques suited to each particular crop and environment. A better understanding of the irrigation requirements of the crop will not only improve management efficiency, but will also have a very significant dollar reduction in the cost of production of the crop.

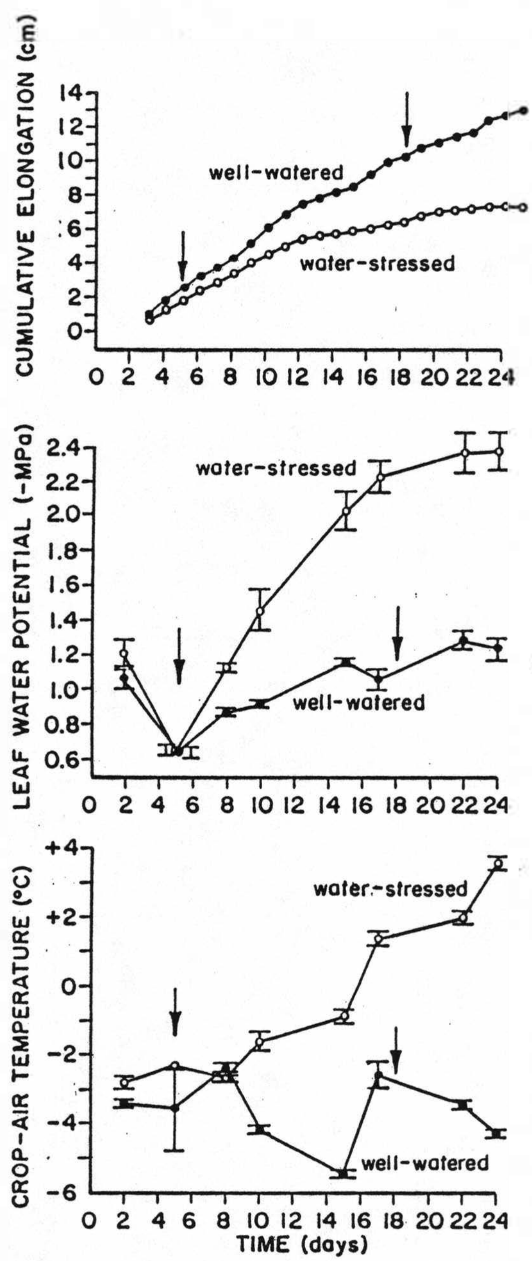

Figure I. The effect of increasing water deficit on cumulative leaf extension, leaf water potential, and crop-air temperature differential.

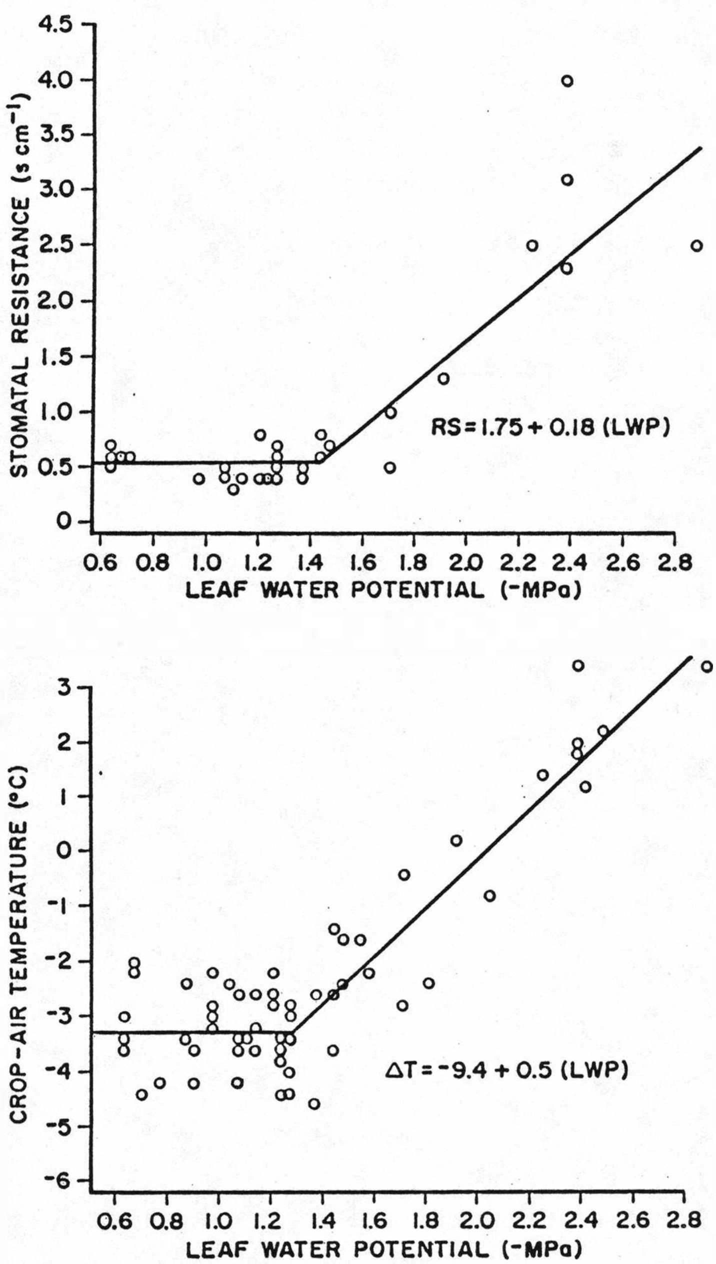

Figure II. The relationships between leaf water potential and stomatal resistance, and leaf water potential and crop-air temperature differential.

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