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Assessment of Water Stress Effect on Cotton Flowering and Boll Setting

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Abstract :- This research was undertaken to investigate cotton (*Gossypium hirsutum* L.) reproductive physiology as it relates to Crop Water Stress Index (CWSI). Five levels of CWSI were established as treatments to assess cotton response to imposed water stress. Indices investigated were .16, .35, .36, .40, and .62. Daily tagging of opened flowers in each treatment was conducted throughout the season. Floral production, abscission and boll retention were negatively correlated to CWSI. A two day lag response was observed between a decrease in CWSI values resulting from irrigation, and daily flowering increase.

Keywords:- *Cotton Physiology; Cotton Water Requirements.*

I. INTRODUCTION

Climate change combined with increasing world population are bringing into use more and more marginal lands such as desert lands, in an attempt to meet increasing demand for food and fiber. Most restricting element by far which impedes use of desert lands for agricultural production is availability, and cost of water pumping. Throughout the world, drought and water deficiencies are major's reasons of limited agricultural productivity of desert land (Martinez Fernandez et al., 2016).

Downfall of this situation on plant yield is low yield, and high variability within, and between years. Agricultural drought is a condition that is characterized by shortage of water supply at critical plant growth stage (Al-Solaimani et al., 2017). Indeed, water is the fundamental element that make up all living being on earth. It is required to keep basic life functions in all living cells and being (Akay and Önder, 2016).

Despite deficit of freshwater resources, irregular precipitations and drought ever presence in warm desert, these lands can become highly productive with controlled irrigation (Çolak et al. 2021). Underground water is readily available in most desert lands, thus good irrigations tools and schemes constitute key component of sustainability of agricultural activities in semi-arid to lands (Wanjura et al., 1995, Evett et al., 1996, Upchurch et al., 1998, Peters and Evett, 2007, O'Shaughnessy and Evett, 2010). Under these conditions, irrigation might significantly complement watering needs towards higher crop yields and qualities (Yavuz et al., 2021). However, high water usage of agriculture in desert regions, and scarcity of this commodity call for wise and efficient use of water on these lands, if agriculture is to remain viable there (Gal et al., 2003; Martinez Fernandez et al., 2016).

There has been much interest in developing quick methods for evaluating water stress level to which a plant can be subjected on a given field and specifics periods and times (Kacira et al., 2002). To this end, various methods such as measurement of soil water tension, leaf water potential, and sap flow have been widely used (Kacira et al., 2002). Although soil water status provides indications on amount of water potentially available for plant uptake, it does not tell whether all that water is being use by the plants. Soil water potential therefore is just an indicator of water supply within a given growing medium, at the time of measurement for it gives no clues as to plants stand-point.

Leaf water potential and sap flow measurements provide direct information about plant water status (Kacira et al., 2002). Use of remote sensing method such as CWSI is a suitable tool to assess plant watering needs; thus help farmers to schedule efficient irrigation and make best water management decisions (Ihuoma and Madramootoo, 2019, Nemeskéri et al., 2015, Ustin et al., 2004, and Zarco-Tejada and Ustin, 2001).

Technics above mentioned are contact technics, thus they require large number of samples to be taken and that is additional constraint that strongly impede on their implementation at commercial production (Kacira et al., 2002). To overcome these limitations, non-contact and plant response based water stress detection techniques are needed. Hopefully, development of space age technology brought up tools that can help monitor plants water need quickly, remotely and without any damage to plants. Those technologies include development of sensors that remotely allow assessment of soil moisture (Idso et al., 1975; Chen et al., 2010), plant water stress (Jackson et al., 1988; Chen et al., 2020), pest infestations (Pinter, 1980), crop yield (Idso et al., 1977), and various other factors affecting crop productivity.

Generally, with regards to assessment of plant watering needs, various technologies and indices based on remote sensing have been developed (BAI Jian-jun et al., 2017). Amongst those, are indices developed to reveal anomaly vegetation index (AVI) (Chen et al. 1994), vegetation condition index (VCI) (Kogan 1995; Deng et al. 2013), apparent thermal inertia (ATI) (Price, 1985), Crop Water Stress Index (CWSI) (Jackson et al. 1988), and temperature vegetation dryness index (TVDI) (Sandholi, et al. 2002). CWSI is calculated using empirical method (Idso et al., 1980; Pinter et al., 1983; Hattendorf et al., 1990; Wanjura and Upchurch, 1998). Theoretical crop water stress index (CWSI) has been also developed (Jackson et al., 1981; Jackson, 1982; Clawson et al., 1989; Stanghellini et al., 1992; De Lorenzi et al., 1993), and it is based on energy balance analysis. Thermal stress index has been investigated to characterize plant water stress (Yuan et al., 2004; Möeller et al., 2007). Empirical and theoretical CWSI have also been used to estimate crop productivity and water stress relationships (Wanjura et al., 1990), and for irrigation scheduling (Nielsen, 1990; Garrot et al., 1994; Gontia and Tiwari, 2008). Theoretical CWSI incorporates incoming solar radiation, relative humidity, air temperature, wind speed, canopy resistance at potential evapotranspiration, and crop height.

Infrared thermometer based technology, can be used to assess various environmental and physiological parameters that affecting crop productivity (Kacira et al., 2002). Earlier researchers have developed indices which can be used to make efficient use of irrigation water based on a remotely obtained canopy-air temperature differential and air vapor pressure deficit (Jackson et al., 1981). Kacira *et al.* (2002) indicated that CWSI–based technique is able to detect plant stress 24 hours to 48 hours before visual stress is detected. Indeed, in water stressed plant, eventual wilting occurs when transpiration demand exceeds available water for plant use. Proper water management practices requires that plant water stress be detected as early as possible to control irrigation timing (Kacira et al., 2002), and usefulness of CWSI as suitable tool to assess plant watering needs is clearly established. Thus it might help farmers to schedule efficiently irrigation, and make best watering decisions (Ihuoma and Madramootoo, 2019, Nemeskéri et al., 2015, Ustin et al., 2004, and Zarco-Tejada and Ustin, 2001). Chen et al., (2010) suggested that drought intensity together with degree indices could better help monitoring and evaluating soil–crop drought, as well complementing crop water stress index (CWSI) in irrigation scheduling.

Recent work by Tanriverdi et al. (2017), indicated that remote sensing is useful in agriculture for stress classification, irrigation scheduling through canopy temperature monitoring and yield prediction. However, Shen and Tian (1999) pointed out that CWSI involves multiple parameters, and some of them not easy to estimate. Indeed, estimation of evapotranspiration (ET) is problematic for remote sensing investigations, and that is a limitation to wide adoption of CWSI in drought monitoring.

Furthermore, measurements of leaf temperature by early workers showed tremendous variability. Different environmental variables act singly or in combination to modify the leaf temperature (Gates, 1968; Carlson et al., 1972). Fluctuation of leaf temperature resulting from stress constitutes basis for using infrared thermometry to assess plant water stress (Ehrler et al., 1978; Ben-Gal et al., 2009; Chen et al., 2020), to schedule Irrigation (Pinter and Reginato, 1982), and to predict yield (Idso et al., 1980, 1981b).

This experiment was undertaken to investigate relationships between Crop water Stress Index (CWSI) as developed by Idso et al. (1981a), and cotton flower production, abscission, and retention. Additionally, research examined usefulness of the CWSI for efficient irrigation scheduling.

II. MATERIALS AND METHODS

➢ *Field design and seeding*

Seeds of short staple cotton (*Gossypium hirsutum* L cv. DPL 90), were planted on a uniform Coarse-Loamy soil. A north-south row orientation and one meter row spacing were used. A randomized complete block design was used for layout of this research. The .61 ha field was divided into twenty equal plots each covering an area of 8 m x 15 m. Each plot was 8 rows wide. Sowing was accomplished using a standard four (4)-row planter at planting rate of 13 Kg/ha. Five (5) water treatments, each replicated four (4) times were used in this experiment.

Each plot was independently provided with water through a semi-automatic underground drip system. The drip system consisted of two sand filters, a pressure regulator, a timer, an electrical pump, various pipes, and a series of twenty pressure gauges and valves each controlling water delivery to a single plot. Liquid nutrients were injected thru a venturi system. Overall, 134 Kg/ha of nitrogen were used on this field. Herbicides and insecticides were not used in this field. Weeds were removed by hands.

➢ *Water treatment*

Irrigation treatments were scheduled based on the Crop Water Stress Index (CWSI). CWSI values of .16, .35, .40, .62, and .36 were respectively named Wet, Medium, Dry, Very dry, and Met treatments. These values represented the maximum water stress level each of treatment was allowed to reach on the average. Above treatments names refer to stress level at irrigation, rather than to amount of water applied. Irrigation was applied on average when these values were reached.

Wet treatment was established as to receive abundant water, much in excess of plants need. Thus, wet treatment was irrigated 10 times during the season. That total to 80 cm of applied irrigation water. Medium, Dry, and Met treatments were established as to receive adequate amount of water, within range of what farmer's would use for normal irrigation. These treatments were each irrigated seven (7) times throughout season. They received 70, 73, and 69 cm of applied water respectively throughout season. Plants in the very dry treatment were irrigated 6 times, which amounted to 67 cm of applied water. However, prior to planting, all treatments received 16 cm of initial watering.

➢ *Canopy temperature and CWSI*

Canopy-air temperature differential was measured under clear sky, three (3) times a week (Monday, Wednesday and Friday). An Everest lnterscience Surface Thermometer

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was used. This handheld infrared gun remotely sensed temperature at the crop canopy. Temperature differential was measured by viewing individual in plot canopy, at an angle about 30° from the horizontal. Readings were taken between 10h00 in morning, to noon. Prior to canopy establishment i.e. first flower stage, individual leaf temperatures were recorded instead of partial canopy temperatures.

Temperatures were measured while walking either northward or southward within an alley. To avoid background variability effects on the readings, the same areas were measured throughout the season. These areas were marked by flags delimitating a 2 m^2 area. These 2 m^2 areas were reserved for flowers study. On each side of all plots, canopy temperatures were read three (3) times, and average of these readings was recorded as the plot canopy temperature. It takes overall about seven (7) minutes to obtain temperature of all 20 plots.

Vapor pressure deficit was recorded once canopy temperature was obtained for half of the field. Although thermometer was calibrated by the manufacturer, its calibration was frequently checked against that of a calibration box, according to calibration procedures recommended by manufacturer. The vapor pressure deficit (VPD) was calculated using the wet and dry bulb method. The wet and dry bulb temperatures were obtained with a portable electric psychrometer. Soil moisture was measured on third row from the west side of each plot with a neutron probe 2 to 3 hours before canopy temperature was read. Neutron probe was used to determine the amount of soil moisture depleted on the first four (4) treatments (wet, medium, dry, very dry). Soil moisture readings were taken only at 30, 61, 91 cm. For the Met treatment, the amount of water needed to bring the plots to field capacity was established through the consumptive use method.

CWSI value of each plot was calculated using empirical method (Idso et al., 1980). Based on the empirical model, initial baseline was established using predicted equation ($Y_1 = 2.0 - 2.4*X$) established for cotton by Idso et al. (1982). In above equation Y_1, X is VPD measured in KPa, and Y, the predicted canopy-air-temperature differential. Based on previous observations (Garrot et al., 1987), and in accordance with observations by Idso et al. (1982), lower baseline shifted upward as reproductive stage began.

New predicted baseline ($Y_2 = 2.65 - 2.10*X$) was previously established by Garrot et al., (1987). In mid-July, baseline shifted again upward to a new position determined by the regression equation Y_3, with following baseline ($Y_3 = 3.7 - 2.1*X$). In late July, baseline shifted back to the initial position (Y_1). Measurements for lower baseline were done over a day or two, starting two days after irrigation. As to encompass a wide range of VPD, readings were extended from 10h00 to 15h00.

➢ *Floral study*

Flowering pattern of cotton plants was studied on a selected 2 m X 1 m area i.e. (2 m^2 area) within each plot. Area was consistently selected on third row from east side of each plot. Within a given selected row, the 2 m^2 area was chosen to be as representative of the plot as possible. Areas were then delimited with flags. Flowers were thereafter tagged with colored plastic tags. Tagging was conducted throughout flowering period on a daily basis. Plastic tags were attached to pedicel of flowers opened within last 24 hours. Newly opened cotton flowers were recognized by their yellow color. Tagging was consistently started between 06h30 and 07h00, and terminated upon completion of all 20 plots. Tagging started on week of 6 July and proceeded without Interruption until 20 September. Each tag was coded as to indicate week and day of tagging. Coding provided exact day's on which a given tag was put on the flower. This information was used to study the water stress effect on the flower and fruit abortion.

To study flower abortion, tags dropped on the ground were picked up daily. The collection of the dropped tags was started on 21 July and proceeded to 29 September. Since tags from aborted fruits and flowers were collected daily, and CWSI was measured only three times a week, abortion data were grouped with dates when CWSI data were collected. Tags collected Saturday through Monday were grouped with Monday's CWSI data, tags from Tuesday to Wednesday and tags from Thursday to Friday were grouped with Wednesday and Friday CWSI data respectively.

Plant height was measured weekly. Height of three plants, picked randomly within the 2 m2 flower tagging area, were taken every Wednesday starting on week 2 of tagging and stopped on week 8 of the tagging period because of lodging problem in the wet treatments.

III. RESULTS AND DISCUSSION

➢ *Crop Water Stress Index*

Five water stress levels were established using Crop Water Stress Index (CWSI) (Tables 1, 2). Treatments were designated wet, medium, dry, very dry, Met and based on CWSI level at which plants were irrigated. For first four (4) treatments, soil moisture depletion was measured with a neutron probe. For fifth treatment, amount depleted was based on cotton consumptive use of water. Lower baseline shifted three (3) times during the season. Initial lower baseline used was Y1 = 2.0 - 2.4*X (Fig. 1).

Table 1: Treatments and seasonal Crop Water Stress indices

TREATMENTS	SEASONAL CWSI	IRRIGATION CWSI
Wet	.04	.18
Medium	.11	.35
Dry	.13	.40
Very dry	.22	.82
Met	.14	.38

Table 2: Daily CWSI Values of each treatment

Days after planting	Treatments					p-Value
	Wet	Medium	Dry	Very Dry	Met	
66	.048	.082	.10	.14	.12	.11
70	.025 b	.093 a+	6.121 a	.130 a	.146 a	.008
74	.024 b	.087 a	.112 a	.143 a	.134 a	.0031
78	.037 b	.085 c	.109 b	.178 a	.132 ab	.0007
82	.038 c	.092 b	.106 b	.168 a	.146 ab	.0001
96	.033 c	.105 b	.123 b	.189 a	.117 b	.0001
106	.035 c	.097 b	.116 b	.178 a	.128 b	.0001
116	.043 c	.113 b	.141b	.221 a	.131b	.0001

Values followed by same letter within a row are not statistically different based on Duncan's Multiple Range test mean separation technique (p=.05).

First upward shift of the lower baseline occurred as plants were changing from vegetative to reproductive stage. Within the week, flowers started opening in all treatments. Lower baseline moved upward from predicted equation Y_1 to equation Y_2 (Fig.1). Upward movement is attributed to increase in plant temperature within few days following floral initiation. Such increase in temperature could result from high temperature of non-transpiring floral parts. Non-transpiring floral parts are the most exposed to solar irradiation. Presumably, they convert incoming radiation into sensible heat, which increases canopy temperature. Idso (1982) found similar shift of lower baseline in period Just after heading of wheat (*Triticum durum* Desf. var. Produra) and barley (*Hordeum vulgare* L).

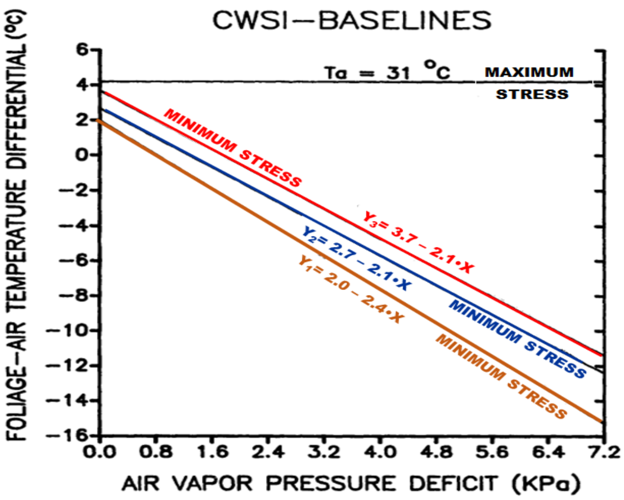

Fig 1: CWSI baselines used during the season

Second shift of minimum stress baseline (from Y_2 to Y_3), occurred in late July. This baseline was used on only two (2) consecutive sampling dates. This upward move of baseline was attributed to high relative humidity (Rh=89 %) prevailing on these days. Fourth and last shift occurred when minimum stress line moved back to its initial position (Y_1). Relative humidity dropped to between 30% and 38% for about a week and subsequent to this drop of relative humidity, plants transpiration would increase and such increase of plant transpiration could cause lowering of minimum stress line.

Minimum stress line remained in this position for the remaining weeks of the season, presumably because green bolls which were set during maximum flowering period were contributing significantly to transpiration. Daily canopy temperature readings were terminated on 31 August because of leaf senescence. Lowest CWSI values averaged over the season were obtained in the wet treatment, and the highest in the very dry treatment (Table 2).

Values shown in Table 2 represent average water stress indices at which plants were maintained for the season. But, treatments were actually established at maximum water stress indices retained for each treatment as irrigation scheduling flags (Table 1). For each treatment, average irrigation CWSI value at which water was applied was three (3) times higher than seasonal average. Thus, plants in wet treatment were maintained at .04 but irrigated at .18, in medium treatment plants were maintained around .11 for the season, and irrigated at .35. For dry, very dry, and Met treatments, plants were maintained at .13, .22, and .14 respectively for the season, and irrigated at .40, .62, and .36, respectively.

- *Reproductive physiology and CWSI*

Flowering started in all plots on average 61 to 62 days after planting. Opening dates of first flower vary greatly with environmental conditions, locations, and cotton varieties. For upland varieties, Munro (1987) indicated that in tropical regions such as Ugandan and Malawi, first flower opens 45 to 70 days after planting. Temperature is major factor controlling number of days to first flowering. Under warm temperature, number of days to first flower is greatly reduced as compared to cooler ambient temperature. In United States cotton growing regions, first flowering usually occurs 70 to 80 days after planting (Longnecker and Erie, 1968). Kittock et al. (1981) indicated that for Southern Arizona, dates to first blossom vary from 54 to 97 days after planting, depending on planting date. The earlier the planting date, the longer the pre-flowering period. They reported that for a 7 May planting date, number of days to first flower is about 50.

Emergence of cotton seedlings is maximum when soil temperature at 20 cm ranges between 15°C and 21°C (Wilkes and Corley, 1968). Delays in opening of first flower could be attributed to increasing night temperatures, combined with high day temperatures. Such combinations might result in delaying flower initiation and raising the position of the first flower node (Mauney, 1966). In our case; after flower initiation, floral development proceeds quickly to peak for

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plants in all treatments by the fourth week of flowering (Fig. 2). Peak flowering date was reached earliest by the plants in dry and very dry treatments. Plants in these two treatments respectively peaked within second week of flowering (Fig. 2). Differential water treatment was initiated for all treatments on 18 June. Thus; above treatments peaked about 28 days after water treatment was initiated By then these treatments had received respectively 26 and 32 cm of water. The peak flowering periods of

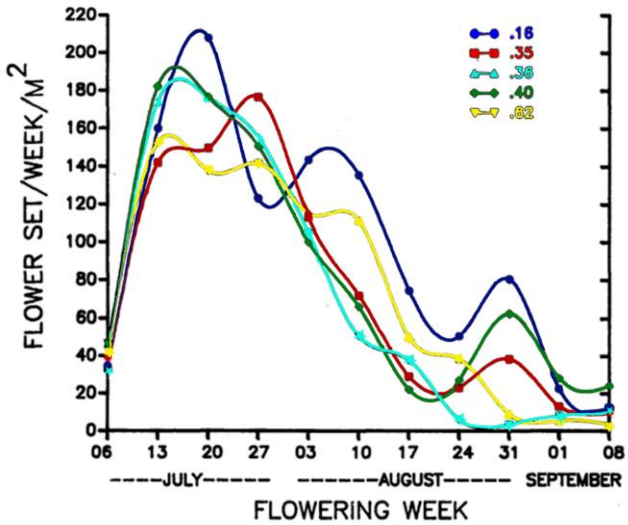

Fig 2: Seasonal flower production in all treatments

Met, and wet treatments occurred a week after the dry and very dry peaked. For medium treatment, peak period came two (2) weeks after that of dry and very dry (Fig. 2). Met, wet, and medium treatments received respectively at time of their flowering peak 41, 53, and 40 cm of water.

Statistical analysis of daily mean flowering of plants in all treatments are shown in Table 3. Five weeks after flowering began in all treatments, plants in wet treatment started producing significantly more flowers than plants those in medium, dry, and very dry treatments. Dry and very dry treatments peaked earliest presumably because of high CWSI values at which they were irrigated. Analysis of water deficit experienced by plants from planting date up to time of their peak flowering, shows that lowest daily water deficit was in wet treatment and that soil moisture deficit experienced by dry and very dry treatments were among highest (Table 4). Several workers have indicated that water stress imposed early in plant development speeds up flowering and boll production of cotton plants. Indeed, many researchers have shown existence of strong correlation between cotton physiological response and water deficit on parameters such as flowering, boll formation and distribution amongst plants (Gerik et al., 1996; Pettigrew, 2004).

McMichael et al. (1972) reported that water stress induces ethylene production in a cotton plant. Hall et al. (1957) suggested that ethylene production induces early flowering in cotton. Induction of flowering by ethylene occurs in plants such as mangos (*Mangifera indica* L.) and also in bromeliads *(Bromelia humilis* L) (De Greef, J. A., et al., 1989; Payàn et al., 2015; Zahir et al., 2015.). Cutout occurred around 3 August (Fig. 2). This hiatus in flower production is a natural phenomenon in the genus *Gossypium* and it occurs without any stress being applied to the plant (Mauney, 1986). Though flowering cessation reflects a normal physiological stage in a cotton plant development, it is markedly influenced by the plant genetic makeup and various environmental stresses.

Table 3: Daily Mean Flower production

Days after planting	Treatments					p-Value
	Wet	Medium	Dry	Very Dry	Met	
78	8.17	6.61	7.17	8.33	8.41	.1547
82	8.64	7.00	7.41	8.66	8.68	.1370
96	9.49 a	9.28 ab	8.95 cb	8.47 ab	8.05 b	.0048
106	9.07 a	7.61 bc	7.91 abc	7.07 c	8.75 ab	.0004
116	7.85	6.26 bc	6.61 b	5.57 c	7.15 ab	.0003

Values followed by same letter within a row are not statistically different based on Duncan's Multiple Range test mean separation technique (p=.05).

Table 4: Daily Mean Soil Water Deficit

Days after planting	Treatments					p-Value
	Wet	Medium	Dry	Very Dry	Met	
66	5.87 c	6.96 b	7.26 ab	6.71 be	8.05 a	.0009
70	5.28 c	7.63 ab	8.03 ab	7.01 b	8.66 a	.0001
74	5.31c	7.26 b	7.65 ab	7.29 ab	8.31 a	.0001
78	5.66 c	7.11 b	7.47 ab	7.85 ab	8.13 a	.0001
82	5.46 c	7.39 b	7.54 ab	7.75 ab	8.38 a	.0001
96	5.56 c	7.34 b	7.79 ab	8.23 a	8.08 ab	.0001
106	5.38 c	7.14 b	7.65 ab	7.85 a	7.72 ab	.0001
116	5.51c	7.24 b	7.59 ab	7.62 ab	8.26 a	.0001

Values followed by same letter within a row are not statistically different based on Duncan's Multiple Range test mean separation technique (p=.05).

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A second peak in flower production occurred about 24 August. This second peak is an indication of a regrowth which produced the new sympodia needed for the flowering to increase in late season. These new sympodia were mainly produced by plants in wet, dry, and medium treatments. These treatments received respectively for the season 80, 73, and 70 cm of water, and these quantities represent highest irrigation water applied. Boll production curves (Fig. 3), indicated that boll maturation occurred in a pattern that closely resembles the weekly flower production. Highest flowering weeks (Fig. 2) also retained to maturation, highest number of bolls (Fig. 3).

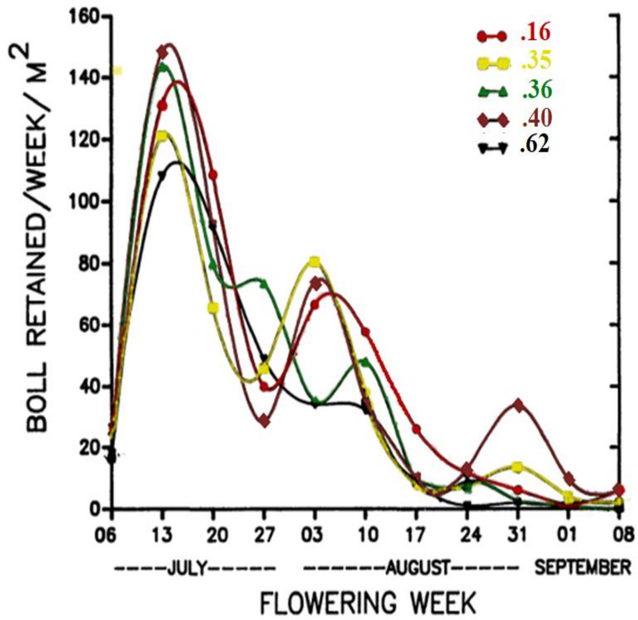

Fig 3: Weekly boll retention in all treatments

In all treatments, peak boll retention occurred in the second week of flowering. The cumulative flower production curves show that floral production had leveled off by the 8th week of flowering for plants in all treatments except wet treatment (Fig. 4). Wet treatment, having experienced least water stress, continued accumulating flowers until early September. The observed leveling off occurred presumably because of competition for carbohydrates between boll loads and growing parts. Plants, unable to provide to needs of both growing shoots and developing bolls, favor boll maturation. Thus during periods subsequent to 8 August, a high percentage of squares and flowers would be expected to abscise. Cumulative boll retention per week of flowering (Fig. 5), showed also a levelling off in boll retention following the 8th week of flowering. Dry and wet treatments, retained highest amount of boll produced per week of flowering, and per square meter (Fig. 5). Developing bolls are strong sinks and strength of this sink reaches its maximum 20 to 30 days after anthesis (Pinkhasov and Thachenko,

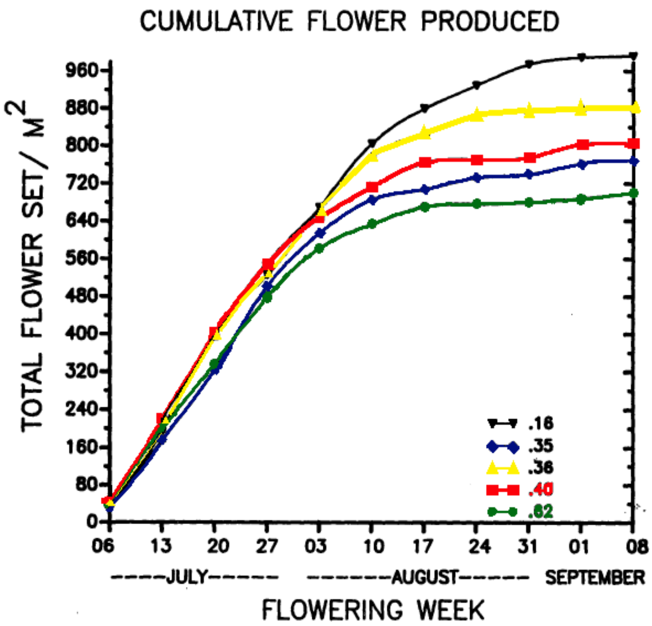

Fig 4: Cumulative flower production

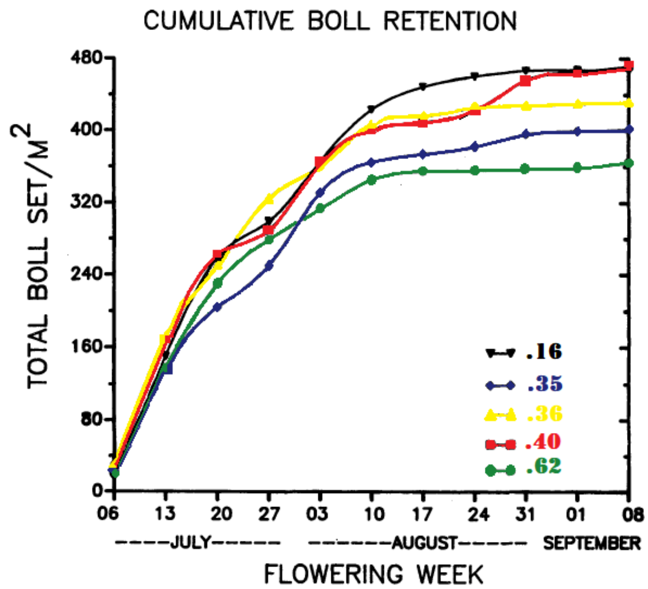

Fig 5: Cumulative boll production

1981). Period of intense flower production extended from 13 July to 3 August. During this period weekly flowering was over 100 flowers/m^2. Thirty days after this period, high demand for carbohydrates by bolls set during previous high flower setting periods brought about this early leveling of flower production in all treatments except wet treatment. Throughout season, wet treatment had significantly more soil moisture available to plants (Table 4). Thus plants in this treatment were able to maintain a longer flowering period. However, most of late flowering occurring in wet treatment did not result in a yield. This is because the largest percentage (53%) of flower and boll abscission occurred in this treatment (Fig. 6).

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Abscission and retention percentages are based on total flowers produced by each treatment. Lowest fruit and flower abscission percentages occurred in dry treatment. Plants in this treatment were able to retain about 56% of the total flowers produced. Medium, Met, and very dry treatments, although they did not produce same number of flowers, retained about same percentage of fruits and flowers (48% to 50%). The relatively low retention percentage of medium as compared to Met is due to an unexpected high number of bolls that were not open at harvest. In all treatments, flowers set early in the season contributed the most at final yield (Fig. 7). The later in the season a flower was set, the more likely it would abscise. This is because early in the season the sink strength of the boll load is not yet strong enough to cause abscission of added flowers. Thus the plants capitalized on early set bolls and provided them with enough carbohydrates to ensure their fast development. Kittock et al. (1981, 1983) indicated that the boll maturation period increases as the season advances. A longer boll maturation period means that assimilates flow into these bolls over a long period.

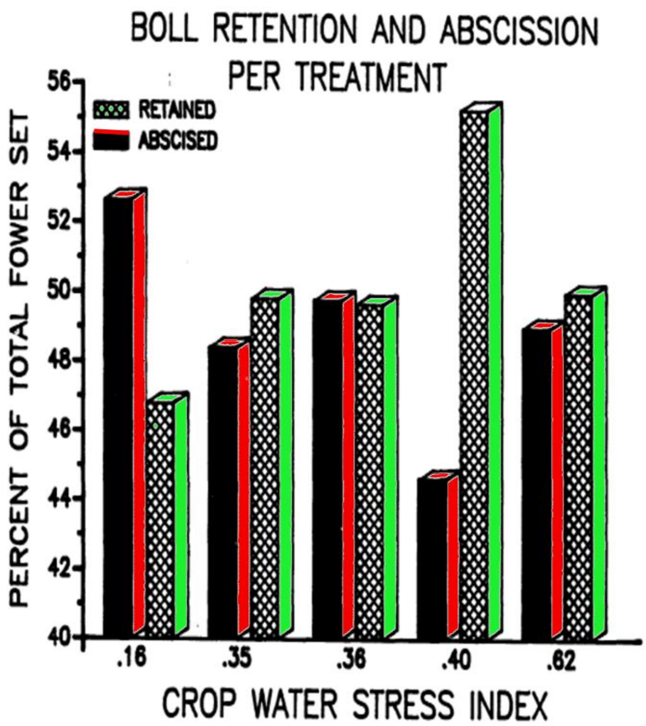

Fig 6: Relationships between total flower production, boll abscission, and boll retention.

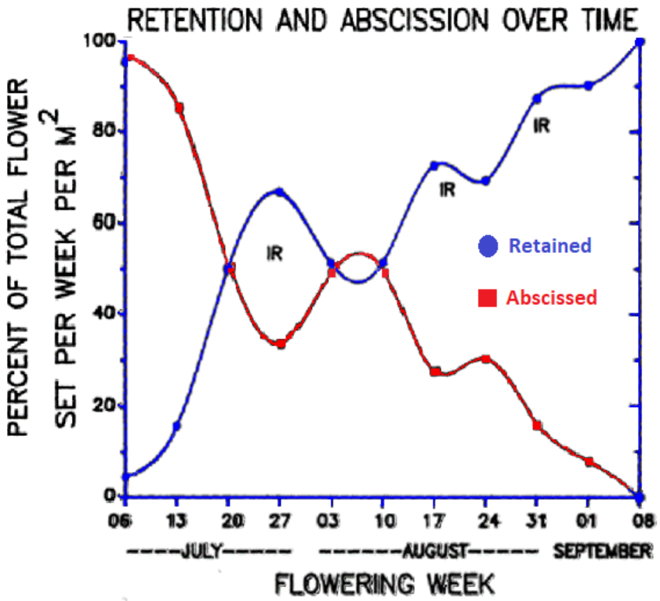

Fig 7. Relationships between boll maturation and boll abscission over time.

Flower production in wet treatment showed that, though flowering was relatively slow compared to the Met, dry, and very dry treatments during early flower setting weeks (Table 3), plants in this treatment steadily increased their average daily flowering as the season advanced (Fig. 3). The daily floral production of the wet treatment increased to the point where plants were producing significantly more flowers after first flower and proceeding steadily thereafter, plants in wet treatment were producing significantly more flowers on daily basis (Table 3). More than half of bolls set in wet treatment were shed before reaching maturity however. Several authors have indicated that with a heavy boll load, cotton plant sheds a large percentage of boll set (Rijiks, 1965; McMichael et al., 1973; Mauney et al., 1980). Shedding percentage found in wet treatment (53%) agrees with shedding percentage indicated by Rijiks (1965). Research results of Onder et al., (2009) also suggested that there is an adverse effect of high irrigation level, on number of opened bolls per plant. High boll shedding percentage observed in wet treatment might presumably be due to inability of photosynthesis to supply all bolls set with an adequate level of assimilate. Lowest percentage of boll shedding occurred in dry treatment. Plants in this treatment aborted about 44% of their boll load, thus giving highest percentage of bolls that matured to harvest. Lack of significant difference in water consumed by the medium and dry treatments (Table 4) indicates that the observed difference in boll retention was due to timing of water application which was determined by CWSI. Although there is no statistical difference between seasonal mean CWSI values of medium and dry treatments (Table 5), the relative difference of .05 stress index units at irrigation time may have been sufficient to allow plants in dry treatment to retain and mature 5% more boll than medium treatment.

Table 5 : Seasonal and irrigation CWSI, vegetative growth, irrigation water applied, and yield data.

Days after planting	Treatments					p-Value
	Wet	Medium	Dry	Very Dry	Met	
CWSI at irrigation	.16 c+	.35 b	.40 b	.62 a	.36 b	.0067
CWSI Seasonal	.04 c	.11 bc	.13 abc	.22 a	.14 ab	.0445
# Irrigation	10	7	7	6	7	
Water applied (cm)	80.21a	70.31bc	73.10 b	67.13 d	69.42 cd	.0001

+Values followed by same letter within a row are not statistically different based on LSD Mean separation technique (p=.05).

➢ *Floral production and irrigation*

Study of relationships between CWSI and flower production shows two (2) days lag response by plants to sharp decrease in CWSI values (Fig. 8)). These sharp decreases in daily CWSI values occur succeeding irrigation or substantial rainfall when plant stress is reduced. Increase in flowering rate subsequent to irrigation is better observed by plotting flower production versus days plant were irrigated (Fig. 9). Flower production increased two (2) to three (3) days after irrigation (Fig. 9). Prior to irrigation, flower abscission increases up to a day after irrigation. Floral abscission decreases for next two (2) to three (3) days following irrigation.

➢ *Correlations matrixes*

As expected, a strong negative correlation exists between boll production and CWSI (Table 6). This confirms previously observed decreasing trend of boll production in relation to increasing water stress. Seed cotton production was correlated (r = -.68, p=.001) to both seasonal and irrigation CWSI. This low correlation coefficient is likely attributable to errors introduced by hand picking seed cotton.

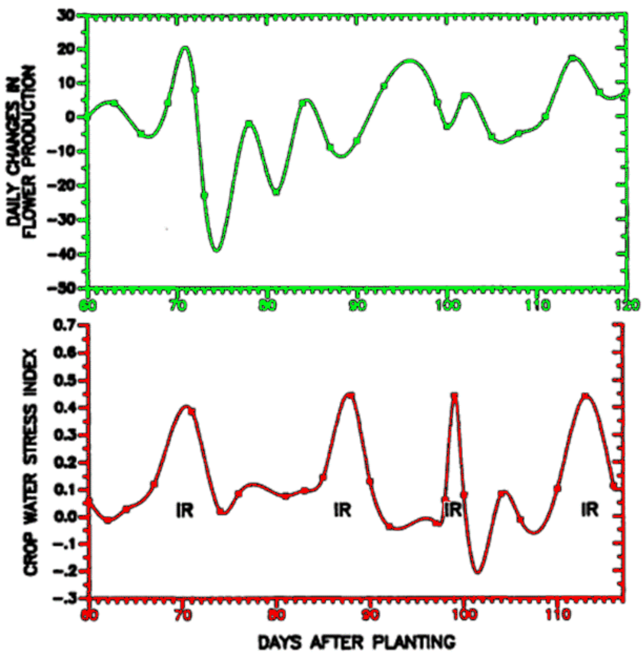

Fig 8. Relationships between decrease of daily CWSI and flower production.

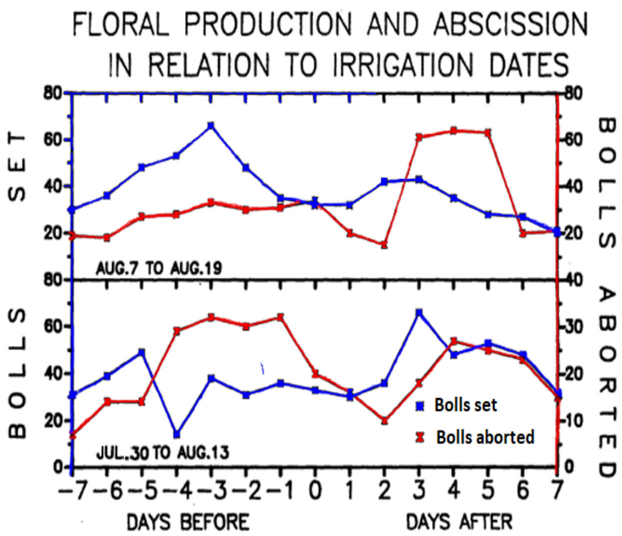

Fig 9. Change in floral production following irrigation

Table 6: 'Correlation matrix of water treatments and plant height

	Water Def1.	Water Def2.	Water Applied	Height
Water Def1.		.987**	-.961**	-.961**
Water Def2.	.987**		-.921*	-.994*
Water Applied	-.961**	-.921*		.927*
Height	-.961**	-.994*	.927*	

** Correlation coefficients significant at 1% error level
* Correlation coefficients significant at 5% error level
+ Correlation coefficients significant at 10% error level
Def.1 : Soil moisture deficit in first 60 cm
Def.2 : Soil moisture deficit in first 91 cm.

This particular lack of significance is only true with regard to linear correlation. Furthermore on a small field, with many differentially irrigated plots adjacent to each other, it is reasonable to expect the presence of temperature and wind gradients across the field. Such gradients could result from the unequal amount of evapotranspiration proceeding in the different treatments. In turn these gradients could create enough wind turbulence above the canopy to affect the canopy temperature readings. Water deficits measured in the top 60 and 91 cm of soil correlated well with CWSI. Jackson et al. (1981), reported a similar close relationship between CWSI and soil water deficit. Working on corn (*Zea mays L.;* Yedan 13), Chen and colleagues (2010), reported that on corn, that at end of an imposed drought period, although soil water below 70 cm still remained at high level, soil water is not easily transported to root zone, in upper layer for plants uptake. Such correlations are to be expected for the CWSI is a measure of the plant response to existing soil water potential. Water deficit correlates well with most variables measured (Table 6).

IV. SUMMARY

CWSI was calculated based on the empirical model, and three (3) minimum water stress baselines were used for whole season. First minimum stress baseline ($Y_1 = 2.0 - 2.4*X$) was developed by Idso et al., (1982). This baseline was used for most of the season. Plant canopy was established using this model for the whole vegetative growth period. At reproductive stage, plants canopy temperature increased considerably and that caused minimum stress baseline to be higher than before ($Y_2 = 2.7 - 2.1*X$). Third upward shift occurred in late July and was maintained for only two consecutive readings. This last position was determined thru predicted equation ($Y_3 = 3.7 - 2.1*X$). This upward move of baseline was ascribed to high relative humidity (Rh=89 %) prevailing on these days. Lastly, minimum stress line moved back to its initial position (Y_1).

Relative humidity diminished to take values between 30% to 38% for about a week, and ensuing this reduction of relative humidity, plants transpiration increased. The lowering of plants canopy temperature was basis for assumption that transpiration cooling fraction of plant canopy increased during that period. Such increase of plant transpiration would cause lowering of minimum stress line. The minimum stress line no longer shifted from the Y_1 position during the remaining days of season. This was presumably because green bolls set during maximum flowering period, were contributing significantly to transpiration. Flower production began in all treatments 60 to 61 days after planting. Following flower initiation, flower and boll production proceeded quickly to peak for all plants by fourth week of flowering.

Flower development followed traditional cotton flowering pattern. Following peak flowering weeks, flower development steadily declined in all treatments until 9 September, when it ceased. Before it reached a complete halt, flower production levelled off in all treatments by 24 August. Daily flowering of plants in wet treatment became significantly higher than that of other treatments 36 days after flowering began. There was no significant difference in the daily flowering of plants in medium, dry, and Met treatments. Plants irrigated at high water stress indices (.40, .62) peaked earliest. Early water stress imposed on these plants, could have induced this early high flower production through hormonal change (McMichael et al., 1972; Guinn, 1986).

It is speculated that since under water stress, *G. hirsutum* L. produces ethylene, this might have caused the early peak of plants irrigated at high water stress indices. A two (2) days lag response after irrigation was noticed before flower production increased. Period of intense flower production extended from 13 July to 3 August. During this period, weekly flowering was over 100 flowers/m2. Highest flower and boll production occurred at stress level of .16, and lowest at .62. High boll production of wet treatment did not produce highest yield. This is because, most of bolls set in wet treatment were aborted before reaching maturity. This high bolls abscission percentage was due to inability of plants in wet treatment to generate enough assimilates to sustain need of whole boll load. Further hindrance to retention of all bolls set was, high vegetative growth exhibited by plants in this treatment. Boll retention percentage in wet treatment was among lowest. Dry treatment, maintained at a CWSI of .40, had lowest boll abortion and highest retention percentage. Boll retention percentage of medium, Met, and very dry treatments were similar.

The CWSI calculation based on the empirical model has proven to be an efficient irrigation management tool. Water consumption was significantly reduced and yields were highest in treatments established between .35 and .40. Treatment establishment is a dear indication of usefulness of CWSI as suitable tool to assess plant watering needs; thus with high potential to help farmers manage efficiently irrigation water make best managerial decisions for their crops.

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