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Metabolic activities and lint production of water stressed cotton

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Abstract:

This research was undertaken to investigate cotton (*Gossypium hirsutum* L.) metabolic activities and lint production following imposed water stress. Water stress was applied using empirically derived stress indices as developed by Idso and colleagues for Crop Water Stress Index (CWSI). We used Five (5) levels of stress as treatments to assess cotton physiological response to water deficiency. Indices used were .16, .35, .36, .40, and .62. Metabolic parameters measured were diffusive resistance, transpiration and apparent photosynthesis. Boll and lint production were also subsequently measured. With regards to metabolic activities, negative relationships were observed between apparent photosynthesis, transpiration, leaf area and CWSI. Boll abscission and retention were also negatively correlated to CWSI. As for lint production, there was no significant difference between treatments at stress level used. Plants irrigated at stress level either below .30 or above .40, tended to produce relatively lower lint comparatively to plants upheld between .30 and .40. Plant height, positively correlates with amount of water applied.

KEYWORDS: Cotton; diffusive resistance; apparent photosynthesis; lint; Water stress index.

Introduction

Plant development is a process severely impeded by inadequate water level at critical growth phases. Water is indeed fundamental element to survival and successfulness of all life on earth. It is required to keep basic life functions in all living cells and beings (Akay and Önder, 2016). Thus, for high value crop such as cotton (*Gossypium hirsutum* L.) which provides both fiber and large amount of edible oil and animal feed (Zhang et al., 2017). Cotton crop is grown over a wide range of environmental conditions, and for the plant to be able to sustain acceptable to high productivity level in adverse conditions, efficient water usage by the crop is unconditional (Osakabe et al., 2014; Zhang et al., 2017).

Several morpho-physiological and biochemical changes that adversely affect development as well as productivity of cotton crop might result from drought stress (Ullah et al., 2017). Water stress can severely affect plant growth and development with substantial effect on biomass accumulation (Loka et al., 2011; Ul-Allah et al., 2021). Water stress declines number of bolls set per plant, bolls weight, and seed cotton yield. It affects furthermore fiber length, strength, quality seed index which are also reduced (Ul-Allah et al., 2021). Moreover, drought stress provokes decreases in physiological traits such as plant height, leaf dry weight, stem dry weight, leaf area index, node number, canopy and root development (Loka et al., 2011).

Water stress impede as well on physiological activities thru lowering of relative leaf water contents, transpiration rate and leaf water potential, resulting in an increase of leaf and canopy temperature (Kumar et al., 2001; Rehman et al., 2021). Cotton crop strategies to cope with water deficiency hence to minimize yield losses includes cutting down water exhaustion thru dwindling number of leaves, and reduction of leaves total surface area (Ibid.). Likewise, cotton plant could avoid heat stress by high transpiration ability thru substantial a paraheliotropic leaf movement, which contributes to avoid heat and drought by reducing amount of incident solar radiation on leaf (Isoda and Wang, 2002). This drought copping strategy of cotton plants is opposite to the one developed by soybean plants thru combination of paraheliotropic leaf movement and reduced transpiration (Ibid.)

Transpiration is an important physiological process which cools plants thus reduces net radiation load. Undeniably, it is well established that evaporation and transpiration are plant physiological cooling system that lower leaves and plant temperatures thru water changing phase from liquid to gas, and thus, it removes great quantity of latent heat from the evaporating surface. Leaves temperature is a function of as well soil moisture availability in root zone, as plant's general external conditions. Transpiration proceeds at higher rates in healthy non-stressed plants than in stressed plants (Jackson, 1982; Rehman, et al., 2021; Tombesi, et al., 2022). Continued transpiration depletes soil water and subsequent water stress induces partial closure of stomates which in turn reduces transpiration rate (Wiegand and Namken, 1966; Jackson et al., 1977; Ullah et al., 2017; Rehman, et al., 2021; Tombesi, et al., 2022).

Stomatal activities affected by water stress can influence CO_2 absorption, and that induces noteworthy negative impact on photosynthesis and plant growth (Osakabe et al., 2014; Khan et al., 2018). In presence of water scarcity, transport systems of ions and water across membrane, function to control turgor pressure in guard cells, thus to stimulate stomatal closure (Osakabe et al., 2014). ABA is rapidly produced in response drought, and that trigger a cascade of physiological responses, which include stomatal closure (Ibid.). ABA is an important stress hormones which participates in stress responses, development and reproduction (Boudsocq and Laurière, 2005). Osmotic stress due to drought or water shortage is released through water loss and turgor pressure (Ibid.). ABA is generally produced in roots and then transported to stomata where it induces closure of guard cells in responses to drought (Kuromori et al., 2010). Cotton plant is able to significantly decrease total stomatal area to adjust to water stress (Inamullah and Isoda, 2005). Resulting decrease in latent heat exchange causes leaf temperature to increase (Tanner, 1963; Gates 1964; Rehman et al., 2021) due to shift in energy balance of the system.

Water shortage affects reduces stomata conductance, photosynthetic rate and transpiration rate. Thus, to handle moisture deficit, cotton as other plants, did develop range adaptation changes thru morphological, physiological, biochemical and molecular mechanisms adjustment to cope with water deficit (Ullah et al., 2017).

Fang and Xiong (2015), grouped plant's drought lenience in four (4) categories based on their strategies to avoid drought, to escape or to endure it. Drought avoidance is used in response to mild water stress by maintenance of key functions such as stomata regulation and root system (Ibid.). Drought endurance is ability of plants to resist to harsh dehydration by physiological adjustment of osmoregulation (Luo, 2010), and activation of stress induced gene expression and additional molecular pathways (Seo and Koshiba, 2002; Yamaguchi-Shinozaki and Shinozaki, 2006; Danquah et al., 2014; Mehrotra et al., 2014;

Yoshida et al., 2014; Dong et al., 2015; Ma et al., 2016). Drought escape is the ability of plants to adjust their growth period or lifecycle, in such a way as for cotton plants with short life cycle, could avoid expected seasonal drought (Manavalan et al., 2009). Lastly, plant's drought recuperation, relates to ability of harshly drought hit plants, to recover from the choc and maintain growth and yield (Fang and Xiong, 2015).

Stomatal regulation in order to reduce water loss thru leaves plays key role in cotton plants response to water stress. Leaves dwindling, drooping and rolling result in less radiation, thus, reduced water loss (Fang and Xiong, 2015). Plants may also display drought lenience characters such as thicker and smaller leaves, denser epidermal cuticle, more compact palisade tissues, smaller and denser stomata, higher palisades to spongy ratio, thickness of parenchyma, and greater vascular bundle sheath (Hetherington and Woodward, 2003; Iqbal et al., 2013; Ullah et al., 2017).

Stomata regulation performs key role in gas exchange between tissues and atmosphere, and it performs central processes in plants energy production and continued cellular function (Ullah et al., 2017). Transpiration account for 90% of water lost through stomata's openings (Wang et al., 2009). Whenever transpiration pace is high, stomatal closure is initial step towards reduction of moisture loss in presence of water scarcity. Thus, stomata conductance might be latent indicator of drought lenience in cotton for, there is a negative correlation between drought tolerance, and stomata conductance (Ibid.). In presence of water shortage, stomata close and that leads to reduction of CO_2 intake (Rud et al., 2014). This reduction in turn, affects photosynthesis rate and subsequent growth and yield (Chaves et al., 2009). Cases were reported where stomata's conductance was not associated with rate of photosynthesis (Von Caemmerer et al., 2004; Xu et al., 2010).

As water deficit rise up, photosynthetic rate and growth are greatly reduced in field cotton (Deeba et al., 2012; Li et al., 2012). Young leaves of cotton are photosynthetically more tolerant to drought and heat, than mature leaves. Chastain et al. (2016) exposed young leaves to 37 °C temperature, no decline was observed in net photosynthesis rate. To the contrary, when they exposed older leaves to same temperature, net photosynthesis rate drastically declined by 66%. Conclusion is that drought stress reduces photosynthesis in cotton plant, and that reduction in turn affects growth and lint production.

Several early workers have recognized potential use of leaf temperature measurements (Tanner, 1963; Wiegand and Namken, 1966) and canopy temperature measurements (Bartholic et al., 1972; Idso et al., 1981a; Jackson et al., 1977; Choudhury, 1986) to assess plant water status. Measurements of leaf temperature showed tremendous variability because various environmental variables act singly or in combination, to modify leaf temperature (Gates, 1968; Carlson et al., 1972). Carlson et al. (1972) found a negative relation between the leaf temperature and relative water content of two soybean (*Glycine max* L Merr.) cultivars. The position of the leaves on the stem Influences the leaf temperature of potato (*Solanun tuberansum* L) and tomato *(Lycopersicon eaculentum* L) (Waggoner and Shaw, 1952). Under clear days, the upper leaves, which are exposed to more sunlight than the lower leaves, are warmer than the air temperatures. The lower leaves, because of the shading effect, are cooler than air temperature. The orientation of the leaves with regard to the insolation also affects their temperatures. Leaves that are parallel to the insolation (upright leaves) are cooler than leaves perpendicular (horizontal) to the insolation (Waggoner and Shaw, 1952; Stevenson and Shaw, 1971). Water status of plant also affects the leaf temperature (Gates, 1968). Leaf-air temperature differential of peas (*Vigna sivensis* L (Endl.) var. Burgundi) showed that leaf temperature was lower than air temperature in well watered peas, whereas in water-stressed peas, cotton or soybean, leaf temperature was higher than the air temperature (Clark and Hiler, 1973; Inamullah and Isoda, 2005). Similarly, Sumayao et al., (1980) found leaf temperature of well watered corn (*Zea mays* L *av.* Prairie Valley) and sorghum *(Sorghum bicolor* L cv. SG-40 GBR) was lower than the air temperature when the latter exceeded 33°C. 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). More recent studied on cotton (*Gossypium barbadense*), showed that drought stress detrimentally effects plants which may lose up to 50% of dry matter accumulation (Hejnak et al., 2015).

Infrared thermometer based technology, can be used to assess various environmental and physiological parameters that affect crop productivity (Kacira et al., 2002). Indices have been developed to make efficient use of irrigation water based on 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 (Zarco-Tejada and Ustin, 2001; Ustin et al., 2004; Nemeskéri et al., 2015; Ihuoma and Madramootoo, 2019). 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. The CWSI is a practical tool that provide putative estimation of water stress experienced by given plant at a specific moment. The concept assumes that rapidly reducing soil moisture from root zone, acts to correspondently reduce plant transpiration which reversely increases plant's leaves and canopy temperature. Opposite phenomenon happens when one the other hand moisture increases in soil profile. Fluctuation of leaf temperature resulting from stress constitutes basis for using infrared thermometry to assess plant water stress (Aston and Van Bavel, 1972; Bartholic et al., 1972; Idso and Ehrler, 1976; Blad and Rosenberg, 1976; Ehrler et al., 1978; Idso et al., 1978), to schedule Irrigation (Jackson et al., 1977; Pinter and Reginato, 1982), and to predict yield (Idso et al., 1977, 1980, 1981b).

Empirical Crop Water Stress Index (CWSI) is a simple technic based on calculation made from plant's canopy temperature and Vapor Pressure Deficit data collected using infrared thermometry to measure air dryness (Jackson et al. 1981). The technic assesses plant water deficiency on basis of only two (2) factors. The environmental factors taken into account by empirical model are air temperature and the air vapor pressure deficit. Plant factor included in model is canopy temperature (Jackson et al., 1977; Idso et al., 1981a; Idso, 1982). Factors such as plant density, foliage density, plant growth stage, and plant height are not taken into account. Plant and foliage densities affect percentage of ground cover, and afterward percentage of reflected radiation. Above two (2) factors also influence composite temperature read by thermometer (Idso, 1982). Soil fraction of this composite varies with crop type and growth stage. As previously indicated, soil fraction is more important during early stage of plant development, before ground coverage is total (Ibid.). Plant height is very important to take into account for vapor pressure deficit is usually evaluated at 1 m above the vegetation cover (Ib.). It is fairly well established that the zone of zero displacement is at approximately two-thirds (2/3) of plant height (Oke, 1987). Above this height; the wind speed increases in a logarithmic fashion. So it is reasonable to think that at a meter above canopy, wind speed is higher than that experienced by plant. Thus, some adjustment of the vapor pressure deficit taken a meter above the canopy is needed. In addition, empirical model depends on air vapor pressure. Although relative humidity affects stomatal aperture and consequently transpiration, it is questionable as to how closely one can relate air vapor pressure deficit to the actual stress experienced by the plants.

Another concern with the empirical model is establishment of the baselines. Lower baseline is founded on non-stressed plants, and it is established by taking temperature and vapor pressure deficit readings over the course of a day or two. In a season, this lower baseline shifts upward or downward, depending on the plants' growth stage and flower development (Idso, 1982, Jackson, 1987). Estimation of upper limit of empirical model is based on ambiguous methods (Jackson, 1987).

The complexity linked to the determination of the upper limit was also reported by Idso (1982). How accurate can one be in determining the point at which transpiration has completely stopped and particularly how it is possible to take only canopy temperature readings when the plants are wilted beyond repair? A consequence of this wilting is the appearance of an extremely large soil fraction which undoubtedly influences the temperatures read by the thermometer.

To avoid such composite reading, one is reduced to taking very close readings with the aid of narrow opening thermometer. Once such readings are obtained, how representative are they of actual temperature experienced by the canopy as a whole? Is it reasonable to assume that single leaf temperatures of non-transpiring plants is identical to that of the whole canopy? Or should such temperatures be used only as good approximation of canopy temperature? In either case, using single leaf temperatures as representative of canopy temperatures ignores the fact that factors such as wind speed affect the canopy and the leaf differently. The canopy as a whole is more subject to turbulent air flow, eddies, and advective heat (Oke, 1987). Transpiration in a single leaf is more affected by laminar air flow that constantly moves the boundary layer.

Idso and Reginato (1982), and Choudhury (1986) showed that an inverse linear relationship exists between CWSI and net photosynthesis on cotton and Reginato (1983) observed similar relationships between CWSI and available water on guayule (*Parthenium argentatum*). Crop yield also appears to be linked to CWSI through an inverse relationship (Reginato, 1983).

A curvilinear relationship appears to exist between CWSI and stomatal conductance (Reginato, 1983) and between canopy net photosynthesis and CWSI given a high internal CO_2 concentration (Choudhury, 1986). Under low internal CO_2 the relation between CWSI and canopy net photosynthesis becomes more linear. In order to make good use of the CWSI in irrigation scheduling, Jackson (1982) suggested that irrigation should be applied when the CWSI value is between 0.3 to 0.50. Within this interval, vegetative growth rate is only reduced. The reduction depends on the plant species, nutrient availability, plants health etc. Above 0.5, growth will stop and yield loss may occur (Jackson, 1982). According to Rehman and colleagues (2021), major effects of water stress on cotton plants are lowered photosynthesis resulting from reduced leaf expansion, early leaf senescence, deteriorated photosynthetic machinery and reduction in food production. For better cotton production, availability of needed volume of water is compulsory for water shortage affects photosynthesis either positively, or negatively (Aujla et al., 2005). Negative effects on photosynthesis will decrease carbon uptake, and that translate to higher boll abscission (Aujla et al., 2005; Kuromori et al., 2010)

This study was undertaken to determine the stress indices which will result in highest lint production, while saving on water usage to grow field cotton. Previous workers have estimated stress level between .30 and .50 can be used for irrigation scheduling. Five Crop Water Stress Indices (.16, .30, .35, .36, .40, .62) were investigated to refine above range. Relationships between CWSI and plant heights, apparent photosynthesis, transpiration, and diffusive resistance activities and lint production were examined.

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 0.61 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. Overall, 134 Kg/ha of nitrogen were used on this field. Weeds were removed by hands.

Water treatment

Irrigation treatments were scheduled based on the crop water stress index (CWSI). CWSI values 0.16, 0.35, 0.40, 0.62, and 0.36 were respectively named Wet, Medium, Dry, Very dry, and Met treatments. These values represented the maximum water stress level each of the treatments was allowed to reach on the average. The above treatment names refer to the stress level at irrigation rather than to the amount of water applied. Irrigation was applied on the 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 season. That is 80 cm of water. Medium, Dry, and Met treatments were established as to receive adequate amount of water, within the range of what farmer's would use for proper irrigation. Treatments were each irrigated seven (7) times throughout season. They received 70, 73, and 69 cm of water respectively for the season. Plants in the very dry treatment were irrigated 6 times, which amounted to 67 cm of water applied. 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 Interscience Surface Thermometer was used. This infrared gun remotely sensed temperature at crop canopy. Temperature differential was measured by viewing individual plot canopy at an angle about 30° from the horizontal, between 10h00 in morning to solar noon. Prior to canopy establishment (first flower stage), individual leaf temperatures were recorded instead of partial canopy temperatures. For all readings, thermometer was set at the fast position for instantaneous temperature. Data were recorded upon stabilization of temperatures read. Temperature was measured on both east and west sides of each plot. Temperatures were measured while walking either northward or southward within an alley. To avoid background variability effects on readings, same areas were measured throughout season. These areas were marked by flags delimitating a 2 m^2 area. These 2 m^2 areas were reserved for data collection.

Vapor pressure deficit was recorded once canopy temperature was obtained for half of field.

Although thermometer was calibrated by the manufacturer, its calibration was frequently checked against that of a calibration box using procedures recommended by manufacturer. Vapor pressure deficit (VPD) was calculated using wet and dry bulb method. Wet and dry bulb temperatures were obtained with a portable electric psychrometer.

Soil moisture measurement

Soil moisture was measured on third row from west side of each plot with a neutron probe 2 to 3 hours before canopy temperature was read. Neutron probe was used to determine amount of soil moisture depleted on first four treatments (Wet, Medium, Dry, and Very Dry). Soil moisture readings were taken only at 30, 61, 91 cm. For Met treatment, amount of water needed to bring plots to field capacity was established through consumptive use method. CWSI value of each plot was calculated using empirical method (Idso et al., 1980).

Phenologic data collection

Field data were collected over 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. Daily colored plastic tags were used to follow same individual plant throughout season for phenology data collection (flowering, boll setting dates and number).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.

Daily dropped tags on ground were picked up and collection of 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 also was measured weekly on three (3) randomly hand-picked plants within the flag delimited area of 2 m^2 were taken every Wednesday, starting on week 2 of tagging, and stopped on week 8 of the plant's tagging period, because of lodging problems observed in wet treatments.

Metabolic activities measurements

Photosynthesis, transpiration, and diffusive resistance data were collected 26 August and 11 September. LiCor steady state porometer was used to obtain leaf transpiration (µg $cm^{-2}s^{-1}$), diffusive resistance (s cm^{-1}), cuvette temperature (°C), and leaf temperature (°C). Data were collected between 11h00 and 14h00 on both 26 August and 11 September. Data were read on first or second fully developed leaves of selected plants. Leaves selected were fully exposed to sun light and in good health. Selected leaf was enclosed between broadleaf aperture cap and cuvette. Enclosure was done in such a way that thermocouple surmounting cuvette was on abaxial side of leaf. Data were recorded upon stabilization of readings, which usually occurred in about 20 seconds.

C02 gas exchange data were obtained with syringe method (Clegg et al., 1978, Ehleringer and Cook, 1980, Cock et al., 1985). Plexiglas leaf chamber with an internal volume 2.36 liters enclosed an upper, sunlit, and fully developed leaf. Chamber gases were circulated with small battery driven fan. Air inside chamber was sucked out with syringes. Syringes penetrated chamber through two (2) rubber septa mounted on one side of plexiglas chamber. Leaf was inserted in chamber in such a way that petiole passed through sealed opening on side opposite to syringes. Fan was turned on after leaf was properly enclosed in chamber. First syringe was pulled 5 seconds after motor was turned on. Second syringe was pulled 30 seconds later. Syringes were then removed from chamber, stopped with rubber stopper, and placed in ice container. The leaf was clipped and inserted within a plastic bag which was placed on ice. In each plots, photosynthesis and porometer data were collected on three (3) plants located on same tagged row.

CO_2 content of each syringe was determined with an open system infrared gas analyzer. The system included a nitrogen gas carrier, a drying column for water removal, an infrared gas analyzer, a fluke multimeter, and flow meter. Prior to readings, system was calibrated using gases from two (2) standard tanks containing 411 and 354 ppm CO_2. The leaf area was measured with a LICOR area meter. Upon measurement of area, leaf dry weight was determined following 36 hours drying period. Leaves were dried in constant temperature cabinet at 75 °C, then weighted on an electric scale.

Collected data were analyzed using Statistical Analysis System (SAS) software package. Means were separated using Least Significant Difference technique for smaller samples size, and Duncan's Multiple Range (DMR) test for large samples size. Linear correlations were performed to study relationships between variables.

Results and discussions

CROP WATER STRESS INDEX (CWSI)

Five water stress levels were established using Crop Water Stress Index (CWSI). Treatments were designated Wet, Medium, Dry, Very Dry and Met on basis of CWSI level at which plants were irrigated (Table 1). Wet treatment was established to receive abundant water, much in excess of plants need. Wet treatment was irrigated 10 times during the season which totalized to 80 cm of water applied. Medium, Dry, and Met treatments were established as to receive adequate amount of water, within range of what a farmer would use for proper irrigation (Table 2). Latter treatments were each irrigated 7 times throughout the season and received 70, 73, and 69 cm of water respectively for whole season. Plants in Very Dry treatment were irrigated 6 times and that was a volume of 67 cm of applied water (Table 2). Applied water stress level (CWSI=.16) for irrigation of Wet treatment was significantly lower than that of others treatments, and level (CWSI=.62) of the Very Dry treatment was highest (Table 2). Levels for Medium, Dry and Met were statistically not different. Seasonal CWSI values and average applied water values, in all treatments, same trend as irrigation CWSI was observed (Table 2). With regards to daily estimation of CWSI values of each treatment, over the season, lowest CWSI values were obtained in wet treatment, and highest in the very dry treatment, excepted for first week of data collection (Table 3). Indeed, 66 days after crop establishment, there was no difference among CWSI values of all treatment (p-value=.11). Measurements of days 70 and 74 after planting gave

Table 1: Treatments and seasonal Crop Water Stress indices

TREATMENTS	SEASONAL CWSI	IRRIGATION CWSI
Wet	.04	.16
Medium	.11	.35
Dry	.13	.40
Very dry	.22	.62
Met.	.14	.36

Table 2: Seasonal and irrigation CWSI, number of irrigation and quantity of applied irrigation water.

Variables	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).

Table 3: Daily CWSI Values of each treatment

Days after planting	Treatments					p-Value
	Wet	Medium	Dry	Very Dry	Met.	
66	.048	.0820	.10	.14	.12	.11
70	.025 b	.093 a+	.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).

non-significant difference in CWSI values of all treatments, excepted wet treatment which was significantly lower than others (Table 3).

In first four (4) treatments, I mean Wet, Med, Dry and Very Dry, soil moisture depletion was measured with a neutron probe. For fifth treatment, amount depleted was based on cotton consumptive use of water. Values shown in Table 4 represent average water stress indices at which plants were maintained for the season. But, treatments were actually established at maximum water stress indices kept 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.

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). During the water deficit monitoring term of 50 days, from day 66 after planting to day 116, Wet treatment displayed on average water deficit of 5.5, and Met treatment 8.2. As for medium, dry and very dry treatments, their averaged water deficit were 7.3, 7.6 and 7.7 respectfully (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).

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
111	5.51c	7.24 b	7.59 ab	7.62 ab	8.26 a	.0001
116	5.33 c	7.24 b	7.75 ab	5.26 a	7.82 ab	.0001
Monitoring Term	*Average Soil Water Deficit*					
50	5.5	7.3	7.6	7.7	8.2	

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

Metabolic activities and CWSI

Analysis of mid-season (26th August) photosynthesis and transpiration data shows significant but conflicting results (Table 5). While plants in wet treatment were transpiring most, their photosynthesis rate of 20.31 $mg/dm^2/h$ was among lowest of set, second only to that of Met treatment at rate of 18.93 $mg/dm^2/h$, the lowest. Higher transpiration rates indicate more widely opened stomata (Jackson et al., 1977; Ullah et al., 2017; Rehman, et al., 2021; Tombesi, et al., 2022). Under such conditions, it is reasonable to expect photosynthesis rates higher than those actually measured for wet treatment. Higher photosynthesis rates were observed in medium dry and met treatments with 25.75, 26.53 and 23.21

mg/dm^2/h respectively. Prior to photosynthesis measurement, wet treatment was last irrigated on 19 August, medium and dry treatments on 18 August, and very dry and Met treatment on 13th August. Water deficits on days photosynthesis was measured (day 111 on Table 4) were lowest in wet treatment. So above irrigation dates and soil water deficit indicate that wet treatment should photosynthesize more. Low photosynthesis rates could be due to errors inherent to the technique or errors arising from user. Operator errors could be improper timing between syringes both in field and in lab, inadequate sealing of plastic chamber, or unhealthy leaves. Low canopy temperature and high transpiration rate occurring in wet treatment, indicate that stomata of these plants

Table 5: Photosynthesis, transpiration, diffusive resistance, and leaf area (26th August).

Days after planting	Treatments					p-Value
	Wet	Medium	Dry	Very Dry	Met	
App. Phot. (mg/dm^2/h)	20.31 b+	25.75 a	26.53 a	23.21ab	18.93 b	.0110
App. Phot. (mg/g^2/h)	31.71bc	41.19 a	40.17 ab	30.04 c	27.41 c	.0154
Transpiration (µg/cm^2/s)	27.78 a	24. 66 ab	20.30 abc	17.92 c	22.14 bc	.0900
Diff. Resis. (s/cm)	.61 a	.73 ab	.90 bc	1.36 c	.74 ab	.1000
Leaf Area (dm^2)	.95	.85	.83	.89	.89	.7900
Leaf Temp. (°C)	30.1 c	30.4 bc	31.1 ab	31.4 a	30.6 abc	.00670
Leaf Dry Weight (g)	.61	.57	.55	.68	.63	.6300
Cuvette Temp. (°C)	32.0 a	31.9 a	32.1 a	32.0 a	31.9 a	.0001
CWSI++	.41	.47	.46	.60	.60	.1630

+Values followed by same letter within a row are not statistically different based on LSD Mean separation technique (p=.05).
++ CWSI calculated based on theoretical model
App. Phot.: apparent photosynthesis
Diff. Resis.: Diffusive resistance

were widely opened. High gas exchange rates are expected when stomata are open (Jackson et al., 1977; Ullah et al., 2017; Rehman, et al., 2021; Tombesi, et al., 2022). So low photosynthesis rates observed in wet treatment could be an artifact due to single leaf photosynthesis measurement. Transpiration rates were highest in wet treatment and lowest in very dry treatment. Transpiration rate decreases with increasing CWSI level (Fig. 1). Conversely, diffusive resistance and leaf temperature increased linearly with increasing CWSI values, treatment differences were not statistically significant though (Table 5). There was no significant difference between leaf area and dry weight of plants in all treatments. However it is interesting to note leaves of plants in wet treatment produced 6% more area than those in very dry treatment, and that they weighed 10% less. This could result from higher cell numbers per unit leaf area, and heavier cell materials resulting from water stress in very dry treatment (Cutler et al., 1977; 1978; Osakabe et al., 2014).

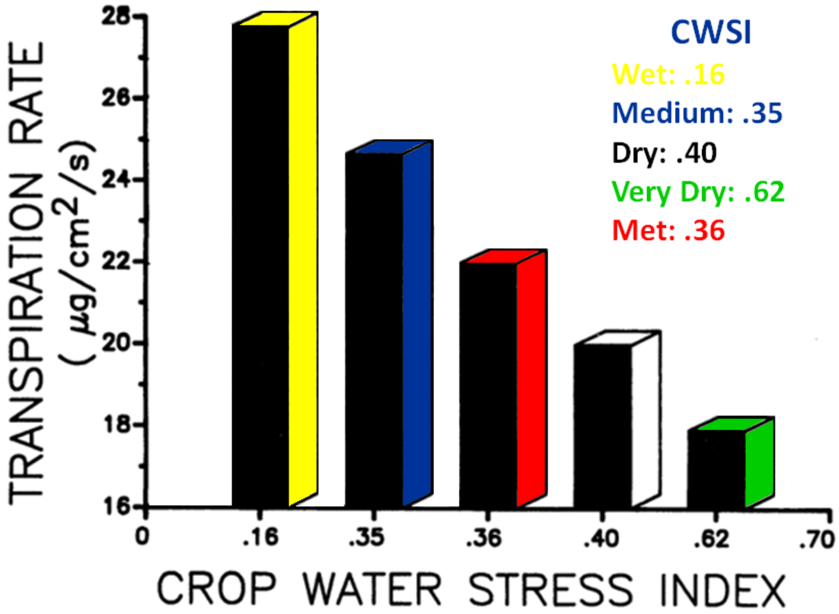

Figure 1. Relationships between transpiration and CWSI (Based on 26th August data)

Under stress (salt or water), cells produce large and heavier stress proteins such as proline and betaine, which help cells to osmotically adjust so that metabolic activities can proceed in spite of the stress (Brown et al., 1976; Jones and Gorham, 1983). Photosynthesis data obtained on 11th September (Table 6) show no significant difference in photosynthetic rate of all plants. Furthermore there was no trend between photosynthesis and treatments CWSI values. This lack of trend is attributable to senescence observed in most treatments. In addition to leaf senescence, high degree of lodging was observed in wet treatment. Decrease in average temperature from 41°C in mid-July, to 26°C in early September triggered fungal (*Verticilium dhalia*) attack on wet treatment. Cool temperatures and wet conditions prompt *v. dhalia* attack on susceptible crop such as *G. hirsutum* L (Gutierrez and Devay, 1986). The disease was not severe enough to significantly reduce crop yield however. Above factors could be cause of inconsistency in data in relation to maximum CWSI values. Inverse relationship observed between large leaf areas of plants in wet

Table 6: Photosynthesis, transpiration, diffusive resistance, and leaf area (11th September) August).

Days after planting	Treatments					p-Value
	Wet	Medium	Dry	Very Dry	Met.	
App. Phot. (mg/dm2/h)	12.41	17.35	16.06	22.7	22.0	.4300
App. Phot, (mg/g^2/h)	18.8	23.7	20.8	27.0	28.0	.6400
Transpiration (µg/cm^2/s)	14.32 bc	14.03 c+	15.96 bc	19.47 ab	21.55 a	.0420
Diff. Resis. (s/cm)	2.87 a	2.79 a	2.07 ab	1.71 b	1.50 b	.0488
Leaf Area (dm^2)	.80 a	.76 a	.73 a	.75 a	.80 a	.0540
Leaf Temp. (°C)	37.0 a	36.8 ab	36.1 abc	35.5 c	35.8 ab	.0430
Leaf Dry Weight (g)	.53 a	.58a	.58a	.65 a	.62 a	.0470
Cuvette Temp. (°C)	37.1a	372 a	36 a	36.6 a	37.1a	.0140

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

++ CWSI calculated based on theoretical model

treatment and high dry weight of plants in very dry treatment was again observed on 11th September (Table 6). This inverse relationship is definitely an indication that plants irrigated at stress levels above .60 have tendency of producing heavier cells than those irrigated at stress indexes below .16. Although analysis of variance of both leaf dry weight and leaf area were significant at 5% level, treatment means were not far apart enough for LSD-test to segregate them into distinct groups. Apparent photosynthesis data collected on 26th August and 11th September (Tables 5, and 6), indicate that though plants in wet treatment were still setting new flowers late in season, photosynthesis occurring in these plants was not high enough to produce extra assimilates needed to ensure growth and development of these newly produced bolls. Furthermore the photosynthetic demand by bolls set three (3) weeks prior to 26th August was at its highest. Thus, assimilates produced in upper canopy were drawn to feed bolls located within middle to lower canopy. Pinkhasov (1981) and Pinkhasov and Khoang (1981) indicated that this down drawing of assimilates by maturing boll in mid-canopy is enough to cause shedding of about 80% of the newly set bolls. This explains high percentage of boll abortion observed in wet treatments, following 8th week of flowering (Fig. 2). During last few weeks of flowering these plants aborted 70 to 100% of flowers set during this period. Following 28th August when all treatments were irrigated, water was turned off on all treatments until 1st October when all treatments were last irrigated. Lack of irrigation water and any significant rainfall during the period extending from 31st August to 11th September, reduced almost by half plants apparent photosynthesis, transpiration, diffusive resistance as they relate to activities on 26th

August (Tables 5, and 6). Reduction of plants photosynthesis and transpiration rates were visible in all treatments except for very dry and Met treatments. Prior to 1st October, all treatments were last irrigated on 28th August except very dry treatment which received water on 30th August. During period between 31st August and 11th September, Met and very dry treatments had significantly more soil moisture than the other treatments. Plants in these treatments had comparatively low diffusive resistance and high transpiration. This high transpiration and low diffusive resistance indicated that plants in Met and very dry treatments had their stomata opened wider than stomata of plants in wet, medium, and dry treatments. It appears that plants stressed to a CWSI value of .60 (very dry) recover and maintain high transpiration up to 10 days after irrigation. This number of days is calculated from last irrigation dates (28th and 31st August) to date photosynthesis and transpiration were measured (11th September). Although values presented in Tables 5 and 6 are within previously reported range (Bielorai and Hopmans, 1975; Cain, 1984; Radin et al., 1988), relatively high transpiration values for very dry and Met treatments can be questioned in light of previous work by Bielorai and Hopmans (1975). Indeed, their work showed that transpiration rate of plants stressed to wilting point (water potential of -1.62 MPa), peaks two days after irrigation at a rate three times greater than pre-irrigation values.

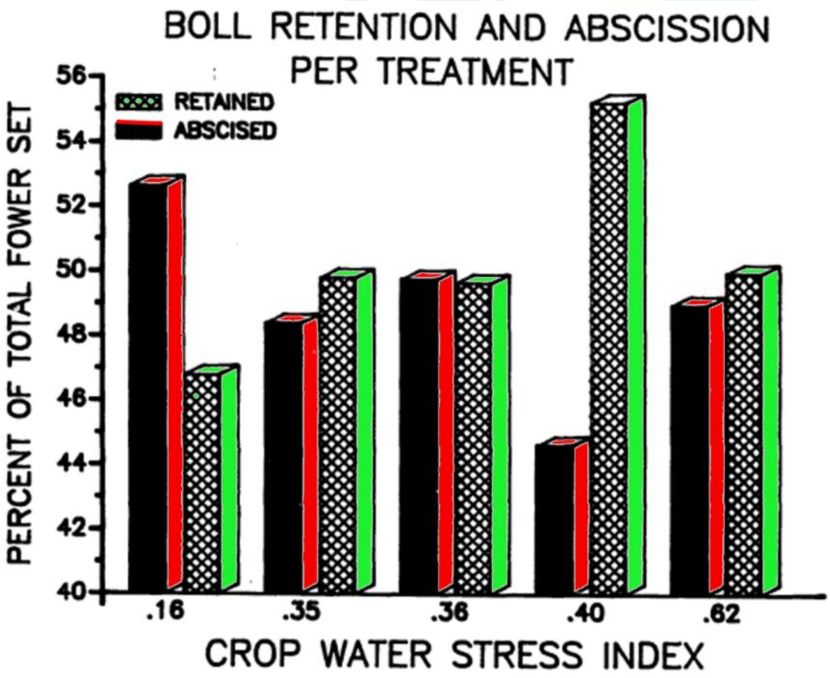

Figure 2. Relationships between total flower production, boll abscission, and boll retention. Irrigation and yield

CWSI, irrigation and yield

As previously indicated, actual denomination of treatments is with reference not to amount of water applied, but rather to stress level at which water was applied. There was no significant difference between amount of irrigation water applied to dry and medium treatments (Table 7). Plants in dry treatments were irrigated at a significantly higher stress level (.40). Both treatments were irrigated same number of times though. On basis of their respective irrigation time, plants in dry treatment deplete more soil moisture than those of medium treatment. Irrigating both treatments to field capacity required putting more water in dry treatment as compared to medium treatment. This explains why dry treatment received more water than medium. Wet treatment (.16) yielded 1.67 Mg/ha of lint. This yield is within range reported by Garrot et al. (1987) for plants held at crop water stress index level of .15. The relatively high lint yields of plants in wet treatment indicates that

Table 7: 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
Height (cm)	105 a	91 b	86 bc	80 c	82 bc	.0001
Seed cotton (Mg/ha)	4.76	4.20	4.54	3.76	4.62	.6471
Lint (Mg/ha)	1.67	1.70	1.72	1.41	1.72	.1112

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

at index values of .15 to .16, although they are associated with high irrigation frequencies, amount of water actually applied does not cause water logging problems. In response to high irrigation frequencies, plants in wet treatment produced significantly more vegetative growth as measured by plant height, than those in others treatments (Table 7). Since these plants produced more vegetative parts, fraction of their total assimilates which was devoted to reproductive parts was low as compared to what it would otherwise be under limited stress conditions. Consequence of that was relatively low yield of plants with high water, as compared to yield of plants irrigated at stress levels amid 0.35 to 0.40. Plants irrigated at 0.35, 0.36, and 0.40 yielded 1.70, 1.72, 1.72 Mg/ha of lint respectively. This relatively low yield of plants in wet treatment (Fig. 3) is in agreement with previous observations by Jordan (1986) who reported that yield increases parabolically with height. This mean plants at two extremes of vegetative growth have lower yield as opposed to high yield of plants with average vegetative growth. Vegetative growth alone may not account however for relatively low yield observed in wet treatment, compared to medium, dry and Met

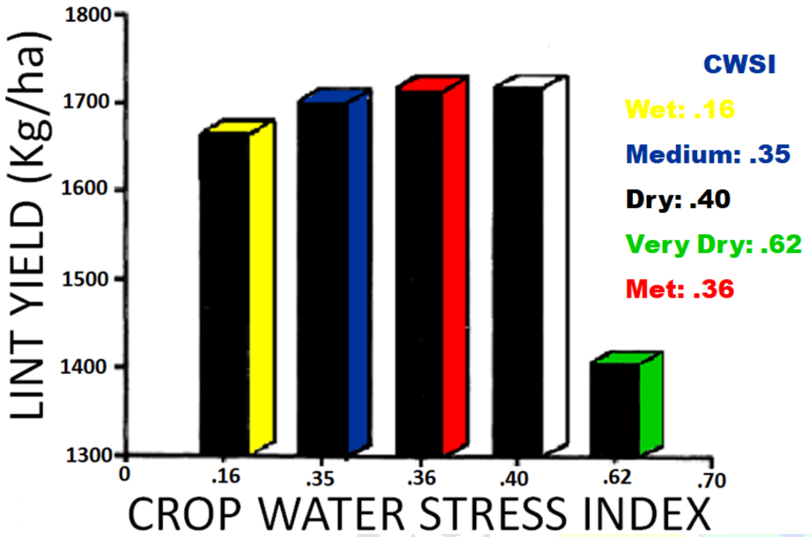

Figure 3. Relationships between lint production and CWSI.

treatments (Fig. 3). This is because analysis of flower production in wet treatment showed that though flower production was relatively slow compared to Met, dry, and very dry treatments during early flowering weeks, plants in this treatment steadily increased their average daily flowering as the season advanced. Daily floral production of wet treatment increased to 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 8). 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, a cotton plant sheds a large percentage of boll set (Bruce and Romkens, 1965; McMichael et al., 1973; Mauney et al., 1980; Guinn, 1998; Tariq et al., 2017). Shedding percentage found in wet treatment (53%) agrees with shedding percentage indicated by Rijiks (1965). This high boll shedding percentage observed in wet treatment was presumably 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 the highest percentage of bolls that matured to harvest. Lack of significant difference in water consumed by medium and dry treatments (Table 4) indicates that 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 7), 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. Plants within .35 to .40 stress indices, produced 63% of total lint harvested. These plants were able to achieve this high production performance as a result of their high boll retention and maturation percentage. Plants irrigated within these water stress indices were

Table 8: 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).

stimulated by their moderate water stress, to flower early and reach peak period early. Plants at extreme CWSI yielded relatively low as compared to plants irrigated in medium ranges (.35 to .40). Low yield of plants at extreme was mainly due to sharp increase in percentage of bolls abscised when stress levels were either above .40 or below .16. When stress index is over .40, yield decline is much sharper than yield decline resulting when stress level is below .16.

Reason for lesser decline in yield of plants irrigated around .16 is that under high soil moisture, plants may produce more flowers and bolls than they can nurture. So although they abscised about 53% of their flowers, the 47% which matured to harvest still represented considerably more lint. On the other hand, soil water deficit corresponding to stress level of .60 and above considerably reduced number of sympodia and fruiting sites by considerably depressing plant growth (Fig. 4, Table 7). Development of new sympodia is dependent upon vegetative growth of plants. Consequently, plants such as those in very dry treatment (0.62 stress level) with relatively low vegetative growth (Fig. 4, Table 7), do not

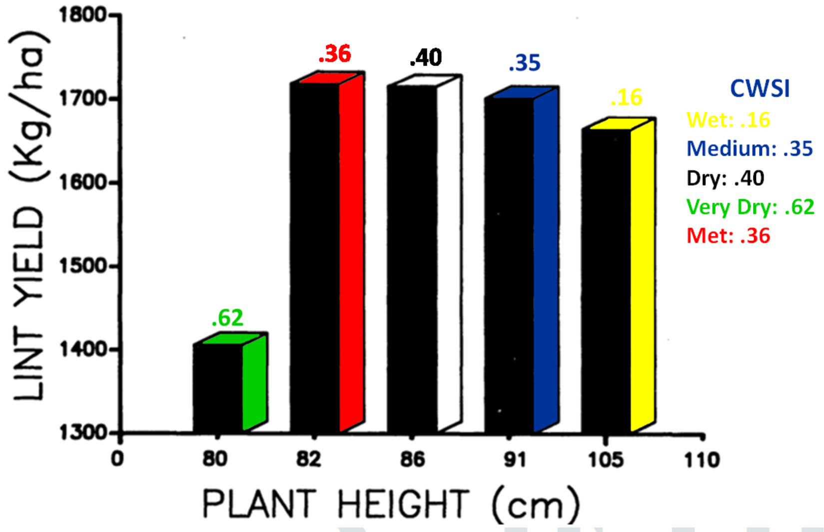

Figure 4*.Relationships between lint production and CWSI.*

have a canopy sufficiently developed to promote development of additional sympodia. These plants yielded 29% less lint than plants in best treatment (.40 stress level). Plants in wet treatment (.16 stress level) also had relatively low yield but high growth. These plants produced lesser lint and seed cotton than plants in optimum range (.35 to .40 stress level). This yield reduction may have been result of very high boll shedding that took place in this treatment. Nutritional insufficiency mentioned earlier is assumed to be cause of this high shedding (Tariq et al., 2017).

Correlations matrixes

Correlation matrixes presented on tables 9 and 10 are based on average responses of the

Table 9: Correlation matrix of water treatments, vegetative growth, yield and boll production and abscission

	Water def1.	Water def2.	Water Applied	Height	Yield	Bolls set	Retained Bolls	Aborted Bolls	CWSI
Water def1.		.987**	-.961**	-.961**	-.462	-.913*	-.790	-.941**	.940**
Water def2.	.987**		-.921*	-.994*	-.426	-.913*	-.695	-.903*	.927*
Water Applied	-.961**	-.921*		.927*	.418	.917*	.836+	.876*	-.862*

Height	-.961**	-.994*	.927*		.414	.827*	.683	.883*	-.916
Yield	-.462	-.426	.418	414		.607	.724	.412	-.721
Bolls set	-.913*	-.913*	.917*	.827*	.607		.961*	.935**	-.909*
Retained Bolls	-.790	-.695	.836+	.683	.724	.961*		.809+	-.841+
Aborted Bolls	-.941**	-.903*	.876*	.883*	.412	.935**	.809+		-.891*
CWSI	.940**	.927*	-.862*	-.916	-.721	-.909*	-.841+	-.891*	

** 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.

two (2) days metabolic activities were collected. As expected, strong negative correlation exists between boll production and CWSI (Table 9). 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 the seed cotton. No significant linear correlation exists between lint production and CWSI. This particular lack of significance is only true with regard to linear correlation. The nature of

Table 10: Correlation matrix of apparent photosynthesis, transpiration, and diffusive resistance

	APSl	APS2	Trans. Resis.	Diff. Resis.	Cuvette Temp.	Leaf Temp.	Leaf Area	Leaf Weight
APSl		.999***	.0481	.138	.806	.366	-.972*	-.909*
APS2	.999***		.0481	.124	.807	.359	-.977*	-.909*
Trans. Resis.	.0481	.0481		-.972*	-.528	-.915*	-.242	-.427
Diff. Resis.	.138	.124	-.972*		.652	.960*	.0826	.279
Cuvette Temp.	.806	.807	-.528	.652		.831	-.683	-.528
Leaf Temp.	.366	.359	-.915*	.960*	.831		-.168	.-528
Leaf Area	-.972*	-.977*	-.242	.0826	-.683	-.168		.980
Leaf Weight	-.909*	-.909*	-.427	.279	-.528	-.528	.980	

** Correlation coefficients significant at 1% error level
* Correlation coefficients significant at 5% error level
+ Correlation coefficients significant at 10% error level
APS1: Apparent photosynthesis leaf area based (mg/dm^2/h).
APS2: Apparent photosynthesis leaf dry weight based (mg/g/h).

relationship between lint production and CWSI is not linear but curvilinear (Fig. 5). This curvilinear relation shows a high coefficient of determination (R^2=.65; p=.001). Furthermore on a small field, with many differentially irrigated plots adjacent to each other, it is reasonable to expect presence of temperature and wind gradients across field. Such gradients could result from unequal amount of evapotranspiration proceeding in different treatments. In turn, these gradients could create enough wind turbulence above canopy as to affect canopy temperature readings. Water deficits measured in 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. Such correlations are to be expected for CWSI is a measure of plant response to existing soil water potential. Water deficit correlates well with most variables measured (Table 9). Lint yield on the other hand does not correlate with any

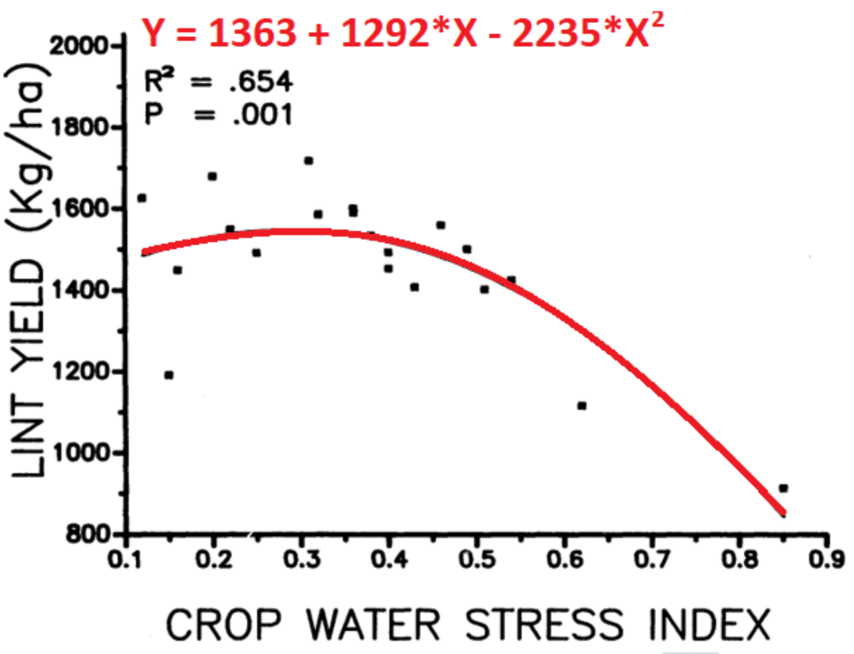

Figure 5. Quadratic relation between lint production and CWSI.

other variable. Plant height correlates positively with amount of water applied. Correlation coefficients in Table 10 do not show any significant associations between measured physiological parameters (transpiration, photosynthesis, and diffusive resistance) and CWSI. Several workers (Idso and Reginato, 1982; Idso et al., 1984; Choudhury, 1986; Ben-Gal, et al., 2009) reported close relationships between photosynthesis and CWSI. Lack of significant relationships between photosynthesis and CWSI (Table 10) is assumed to be due to imprecision of the technique used to measure field photosynthesis, and to limited readings taken during season. Photosynthesis data obtained on 11 September might have been also affected by senescence factor.

Summary

Cotton (*G. hirsutum* L) plants were exposed to selected water stress level throughout season as to study plant's responses to imposed moisture deficiencies. Water stress levels were established on basis of empirical CWSI (Idso et al., 1980). Irrigation treatments were scheduled based on crop water stress indices of 0.16, 0.35, 0.40, 0.62, and 0.36 labelled Wet, Medium, Dry, Very Dry, and Met treatments respectively. Treatment label refer to stress level at irrigation, rather than to amount of water applied. Irrigation was applied on the average when these values were reached. Throughout season, Wet treatment was irrigated 10 times which totalized to 80 cm of water applied. Medium, Dry, and Met treatments received adequate amount of water, within range of what farmer's would use for irrigation. Latter treatments were each irrigated 7 times throughout season and received 70, 73, and 69 cm of water respectively during whole season. Crops in Very Dry treatment were irrigated 6 times, and that amounted to applied water volume of 67 cm.

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. Flowering scheme followed traditional cotton flowering pattern. After peak flowering weeks, flower development steadily declined in all treatments until it ceased. Prior to cessation, flower production levelled off in all treatments. Daily flowering in wet treatment became significantly higher than that of other treatments only 36 days after flowering initiation. Daily flowering pattern of plants in medium, dry, and Met treatments displayed no significant difference. Plants irrigated at high water stress indices (.40, .62) peaked the earliest, and this imposed early water stress might have induced this premature high flower production through hormonal change. It is speculated that since under water stress, *G. hirsutum* L. produces ethylene, this might have caused this early peak of plants irrigated at high water stress indices. Following irrigation, two (2) days lag response was noticed before flowering increased.

During period of intense flower production, weekly flowering was over 100 flowers/m^2. Highest flower and boll production occurred at lowest stress level of .16, and lowest flowering of set at .62 water

stress level. High boll production in wet treatment did not translate to highest yield, for most of bolls set in wet treatment were abscised before maturation. Observed high boll abscission percentage could result from inability of plants in this treatment to generate enough assimilates to sustain need of the whole boll load. Lower boll retention in wet treatment could also result from high vegetative growth exhibited by plants in wet treatment. Lowest boll shedding was observed in dry treatment, maintained at .40 CWSI. Outcome of this high retention percentage was relatively higher lint production than in any other treatment. Boll retention percentage of medium, Met, and very dry treatments were similar.

With regards to lint production, there were no statistical differences between treatments means. Lint yield was 1.67, 1.70, 1.72, 1.72, and 1.41 Mg/ha for Wet, Medium, Dry, Met, and Very Dry respectively. Relationships between lint production and CWSI appeared to be non-linear, and was better described by quadratic formula. Lint yield was related to CWSI through $Yield = 1363 + 1292*(CWSI) - 2235*(CWSI)^2$. Predicted quadratic formula, fit data with a coefficient of determination R^2=0.65 and p-value=0.001. CWSI calculation based on 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. High variability observed within treatments lint production was an indication that used model was insensitive to others environmental factors not integrated into it. Treatment establishment is dear indication of usefulness of CWSI as irrigation management tool.

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