A "TWO LEAF MODEL" FOR MAIZE CANOPY WATER LOSS ESTIMATON UNDER VARIED WATER STRESS[1]

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ABSTRACT

The precise estimation of transpiration from plant canopies is important for the monitoring of crop water usage and management of many agricultural operations related to the water use planning. The aim of this study was to estimate transpiration from sunlit and shaded fractions of a maize (*Zea mays L.*) canopy by expanding the Penman-Monteith energy balance equation ("big leaf model") to a "two leaf model". This was implemented in line with the research by Fuchs et al. (1987) and Fuchs & Cohen (1989). Results showed that computed transpiration of the shaded canopy ranged from 27% to 45% for the total transpiration when considered fluctuation of atmospheric demand and water stress condition. Hourly and daily estimation of transpiration showed agreement with lysimeter and heat pulse measurement on the well-watered plots. For the water-limited plots estimation efficiency decreased due to difficulties in simulating the canopy stomatal conductance.

Keywords: Transpiration, irrigation, Penman-Monteith

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INTRODUCTION

Progress in the automation of meteorological network data has provided an opportunity for improved management of agricultural systems. Dissemination of information can be used to assist in the monitoring of several key operational areas, such as the usage of water. Moreover, the introduction of automated irrigation systems contributed to an accurate control of the timing and amount of water provided. However, these new technologies require real time determination of crop water usage at field level. Timely application of water is an important aspect of an efficient crop production. The efficiency of water usage can be maximized and losses from deep percolation can be avoided if precise application of water is implemented.

Measurement of evapotranspiration with micrometeorological devices, such as lysimeters or heat tracer methods for detecting sap flow, while precise are generally restricted in their usefulness to research, due to the high costs involved and difficulties in field level routine application. It is easier to estimate evapotranspiration of crops through indicators of atmospheric evaporative demand and plant parameters.

Because shaded leaves comprise a large fraction of the leaf area in the later stages of the growing season, their overall water loss may be significant, since even in low irradiance the stomata still have some degree of aperture, mainly driven by the blue light (Zeiger & Field, 1982).

In maize, the most critical stages in relation to water stress is from the beginning of flowering to the end of grain filling (Matzenauer et al., 1995), when the crop foliage has covered the soil and therefore the shaded fraction is significant. It is necessary to investigate the aspects of transpiration in this portion of canopy in order to achieve precise monitoring of water usage.

The objective of this study was to provide a simple computation of transpiration from the sunlit and shaded fractions of a maize canopy using the Penman-Monteith energy balance equation.

MATERIAL AND METHODS

Local, time, crop and irrigation

The study was conducted during the growing seasons of 1995/96 and 1996/97 in a 0.5 ha experimental area of maize *(Zea mays L.)*, Hybrid Pioneer, in Eldorado do Sul, RS, South of Brazil (30^0 05’S 51^o 39’W, 46 m). The maize was planted in rows of 0.75 m spacing, (67,000 plants/ha) during mid-October in both years. Water was applied by an in-line sprinkler irrigation system. Three experimental plots (5 replications) were used to study maize transpiration: a well-watered which was maintained at field capacity throughout the experiment and two water-limited plots. At 1 of these 2 water-limited plots irrigation was not applied and severe moisture stress was allowed to develop.

Environmental measurements

A steady state porometer was used to measure stomatal conductance. Leaf water potential was measured with a pressure chamber. Soil water potential was monitored with mercury manometer tensiometers. Photosynthetically active radiation (PAR) and wind speed profile was measured, considering the top of sunlit and shaded canopy. Global radiation, air temperature and humidity were also monitored.

A relationship between absorbed photosynthetically active radiation (PAR) and leaf conductance for varied water stress was adjusted. A heat pulse system was used to measure the maize stem sap flow and provide independent field validations. A weighing lysimeter was also used when non-water stress condition was considered.

Model

Transpiration (W/m^2) was calculated separately for sunlit and shaded leaves in accordance with the Penman-Monteith energy balance equation (Monteith, 1965) as:

$$Tr = \{[(s/s+g)Rn] + [rCp(e(T_a) - e_a)/(s+g)(1/g_v)]\}/\{1+[(g/g+s)(g_v/g_s)]\} \qquad [1]$$

With **s** being the slope of the saturation vapor pressure curve (KPa/^{o}K), **γ** the psychometric constant (Kpa/^{o}K), **Rn** the net radiation flux density at the surface of the sunlit or shaded leaves (W/m^2), **ρ** the density of air (Kg/m^3), **Cp** the specific heat of air (J/Kg ^{o}K), **e(T$_a$)** the saturation water vapor pressure at air temperature(KPa) and **e$_a$** the actual water vapor pressure of the air (KPa). The aerodynamic conductance (g_v) for the transport of vapor of the sunlit and shaded canopy is a function of the leaf boundary layer conductance (g_b) and the turbulent transfer coefficient (g_a).

The leaf boundary layer conductance of a leaf is (e.g. Gates, 1980):

$$g_b = 300\left(\frac{U}{d}\right)^{0.5} \qquad [2]$$

with **d** being the average width of maize leaf and **U** the wind speed as computed at the top of sunlit or shaded canopy.

The turbulent transfer coefficient (g_a) for the crop was computed according to Monteith (1975):

$$g_a = k^2 U / \{[\ln(z-d)/z_0][\ln(z-d)/z_E]\} \tag{3}$$

with **k** = 0.41 as the Von Karman constant for turbulent diffusion, **U** is the wind speed (m/s) measured at height **z**(m), **d** is the displacement height (m), $\mathbf{z_0}$ is the roughness length, $\mathbf{z_E}$ the roughness length for sensible heat transfer (m). The d and $\mathbf{z_0}$ were calculated from the wind profile and $\mathbf{z_E}$ was taken as 20% of Z_0 (Garrat & Hicks, 1973).

The g_b conductance was connected in parallel through the entire sunlit or shaded leaf area and in series with g_a (Thom, 1975) to express g_v :

$$g_v = (g_a) + (g_b LAI_\Delta) \tag{4}$$

with LAI_Δ being either the sunlit or shaded leaf area index.

Integrated stomatal conductance of the foliage, g_s (m/s) was determined as:

$$g_s = g_f LAI_\Delta \tag{5}$$

where g_f is the stomatal conductance of either a sunlit or shaded leaf and LAI_Δ is either sunlit or shaded leaf area index.

Leaf conductance for varied water stress conditions was determined in the field and adjusted to PAR (μmol/m^2.s) according to the Gates' model (1980).

Sunlit leaf area (LAI*) was estimated from the total leaf area index (LAI), assuming a spherical leaf angle distribution (Lemeur, 1973):

$$LAI^* = [1 - EXP(-fLAI)]/f \tag{6}$$

with *f* being the mean horizontal area of shad cast by a unit leaf area and according to Monteith (1975):

$$f = 0.5/\cos q \tag{7}$$

with θ being the sun zenith angle.

Total leaf area index (LAI), for the plots in all water stress conditions was estimated from the height of crop as previous determination with same density and growing conditions by França (1997).

The direct components of the global radiation (R_d) at the top of canopy were computed adapting Fuchs et al. (1984) and Santos (1998):

$$R_d = \left(\frac{R_{de}}{R_{ge}}\right)(R_g) \tag{8}$$

with R_{de} being the estimated direct radiation , R_{ge} the estimated global radiation (Campbell, 1977) and R_g the measured global radiation. The diffuse component of global radiation (R_{di}) was considered as the difference between measured global radiation and the direct component calculated by Equation [8].

Net radiation was calculated as detailed in Fuchs et al. (1987):

$$\mathrm{Rn} = \mathrm{LAI}_{\Delta}[\alpha(\mathrm{R}_{de} + \chi \mathrm{R}_{di}) + \chi \mathrm{R}_{l} \tag{9}$$

where α is the leaf absorption coefficient for short wave irradiance, taken as 0.5 (Jones, 1992), R_l is the exchange of long wave radiation between exposed leaves and sky. χ is the view factor for isotropic radiant transfer between leaves and sky (Fuchs et al., 1987), and was defined as:

$$c = \left(\frac{1}{p}\right)\int_0^{2p}\int_0^{p/2} \exp(-fLAI)sinq \cos q dq df \tag{10}$$

where ϕ is the sun azimuth angle.

Direct and diffuse component of global radiation were considered for the calculation of the net radiation for the sunlit canopy fraction, while for the shaded fraction, only the diffuse component was used.

Computation of PAR intercepted by the sunlit foliage followed procedure described by Santos (1998).

RESULTS AND DISCUSSION

Under conditions of high and low atmospheric demand, for well-watered plots, hourly and daily estimated transpiration matched quite well with the measured water uptake, for both the growing seasons.

For water limited-plots, where severe stress developed in both growing seasons, model estimation of transpiration in the high atmospheric demand showed overestimation of the measured water uptake values in the hottest part of the day, which could be due to the difficulty to the correct simulation of the canopy conductance to this condition, where the stomatal variability tend to increase (Turner & Begg, 1991; Turner, 1991).

Modeled contribution of the shaded canopy to overall transpiration represented at least 27% of the crop water loss for extreme conditions analyzed. The partitioning of transpiration between the sunlit and shaded fraction of the canopy was influenced by the variation observed in the atmospheric demand and in the soil water availability. Decrease in the average fraction of shaded/total canopy transpiration with intensifying water stress was observed. This may be due to a significant decrease in the fraction of shaded/sunlit leaf conductance with the development of water stress. It is also due to the fraction sunlit LAI/LAI that is higher in the stressed plots.

Expanding the Penman-Monteith to include the shaded leaves, based on Fuchs et al. (1987) and as well as Fuchs & Cohen (1989), may increase the accuracy of simulated transpiration. It represented a significant fraction of total transpiration obtained in a varied base of atmospheric demand and soil moisture. This is very important for the stages of development when maize has full coverage of the soil and the shaded fraction is very significant. Furthermore, by including the shaded fraction calculations in the original equations does not bring an increase in the model complexity, since the computation of shaded transpiration is done with the same meteorological data used for sunlit computation.

CONCLUSIONS

Transpiration from the shaded canopy accounted for 27% to 45% of the total transpiration, and should therefore be included when modeling crop water loss, moreover with the propose of monitoring the maize crop in the later stages of development when the crop reaches the most critical stages with regard to water deficit.

Estimated hourly and daily transpiration were in agreement with the heat pulse and the lysimeter measurement in the non-stress condition and for all atmospheric demand situations. For plots under severe water stress the difficulties in simulating the canopy conductance decreased estimate efficiency.

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