PHOTOSYNTHESIS AND TRANSPIRATION RATES OF NORMAL AND SUPEROKRA LEAVES FROM A COMPUTER MODEL

D. R. Buxton, Assistant Agronomist
H. N. Stapleton, Agricultural Engineer

Introduction

Net photosynthesis, transpiration, and sensible heat exchange of individual cotton leaves are affected in a complex manner both directly and indirectly by several environmental factors. As will be shown, the effect of these environmental factors on photosynthesis and transpiration can be altered by changing the size and shape of the cotton leaf.

The objective of the work reported herein was to develop a model of a cotton leaf from information available in the literature. A model of this type can allow comparisons between normal and superokra leaves that are difficult to obtain experimentally.

The Model

Basically the model is concerned with solving the following equation:

$$Q_{abs} = R \pm C \pm LE \pm M \pm HS \qquad [1]$$

where Q_{abs} is the radiant energy absorbed by the leaf, R is the energy reradiated, C is the energy exchanged by convection. LE is the energy lost by the transpiration, M is the energy used in metabolic processes, and HS is the heat storage flux due to leaf temperature change. Relationships used to define these terms were obtained from the literature. R is a function of leaf temperature. C is influenced by wind speed, the temperature gradient between the leaf and the ambient air, and the characteristic length of the leaf in the direction of the wind.

LE is solved by the equation:

$$LE = \frac{L(s\rho_1 T_1 - RH\ s\rho_a T_a)}{r_a + r_1} \qquad [2]$$

where L is the latent heat of vaporization for liquid water, $s\rho_1 T_1$ is the saturated concentration of water vapor under the epidermis, $s\rho_a T_a$ is the saturation vapor concentration near the boundary layer, RH is the relative humidity, r_a is the resistance to the movement of water vapor through the boundary layer, and r_1 is the resistance to gaseous diffusion through the leaf epidermis. The boundary layer resistance is a function of leaf size and wind speed.

M is determined from the rate of CO_2 exchange. The equation for photosynthesis is written:

$$P_n = [\frac{C_a - C_c}{r_a' + r_l' + r_m'}] \quad [\frac{P_m(S+s)}{S+s+K}] \quad [1.0 - \frac{A}{B - T_l}(T_l - T_0)^2]^{0.5} \qquad [3]$$

where C_a is the concentration of CO_2 in the ambient air, C_c is the concentration of CO_2 in the chloroplasts, r_a' and r_l' are resistances to CO_2 diffusion through the boundary layer and epidermis, r_m' is the resistance to CO_2 movement through the mesophyll, P_m is the asymptotic rate of photosynthesis on a relative basis, K is equal to the short wave solar radiation (S+s) at one half of P_m, T_l is leaf temperature, T_0 is the optimum leaf temperature for maximum photosynthesis, and A and B are constants. The center term adjusts the equation for light intensity and the term on the right adjusts the rate of photosynthesis for leaf temperature.

The radiant heat load upon a flat leaf can be calculated if the various radiation sources are known, as well as the absorption coefficients of the leaf to these sources. Q_{abs} is obtained from this information and is used to solve Equation 1 by an indirect iterative procedure.

Predicted Experimental Results

The model is used to compare net photosynthetic and transpiration rates of normal and superokra leaves by assuming a standard environment as shown in Table 1. This environment is similar to what might be expected at the periphery of a canopy during a bright, sunny, summer day in Arizona. It is in this region of the canopy that most of the photosynthate for the plant is produced and most of the water is transpired. The assumption must be made that no genetic or phenotypic differences exist between normal and superokra leaves other than leaf shape and size. For this comparison the normal leaf is characterized by a 10 x 10 cm configuration while the superokra leaf is characterized by a 12 x 2 cm configuration.

The model predicts an increase in net photosynthesis with superokra leaves over normal leaves as is shown in Table 2. The difference is predicted both because of a reduction in boundary layer resistance and because of a more favorable leaf temperature. Approximately a 5% increase in net photosynthesis is predicted with the superokra leaf type in all environments with a greater increase in transpiration at the low level of humidity. However, little difference in transpiration between the leaf types is seen at the high relative humidity. As a result, an increase in efficiency of water utilization, EWU, is noted for superokra leaf at RH=80% while a slight decrease in EWU is predicted when RH = 30%. Thus, under field conditions okra leaf should show its greatest advantage when the relative humidity is high. With such conditions, the leaf temperature is likely to be higher than air temperature and the superokra should be cooler than normal leaves because of greater energy exchange by convection. The effect of the reduced leaf temperature will normally be to reduce transpiration and increase photosynthesis. A slight reduction in leaf temperature will have a marked effect on the rate of transpiration.

Table 1

Symbols and standard values used as inputs for the model.

Input	Symbol	Standard value and units
Direct, short-wave, solar radiation	S	1.20 $cal/cm^2/min$
Diffuse, short-wave, solar radiation	s	0.15 $cal/cm^2/min$
Long-wave, thermal radiation from ground	R_g	0.70 $cal/cm^2/min$
Long-wave, thermal radiation from atmosphere	R_a	0.65 $cal/cm^2/min$
Air temperature near leaf	T_a	40 C
Wind speed near leaf	V	1.1 mph

Table 2

A comparison of the predicted response[1] of normal and okra leaves at a wind speed of 50 cm/sec.

Leaf type	RH = 30%				RH = 80%			
	P_n	E	T_1	EWU	P_n	E	T_1	EWU
			Q_{abs} = 2.04 cal/cm^2/min	T_a = 40 C				
Normal	48.1	7.59	37.8	4.32	46.7	3.61	41.8	8.81
Okra	50.4	8.22	38.0	4.18	49.1	3.60	41.4	9.33
% increase with okra	5	8	0	-3	5	0	-1	6
			Q_{abs} = 1.94 cal/cm^2/min	T_a = 35C				
Normal	47.3	6.35	33.9	5.09	47.4	3.12	37.2	10.36
Okra	49.6	6.80	33.8	4.98	49.7	3.08	36.7	11.08
% increase with okra	5	7	0	-2	5	-1	-1	7

[1] P_n = mg CO_2/dm^2/hr, E = g H_2O/dm^2/hr, T_1 = c, EWU = mg [CH_2O]/g H_2O