THEORETICAL SIGNIFICANCE OF FIELD MEASUREMENTS OF RADIATIVE LEAF AND CANOPY TEMPERATURES

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ABSTRACT

The significance of the measurement of leaf and canopy temperatures was demonstrated analytically from energy and radiative balance equations. Theoretical leaf and canopy temperature was shown to be related to water status of the crop and the difference between canopy and air temperatures was related to the vapour pressure deficit of the air, the net radiation and the wind. Experimental work showed that up to a difference of 5 °C was observed between well watered and stressed treatments which confirmed the theoretical relationships.

INTRODUCTION

Physical transport phenomenon at the interface of the plant and the atmosphere depend upon the temperature of the plant temperature (Boissard et al., 1990; Campbell and Norman, 1990). Many research work have attempted to relate leaf temperature to water status of a plant (Fuch and Tanner, 1996; Olufayo et al., 1993). Early attempts have been characterised by sampling problems and instrumental errors. Soil and plant canopy temperatures are easily and rapidly measured using the infrared thermometry method. It is non-destructive and based on the fact that there is an atmospheric window between 8μm and 14μm and a valid relationship between absolute temperature and emitted radiance (Idso et al., 1977; Jackson, 1986).

The paper examines analytically, the theoretical significance of the measurement of leaf and canopy temperatures from energy and radiative balance equations with a view to justifying the experimental observations on sorghum and maize maintained at well-watered and stressed conditions.

THEORY

PHYSICAL BASIS BETWEEN LEAF AND CANOPY TEMPERATURE AND EVAPOTRANSPIRATION

Energy balance of a thin surface

The classical equation of energy balance at a given time in the daytime of a thin surface (bare soil or vegetative canopy) is given by (Figure 1):

$$Rn = G + H + \lambda E \qquad (1)$$

where

Rn is the net available energy (net radiation);
G - conductive heat flux (its magnitude is generally less than the other fluxes)
H - sensible heat flux
λL - latent heat flux) (corresponding to evaporation for a bare soil and evapotranspiration for a vegetative canopy)

The sensible heat flux can be expressed as :

$$H = h(T_s - T_a) = \rho C_p (T_s - T\ )/r_a \qquad (2)$$

where T_s and T_a are the temperatures of the surface and the air, respectively, h $(= \rho C_p / r_a)$ is the coefficient of turbulent transfer for heat, ρC_p is the volumetric heat capacity of air and r_a is an aerodynamic resistance (Jackson, et al., 1981, 1988).

Since the surface is thin, the equation can be applied directly at the surface level where radiative absorption and emission take place. Net radiation is the sum of incoming and outgoing radiation flux, that is,

$$Rn = R_S \downarrow - R_S \uparrow + R_L \downarrow - R_L \uparrow \qquad (3)$$

where the subscripts S and L signify solar (short-wave) radiation (0.15 to 4 μm) and long-wave (>4 μm) respectively. The arrow indicate the flux direction. This equation for the net radiation can also be expressed as various components of radiation exchanges:

$$Rn = (1 - a)R_S + \varepsilon R_a - \varepsilon \sigma T_s^{\ 4} \qquad (4)$$

where
R_s is the global radiation which is partly reflected depending on the surface albedo a;
σT_s^4 corresponds to the long wave radiation emitted by the surface
ε is the emissivity of the surface

(1982) to depend only on air temperature Ta. The upper and lower limits have been used to define a crop water stress index - CWSI (Idso, 1982; Soer, 1980).

EXPERIMENTAL WORK

Field measurements of canopy temperatures of sorghum maintained at well-watered and stressed conditions were carried out. The details of the experimental procedures are contained in Olufayo et al., (1993 a,b, 1994, and 1996). The measurements were carried out using a hand held infrared thermometer (TASCA OSAKA THI300, Japan) having a 10° field of view, a spectral range of 6 to 12µ and a resolution of 0.1°C. Reading were made at temperature of 30°C from the horizon. The diurnal measurements were carried out at intervals of time (15 - 30 min.). Canopy temperature was computed as the average of 10 readings.

Another experiment was performed in a green house at the Federal University of Technology, Akure on maize crop maintained at well watered and stressed condition (Olufayo et al., 1998). . Leaf temperature was measured using type K (Copper and Iron) thermocouple thermometer and measured on the upper side of the well exposed leaf (Ben-haj-salah and Tardieu, 1996). Measurements were taken daily at 8.00 a.m. and 2 p.m.

RESULTS AND DISCUSSION

Canopy temperature, and three-hourly averages of solar radiation, on a sunny day follow the same diurnal trend (Fig. 2). In general, canopy temperature in the stressed plot rises faster at forenoon. In both treatments maximum were observed about solar noon with higher values recorded in the stressed plot. At the other extreme, shortly before sunset the canopy temperature in the dry and wet plots falls to the same values. In all the diurnal measurements, the corresponding values of solar radiation when canopy temperatures of both treatments diverge in the morning is lower than the values when they converge at afternoon. This is due to the rapid rate of fall of canopy temperature of the stressed plot. The results can be explained by equation (12) above. It shows that transpired water evaporates and cools the leaves (Berliner et al., 1984). As water becomes limiting, transpiration is reduced and leaf temperature increases above air temperature because of absorbed radiation. Similar results were observed in a green house experiment at the Federal University of Technology, Akure on maize crop maintained at well watered and stressed condition (Olufayo et al., 1998). The difference between leaf and air temperature was higher in the case of stressed plant than in well watered plant (Fig. 3 and 4).

CONCLUSION

The measurement of leaf and canopy temperature have theoretical bases. It is the tangible manifestation of its energy balance and therefore affected by environmental and plant factors. The theory demonstrated that the difference in canopy and air temperature was indirectly related to evapotranspiration. In other words leaf/canopy temperature should be higher in a stressed plant than a well watered plant and was confirmed to be so in the case of sorghum and maize crop. This difference was as higher as 5 °C.

The use of portable radiothermometers provide a valuable tool in water stress research and practical irrigation scheduling practice.

APPENDIX 1

Recall that equations 1, 2 and 11 are given as:

$$Rn = G + H + \lambda E \qquad (1)$$

$$H = h(T_s - T_a) = \rho C_p (T_s - T)\, r_a \qquad (2)$$

$$\lambda E = \frac{\rho C_p}{\gamma} . \frac{e_c^* - e_a}{r_a + r_s} \qquad (11)$$

We know that the slope of the saturated vapour pressure, Δ is given as :

$$\Delta = \frac{e_c^* - e_a^*}{T_s - T_a} \qquad (A1)$$

This implies

$$e_c^* = \Delta(T_c - T_a) + e_a^* \qquad (A2)$$

Assuming G = 0 and substituting equations 2 and 11 in equation 1 it gives :

$$Rn = \frac{\rho C_p (T_c - T_a)}{r_a} + \frac{\rho C_p (e_c^* - e_a)}{\gamma(r_a + r_c)} \qquad (A3)$$

Substituting equation A2 in equation A3 we have,

$$Rn = \frac{\rho C_p (T_c - T_a)}{r_a} + \frac{\rho C_p [\Delta(T_c - T_a) + e_a^* - e_a]}{\gamma(r_a + r_c)} \qquad (A4)$$

$$= \frac{\rho C_p (T_c - T_a)}{r_a} + \frac{\rho C_p \Delta (T_c - T_a)}{\gamma(r_a + r_c)} + \frac{\rho C_p (e_a^8 - e_a)}{\gamma(r_a + r_c)}$$

$$Rn = \frac{\rho C_p\left(T_c - T_a\right)}{r_a}\left[1 + \frac{\Delta}{\gamma\left(1 + \frac{r_c}{r_a}\right)}\right] + \frac{\rho C_p\left(e_a^* - e_a\right)}{\gamma\left(r_a + r_c\right)} \qquad \text{(A5)}$$

$$= \frac{\rho C_p\left(T_c - T_a\right)}{r_a}\left[\frac{\gamma\left(1 + \frac{r_c}{r_a}\right) + \Delta}{\gamma\left(1 + \frac{r_c}{r_a}\right)}\right] + \frac{\rho C_p\left(e_a^* - e_a\right)}{\gamma\left(r_a + r_c\right)}$$

$$= \frac{\rho C_p}{r_a}\left[\left(T_c - T_a\right)\left[\frac{\gamma\left(1 + \frac{r_c}{r_a}\right) + \Delta}{\gamma\left(1 + \frac{r_c}{r_a}\right)}\right] + \frac{e_a^* - e_a}{\gamma\left(1 + \frac{r_c}{r_a}\right)}\right]$$

$$T_c - T_a = \frac{Rnr_a}{\rho C_p} \bullet \frac{\gamma\left(1 + \frac{r_c}{r_a}\right)}{\Delta + \gamma\left(1 + \frac{r_c}{r_a}\right)} - \frac{e_a^* - e_a}{\gamma\left(1 + \frac{r_c}{r_a}\right)} \bullet \frac{\gamma\left(1 + \frac{r_c}{r_a}\right)}{\Delta + \gamma\left(1 + \frac{r_c}{r_a}\right)} \qquad \text{(A6)}$$

Hence,

$$T_c - T_a = \frac{r_a R_n}{\rho C_p} . \frac{\gamma\left(1 + r_c/r_a\right)}{\Delta + \gamma\left(1 + r_c/r_a\right)} - \frac{\left(e_a^* - e_a\right)}{\Delta + \gamma\left(1 + r_c/r_a\right)} \qquad \text{(12)}$$

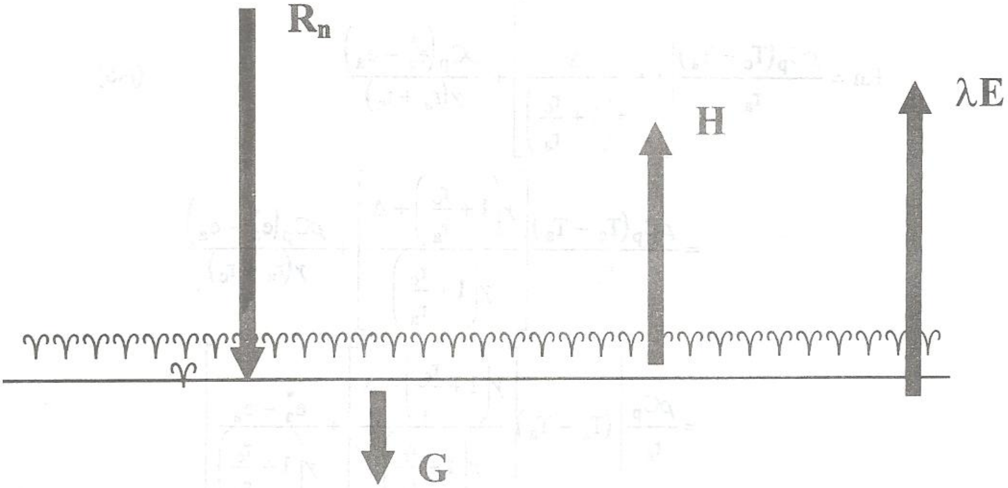

Fig. 1. Energy balance components during daytime

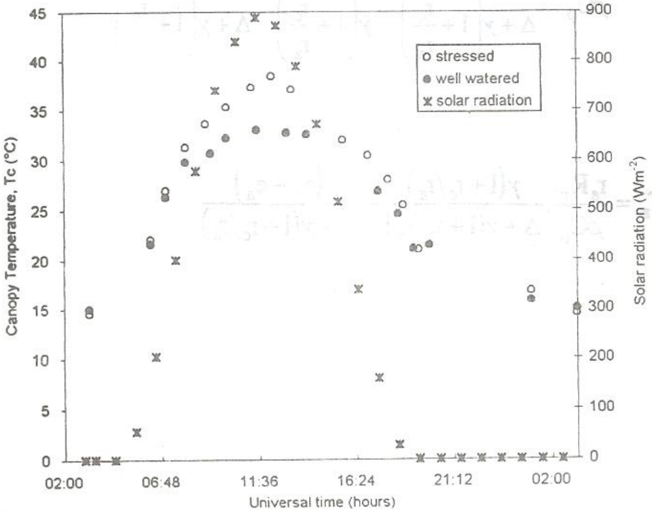

Fig 2 Solar radiation and Diurnal course of canopy temperature under stressed and well watered sorghum.

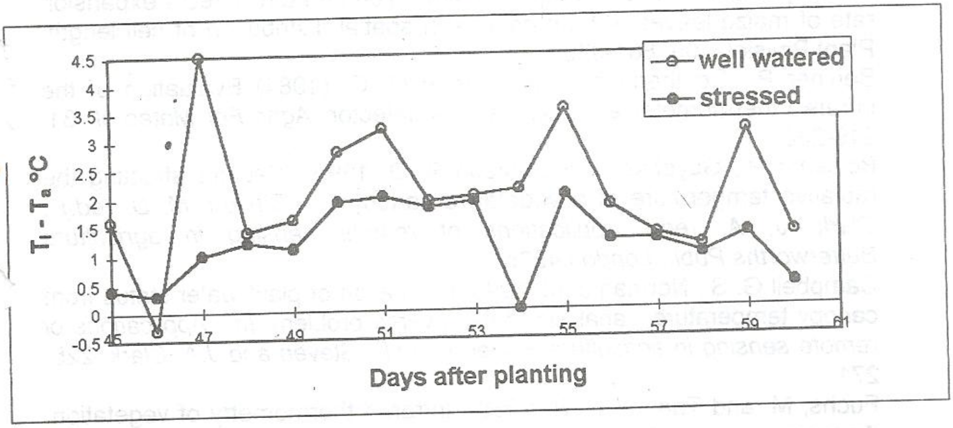

Fig3. Leaf minus Air temperature difference (T_1 - T_a) under well watered and stressed maize crop at 8.00a.m.

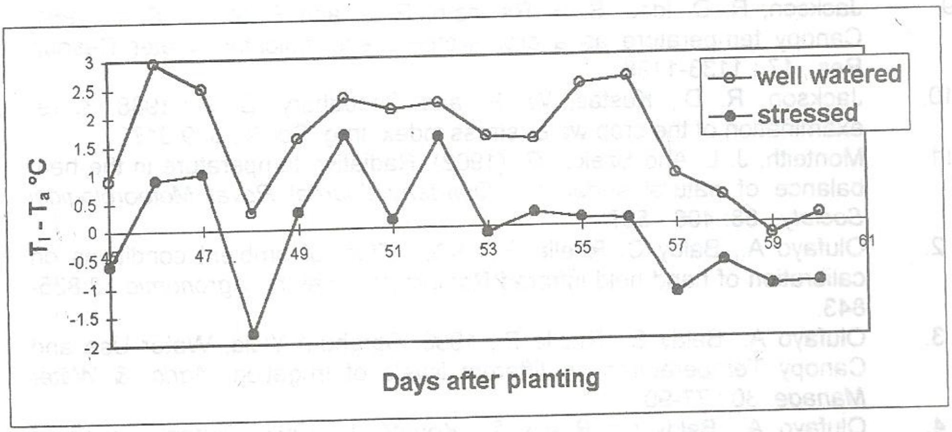

Fig 4 Leaf minus Air temperature difference (T_1 - T_a) under well watered and stressed maize crop at 2.00p.m.

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