

Use of infrared thermometer for water stress detection in faba bean

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Abstract

Response of two faba bean (*Vicia faba* L.) cultivars, viz H72 and BB7 to water stress was studied by subjecting them to water stress duration for 24 days at vegetative stage (S₁), flowering or pod set (S₂) and pod filling stage (S₃) in a field experiment conducted for two successive seasons (1998-99 and 1999-00) at Hudeiba Research Station Farm. The different treatments were arranged in a factorial randomized complete block design. Vegetative growth attributes, reproductive structure abscission and crop phenology were examined. Soil moisture content, actual and potential daily evapotranspiration and crop coefficient values for different growth stages were monitored. Water use efficiency (WUE) was also calculated. The infrared thermometer was calibrated with the gravimetric method for soil moisture detection. The modified Penman equation was correlated with the canopy temperature difference (CTD). They were found to be well correlated ($r = 0.94$) and can be used for detection of water stress in faba bean.

Introduction

Measurements of plant water status can be made at both leaf and plant canopy levels. Such measurements should be more advantageous since crops respond to both soil and aerial environment (evaporative demand).

Research has shown that plant temperature is strongly influenced by plant water status. Canopy temperature (T_c) has been suggested as an indirect method of quantifying crop water stress. The use of canopy temperature to detect water stress is based on the principle that water lost through transpiration cools the leaves below the temperature of the surrounding air under well-watered conditions. As the soil water becomes limiting, transpiration is reduced and leaf temperature increases. If transpiration is greatly reduced or ceases, leaf temperature will be greater than air temperature because of radiation absorbed by the leaf. The handheld infrared thermometer (IRT) is a remotely sensed device that can be used to quickly and easily measure canopy temperature across a large area, at all levels of water stress (Jackson, 1982). The potential of IRT measurements of canopy temperatures for crop water deficit assessment were recognized as being increasingly popular (Hatfield, 1990). It was stated that the IRTs have become important tools in irrigation scheduling and irrigation water management. Fuchs and Tanner (1966) proposed the first basic technique to employ IRT-determined crop temperature to assess the severity of water deficit. They used the differences in (T_c) between various treatments, with a well-watered treatment usually providing the reference (T_c).

Clawson and Blad (1982) used the variability of replicate (T_c) measurements to indicate the level of water deficit. Of the remotely sensed techniques that have been developed, based on canopy minus air temperature ($T_c - T_a$) differential (ΔT), proposed the stress degree day (SDD) which is a timely once mid-day ($T_c - T_a$) measured throughout the season. Idso *et al* (1981a) and Jackson *et al.* (1981) further suggested a crop water stress index (CWSI) to account for the effect of the environmental factors especially the atmospheric vapour pressure deficit (VPD) and the net radiation (Rn). CWSI was based on

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the concept that for any given VPD measured, there is an upper and lower limit for the value ($T_c - T_a$). The relationship of ($T_c - T_a$) to VPD was termed the CWSI-baseline. It was stated that canopy temperature is genetically controlled and the technique (CWSI-baseline) could be used to screen wheat varieties for drought avoidance. The temperature stress day (TSD) index is defined as the canopy temperature of a crop minus the fully-irrigated crop canopy temperature that was measured on a daily basis throughout the growing season.

Results of Diaz *et al.* (1983) indicated that the three canopy temperature-based indices (SDD, TSD and CWSI) worked reasonably well in estimating wheat evapotranspiration and grain yield. They also found no index to be clearly superior to the other two. However, on the basis of the minimal data requirements, the SDD may be the most suitable for use in wheat yield and water use assessments. O'Toole *et al.* (1984) reported that ($T_c - T_a$) was the most accurate in terms of stability over time and sensitivity to the day time, compared to the (T_c) and the CWSI. They identified cotton germplasms that differ in their soil water use by using the (T_c) and $T_c - T_a$ differential of the IRTs in dry land environment Yazar *et al.* (1999) utilized the CWSI to evaluate crop water stress and estimate the water use efficiency of corn. Canopy minus air temperature differential was found to be inversely and linearly correlated with the evapotranspiration in both irrigated and unirrigated chickpea crops. Idso *et al.* (1977) found the canopy-to-air temperature differential to be related to the leaf water potential. Furthermore, Diaz *et al.* (1983) noted that evapotranspiration was inversely and linearly related to the cumulative SDD values for a variety of crops grown under water-stressed conditions. A quantitative comparison of the abilities of infrared thermometry and diffusion porometry (measures stomatal conductance) to distinguish differentially irrigated kidney beans plots, has suggested that water stress is more readily detected by the infrared thermometry (Walker and Hatfield, 1983). Working with rice, O'Toole *et al.* (1984) examined measurements indicating crop water at both leaf level, namely leaf water potential, stomatal resistance, transpiration rate and net photosynthesis (each detected with its measuring device), and crop canopy level (T_c , ($T_c - T_a$) and CWSI) remotely sensed infrared thermometry. The comparison of the two measurement sets pointed out the remotely sensed variables as the most useful techniques for the rapid and the non destructive/ disruptive measurements of the crop water stress than that of the pressure chamber measuring techniques.

The objective of this work was to use an infrared thermometer for detection of water stress at different phenological stages of faba bean. The study also aimed at correlating the average canopy temperature differences with monthly potential evapotranspiration.

Materials and methods

This study was carried out during the 1998-99 and 1999-00 seasons at Hudeiba Research Station Farm, River Nile State, about 300 km to the north of Khartoum (Latitude 17 34' N, Longitude 32 56' E, and Altitude of 351 m asl), Sudan. The climate of the locality is semi-arid with relatively cool and short winter season. The soil of the experimental site is classified as Karima series (order: Entisols, Fine loamy, mixed calcareous super active, hyperthermic, Typic torriflavent), with about 47% clay, 11% silt and 42% sand of a field capacity ranging from 34 to 38% and permanent wilting point from 16 to 18% (w/w) .

The gross plot size was 7x6.2 m; adjacent plots were arranged at 1.2 m space with earthen embankments, 45 cm high, surrounding each plot, to control irrigation water. The experimental design was a randomized complete block in a factorial arrangement with two factors. Treatments were composed of two faba bean cultivars, namely Hudeiba 72 (H72) and Basabeer (BB7), which were brought from the Breeding Department of Hudieiba Research Station, and four irrigation regimes; namely, irrigated control (S_0), stress at

vegetative stage, (S_1), stress at flowering stage (S_2) and stress at pod set stage (S_3)). Stress imposed on phenological stages was through skipping one irrigation at the specified stage. The experiment was replicated three times.

The daily reference crop evapotranspiration was obtained using the modified Penman's equation, as described by Doorenbos and Pruitt (1977)

Correlation studies and water stress evaluation

Canopy temperature differences (CTD) (Canopy minus air temperature, $T_c - T_a$) measurements were made using the IRT (Everset Inter science, INC; model No, 110 BL.) at the same time and manner that followed with the gravimetric method under clear skies. Measurements were made after the crop had attained full land surface cover (35 DAS to physiological maturity) during 1999-00 season. The instrument was held one-meter above the turf at an angle of 45° from horizontal. About 10 readings per plot were recorded of which 7 consecutive readings were chosen and the mean CTD for each plot was used in subsequent calculations. CTD measurements were not made in the first season, because of the lack of the electricity for charging the IRT. Correlation analysis was conducted between the gravimetric soil moisture content, and modified Penman equation and the infrared thermometer measurements to assess any potential relationships and calibrating the device.

Results and discussion

Actual and estimated (potential) crop evapotranspiration

Table 1 shows the actual evapotranspiration (ET_c) and the estimated (potential) evapotranspiration (ET_o) mm/day (of the modified Penman's combination) at different stages of growth and on monthly basis during the two seasons.

Under the 12 day irrigation interval (S_o), the daily mean ET_c values were low when plants were small and intercepted little of the net radiation, increased gradually as plants grew to a peak at pod filling stage (in January), and then decreasing at ripening. Water stress imposed at any stage during plant growth had reduced the daily mean ET_c values. The mean daily ET_o indicated moderate evapotranspiration early in the season, decreasing at flowering and pod set due to decreased air temperature and/or solar radiation. Thereafter, the mean daily ET_o increased until the end of the growing season along with air temperature and soil radiation

The standard 12 days irrigated crop (S_o) attained higher actual evapotranspiration (ET_c) at mid growth period (in January) than earlier or late period of growth. This is mainly because during the mid growth period plants used more water to satisfy the demand for peak growth rate. This also, coincided with the appearance and rapid development of pods. Similar explanation was stated by Fadl (1982) in the Gezira. El Nadi (1970) also stated that, a faba bean crop when grown under continuous wet regime during reproductive phases exhibited higher rates of evapotranspiration. Water stress treatments reduced the ET_c values, the reductions were harsh when water stress was imposed during the reproductive phases. Fadl (1982) recorded a reduction of about 38.8% in ET_c of a fortnightly irrigated faba bean compared to weekly irrigated crop during January in the Gezira. El Naim (1992) found that ET_c of an irrigated sunflower declined as the irrigation interval was extended. The increase in the potential evapotranspiration (ET_o) might have been due to the variation in climatic conditions. The same reason was stated by Allen *et al.* (1998) who reported that the only factors affecting ET_o were the climatic parameters.

Correlation studies and water stress evaluation

The general course of the correlated characters for the water stressed treatments at mid-and end-stress interval are shown in Tables 3 and 4. At mid-stress interval, the average canopy temperature differences CTD ($T_c - T_a$) and the monthly average potential evapotranspiration (ET_a mm/day) of the modified Penman's combination were low, while the gravimetric soil moisture content ($\theta m\%$) and the actual evapotranspiration (ET_c mm/day) were high. Whereas, at the end of the stress duration, a reverse pattern was observed (i.e. higher $T_c - T_a$ and ET_o and lower $\theta m\%$ and ET_c values).

Tables 5 and 6 show the linear regression equations and correlation coefficients (r) at mid and end-stress intervals between CTD measured in the morning (at 10:00 am) and afternoon at (1:00 pm), and the soil moisture content at 15, 30 and 45 cm soil depth, the ET_c and the ET_a .

Correlation analysis indicated that at mid- and end-stress intervals, non significant correlation coefficients were obtained between the CTD and $\theta m\%$ (of the different soil depths at both 10:00 am and 1:00 pm). Generally, the correlation coefficient values were increasing with the increase in soil depth. Negative correlations were observed when ($T_c - T_a$) was regressed on the soil moisture content at the 15 and 45 cm soil depth at the end stress duration. The correlation between the CTD and either of the ET_c and ET_a also followed the similar, non-significant, trend as that of the CTD and $\theta m\%$ at mid-stress interval. However, the correlation estimated between CTD and each of the ET_c and ET_a at the end of the stress interval showed highly significant, positive coefficients at both 10:00 (0.94 and 0.98) and 1:00 pm (0.94 and 0.94) for each variables respectively. Thus, 88.36% of the variation of the CTD at both 10:00 am and 1:00 pm were accounted for by the linear function of the actual evapotranspiration (ET_c). Whereas, 96.04% (at 10:00 am) and 88.36% of the variation in CTD at (1:00 pm) were due to the linear function of the potential evapotranspiration.

Trends in the canopy temperature differences CTD (i.e. $T_c - T_a$) values were consistent with the percent soil moisture content ($\theta m\%$), at mid-and end-stress intervals, in that the highest moisture levels showed the lowest stress level and smallest ($T_c - T_a$), while the lowest moisture level had the largest soil depletion (i.e. highest stress level) and greatest ($T_c - T_a$) values. The ($T_c - T_a$) values increased at the end of stress duration due to the decreased soil moisture content and the reduced evapotranspiration (ET_c). Similar trends in the measured $T_c - T_a$ of the crop water stress index (CWSI) were reported by Yazar *et al.* (1999) when evaluating water stress of corn. However, Throssell *et al.* (1987) found higher ($T_c - T_a$) values with bluegrass turf under water-stress conditions and attributed this to the greater depletion of the available water because of the longer irrigation interval. Jackson (1982) recorded an increased CTD values as the available soil moisture was depleted by wheat. Reductions in the actual evapotranspiration (ET_c), at the end of the stress interval may be attributed to the partial stomatal closure invoked by the foliage due to the water stress initiated through the longer irrigation interval. Whereas, the differences in the potential evapotranspiration (ET_o) between mid-and end stress intervals were mainly due to the differences in the climatic conditions. Allen *et al.*, (1998) reported that the only factors affecting (ET_o) are the climatic conditions. The highly significant correlation between the CTD and ET_c and ET_o at the end of the stress duration indicated that the CTD values were influenced mostly by the environment. Variability in the ($T_c - T_a$) values was found to depress the relationship between ($T_c - T_a$) and the vapour pressure deficit (VPD) to determine the remotely sensed (CWSI) of alfalfa (Idso *et al.*, 1977) and Kentucky bluegrass (Throssell *et al.*, 1987). Other possible reasons for the infrared readings variability were the VPD and the net radiation (Keener and Kircher, 1983). Wind speed was reported to be the primary factor causing erroneous estimation of canopy temperature and hence ($T_c - T_a$)

values (O'Toole and Hatfield, 1983). The ($T_c - T_a$) might have also been influenced by the warmer background soil, despite efforts to view only foliage. Variability in the measured gravimetric soil moisture content was also expected. Hatfield (1990) reported that canopy temperature of a crop must be dependent upon the amount of water remaining in the soil volume and is a function of the rate of water extraction.

Recommendation

Calibration of infrared thermometer with the gravimetric soil moisture procedure and the modified Penman equation of ET_o were highly correlated. The method, thus, may be recommended for use to monitor faba bean water stress.

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Table 1. Comparison of the mean daily evapotranspiration estimated by different methods for faba bean during 1998-99 and 1999-00 seasons

Month	E ₀ (nun/day)	ET ₀ (nun/day)	ET _c (mm/day)			
			S ₀	S ₁	S ₂	S ₃
November 1998	15.7	6.6	2.96	3.0	3.0	2.9
December 1998	13.5	5.7	3.67	2.4	3.6	3.5
January 1999	12.6	5.6	4.72	4.1	3.2	4.0
February 1999	15.3	7.5	3.34	3.3	3.2	2.9
Mean	14.3	6.4	3.60	3.2	3.3	3.3
November 1999	17.8	6.9	4.71	4.5	4.7	4.7
December 1999	13.2	6.2	4.82	3.8	3.9	4.7
January 2000	14.9	6.6	5.03	5.0	4.9	2.9
February 2000	18.2	7.8	3.19	3.0	3.1	2.7
Mean	16.0	6.9	4.51	4.1	4.2	3.7

E₀: Pan evaporation (mm/day), ET_c: Actual Evapotranspiration (mm/day)

ET₀: Modified Penman's estimated evapotranspiration (mm/day) on monthly basis.

Table 2. Comparison of the mean daily evapotranspiration estimated by different methods for faba bean during 1998-99 and 1999-00 seasons

Treatments	S ₀	S ₁	S ₂	S ₃
Month	ET _c /ET ₀	ET _c /ET ₀	ET _c /ET ₀	ET _c /ET ₀
November 1998	0.45	0.45	0.45	0.45
December 998	0.63	0.42	0.63	0.63
January 1999	0.82	0.74	0.57	0.72
February 1999	0.42	0.45	0.43	0.39
Mean	0.58	0.52	0.52	0.55
November 1999	0.68	0.65	0.68	0.68
December 1999	0.76	0.60	0.64	0.76
January 2000	0.76	0.76	0.73	0.44
February 2000	0.4\	0.38	0.41	0.35
Mean	0.65	0.60	0.61	0.56

ET_c: Actual Evapotranspiration (mm/day)

ET₀: Modified Penman's estimated evapotranspiration (mm/day) on monthly basis.

Table 3. Data set used for the assessment of the correlation between canopy temperature differences and the gravimetric soil moisture, the actual and potential evapotranspiration of faba bean under water-stress conditions during 1999-00 season, at mid-stress interval.

Treat.	θ m%			ET _o mm/day	ET _c mm/day	CTD(°C)	
	Soil depth (cm)					10:00 am	1 :00 pm
	15	30	45				
S0	14.2	1.4	23.6	3.1	6.24	2.3	1.1
S2	14.0	19.1	21.8	3.95	6.64	2.3	1.3
S3	17.0	19.9	20.7	7.12	6.64	2.1	1.6
SI	13.3	19.7	22.7	4.21	6.24	2.1	1.4
S2	14.8	18.4	20.7	4.37	6.64	1.6	0.6
S3	15.1	18.3	20.2	6.73	6.64	1.5	1.6
Mean	14.7	19.0	21.6	5.03	6.51	2.0	1.3

θ m%: Gravimetric soil moisture content, ET_c: Actual Evapotranspiration (mm/day)
 ET_a: Modified Penman's estimated evapotranspiration (mm/day), on monthly basis.
 CTD: Canopy temperature differences (T_c - T_a) °C

Table 4. Data set used for the assessment of the correlation between canopy temperature differences and the gravimetric soil moisture, the actual and potential evapotranspiration of faba bean under water-stress conditions during 1999-00 season, at end-stress duration

Treat.	θ m%			ET _o Mm/day	ET _c mm/day	CTD(°C)	
	Soil depth (cm)					10:00 am	1 :00 pm
	15	30	45				
SI	11.1	16.7	20.5	2.54	6.24	1.3	2.2
S2	9.6	15.4	17.5	3.06	6.64	1.5	3.8
S]	11.0	17.4	18.3	4.55	7.82	4.5	5.5
SI	10.9	16.6	21.2	2.63	6.24	0.8	3.5
S2	8.9	17.1	18.7	2.98	6.64	2.2	3.9
S]	10.1	16.5	19.0	4.41	7.82	6.1	5.6
Mean	10.3	16.6	19.2	3.36	6.90	2.7	4.1

θ m%: Gravimetric soil moisture content, ET_c: Actual Evapotranspiration (mm/day)
 ET_o: Modified Penman's estimated evapotranspiration (mm/day) on monthly basis.
 CTD: Canopy temperature differences (T_c - T_a) °C

Table 5. Regression equations and correlation coefficients of the canopy temperature differences on the gravimetric soil moisture content of faba beans under water-stress conditions at different stages of growth during 1999-00 season

Soil Depth (cm)	Mid-stress interval		End-stress interval	
	CTD		CTD	
	10:00 am	1 :00 pm	10:00 am	1 :00 pm
15	Y = 2.93-0.06X R = - 0.23 ns	Y = 0.09X-0.02 R = + 0.29 ns	Y = 3.11-0.4X r = - 0.01 ns	Y = 5.95-0.18X r = - 0.12 ns
30	Y = 0.24X -2.56 R = +0.48 ns	Y = 0.27X-3.83 r = + 0.50 ns	Y = 0.91X-12.41 r = + 0.3 ns	Y = 0.44X-3.2 r = + 0.24 IIS
45	Y = 0.2X- 2.32 R = + 0.75 ns	Y = 2.16-0.04X r = - 0.14 ns	Y = 13.84-0.58X r = - 0.39 ns	Y = 13.32-0.48X r = - 0.52 ns

Y = the canopy temperature differences ($T_c - T_a$) °C, X = Gravimetric soil moisture content (θ_m %), ns. = Not significantly different at 0.05 probability level.

Table 6. Regression equations and correlation coefficients of the canopy temperature differences on the actual and potential evapotranspiration of faba beans under water-stress conditions at different stages of growth during 1999-00 season

Correlation	Mid-stress interval	End-stress interval
CTDx Etc		
10:00 a.m	Y = 0.002X + 1.99 r = + 0.01 n.s	Y = 2.23X - 4.79 r = + 0.94**
1 :00 p.m.	Y = 0.16X + 1.00 r = + 0.63 n.s	Y = 1.37X - 0.50 r = + 0.94**
CTDx ET _o		
10:00 a.m	Y = 7.27 - 0.81X r = - 0.48 n.s	Y = 2.82X - 16.76 r = + 0.98**
1:00 p.m.	Y = 1.65X - 7.29 r = + 0.94**	Y = 0.07X + 0.84 r = + 0.04 n.s

Y = The canopy temperature differences ($T_c - T_a$) °C, X = Either actual (ET_c) or potential evapotranspiration (ET_o) mm/day, ns. = Not significantly different at 0.05 probability level, **: Correlation was significantly different at 0.01 probability level