Automated Measurement of Crop Water Status Using Canopy Temperature and Biophysical Principles

Christopher Parry[1], Mark Blonquist Jr.[2], and Bruce Bugbee[1]
[1]Plant, Soils, and Climate, Utah State University, Logan, UT
[2]Apogee Instruments, Inc., Logan, UT

UtahState University
DEPARTMENT OF PLANTS, SOILS, & CLIMATE



Abstract

Methods that directly determine plant physiological responses to water availability, such as the measurement of stomatal conductance, have the potential to be significantly more sensitive and accurate than indirect approaches, such as soil moisture measurement. Stomatal conductance is a rapid physiological response to leaf water potential. Stomatal conductance in single leaves has long been calculated using energy balance principles. This same biophysical approach can be extended to plant communities using: 1) standard meteorological measurements, 2) accurate measurement of average canopy temperature, and 3) knowledge of canopy architecture. Here we use a two-source energy balance model designed for the calculation of stomatal conductance (g_C) in row crops with random spatial distribution within rows. The two source model separates soil and canopy heat sources and accounts for the unique characteristic of vegetation clumped in rows. The distribution of plants in rows affects not only the radiation penetration in the canopy, but also the separation of soil and canopy heat sources. Using the necessary environmental measurements, aerodynamic parameters and model modifications, g_C was continuously determined for 13 corn and 8 cotton crops throughout the Midwest and Southern United States, and Argentina. This g_C value was then compared to a calculated reference g_C for a well-watered crop. This ratio is an indicator of crop water status, which is called the stomatal conductance ratio (SCR). The SCR was close to one after each irrigation or significant precipitation event, and steadily declined until the next irrigation event. Daily SCR values were weighted to correspond with growth stage sensitivity to drought stress. These weighted values were highly correlated with yield (r^2 values above 0.9). This biophysical approach has the potential to provide a powerful tool for precision irrigation management.

Thirty minute averages of canopy temperature, air temperature, relative humidity, wind speed, and solar radiation, along with periodic estimates of canopy height, were collected and processed with a datalogger at each site. Real-time estimates of canopy water status via SCR were displayed on a webpage.

Canopy Stomatal Conductance Equation is Derived from Energy Balance Components

$$R_{nC} = H_C + \lambda E_C + A_n$$ (1) Energy balance equation for a plant canopy

$$H_C = g_H C_P (T_C - T_A)$$ (2) Sensible heat flux (Campbell and Norman, 1998)

$$\lambda E_C = g_T \lambda \left(\frac{e_{SC} - e_A}{P_B} \right)$$ (3) Latent heat flux (Campbell and Norman, 1998)

$$g_T = \frac{1}{(1/g_V) + (1/g_C)} = \frac{g_V g_C}{g_C + g_V}$$ (4) Total conductance (g_T) = Bounday layer (g_V) and stomatal conductance (g_C) in series

$$g_C = \frac{g_V P_B \left[(R_{nC} - A_n) - g_H C_P (T_C - T_A) \right]}{g_V \lambda (e_{SC} - e_A) - P_B \left[(R_{nC} - A_n) - g_H C_P (T_C - T_A) \right]}$$

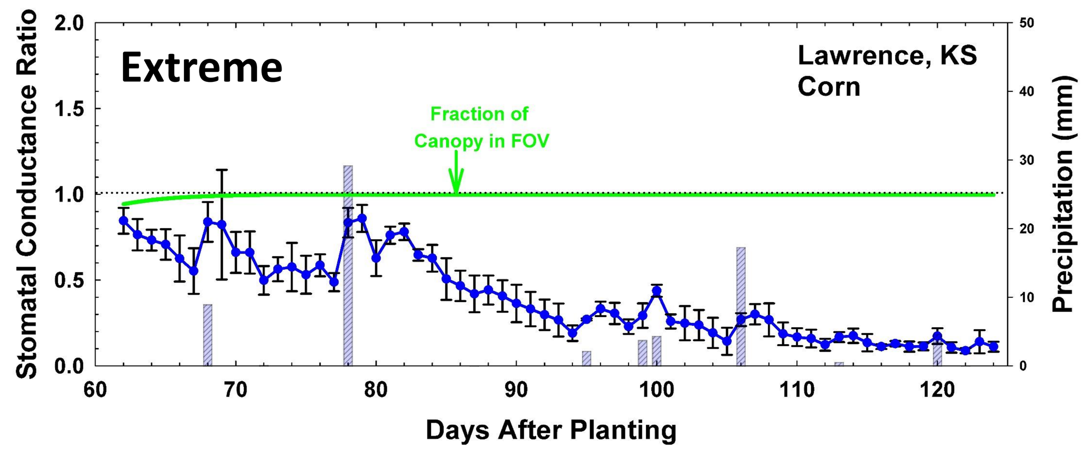
Reference Canopy Stomatal Conductance

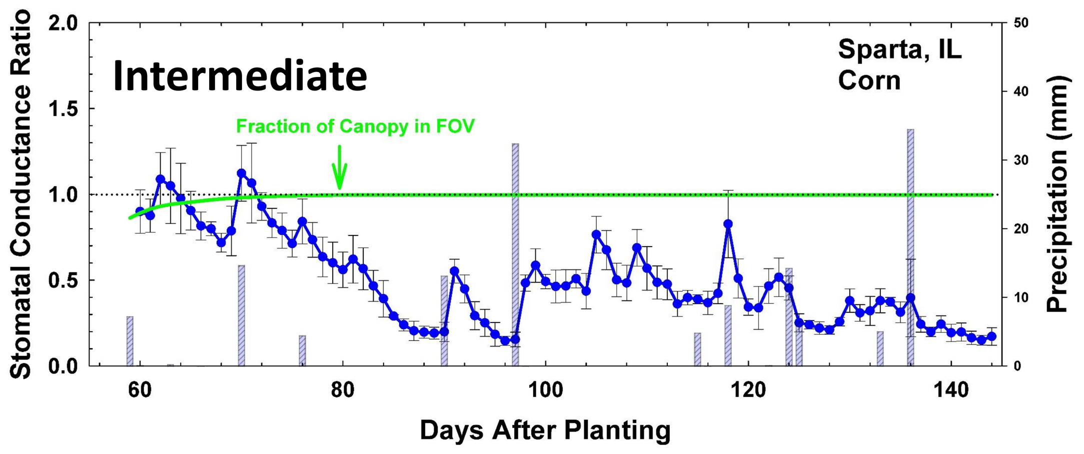
$$g_L = m \frac{A_{nL} RH_L}{CO_{2L}} + b$$ (Ball-Woodrow-Berry model)

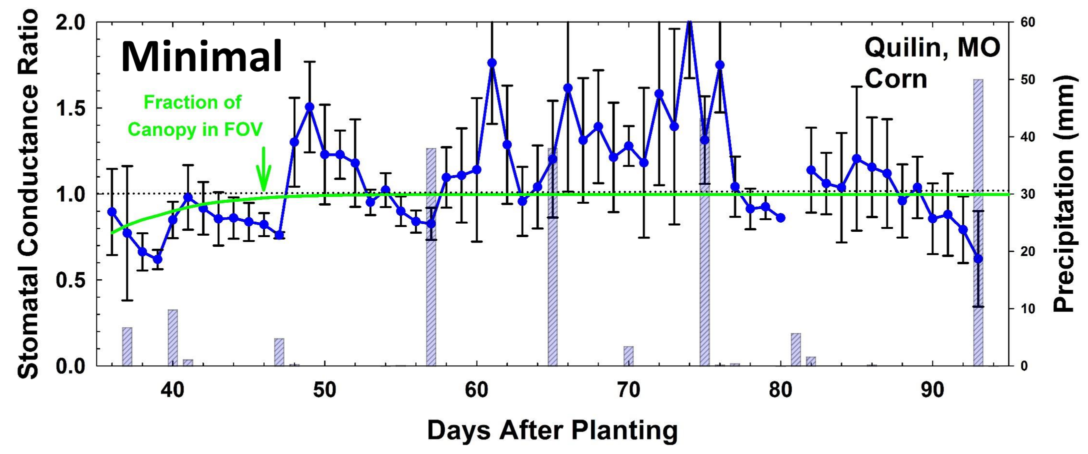
$$reference\ gc = g_{Lsun} * LAI_{sun} + g_{Lshade} * LAI_{shade}$$

$$\textbf{Stomatal Conductance Ratio (SCR)} = \frac{Actual\ gc}{Reference\ gc}$$

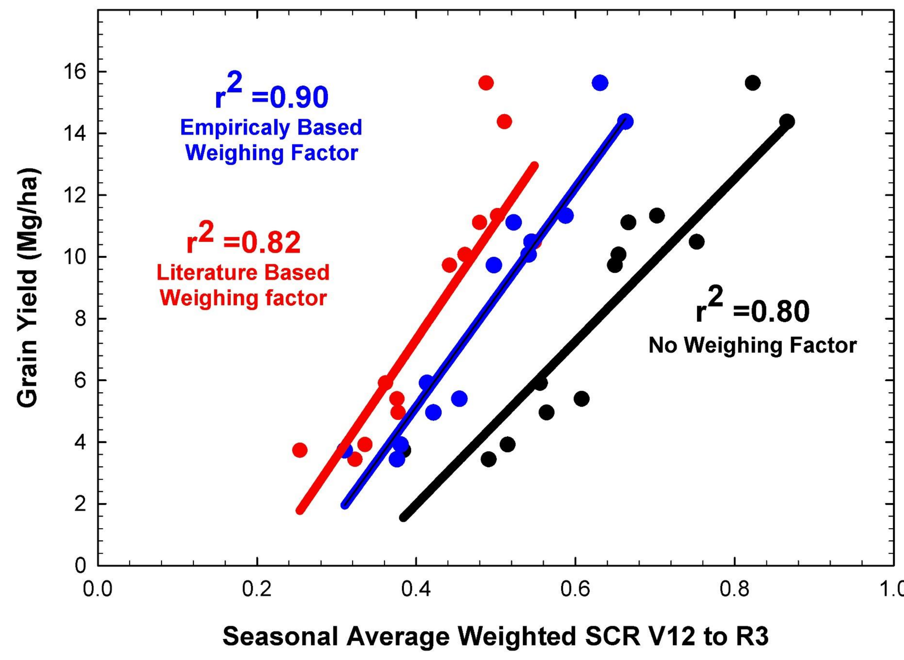
Drought Stress in Corn







Seasonal Average SCR Can Predict Yield



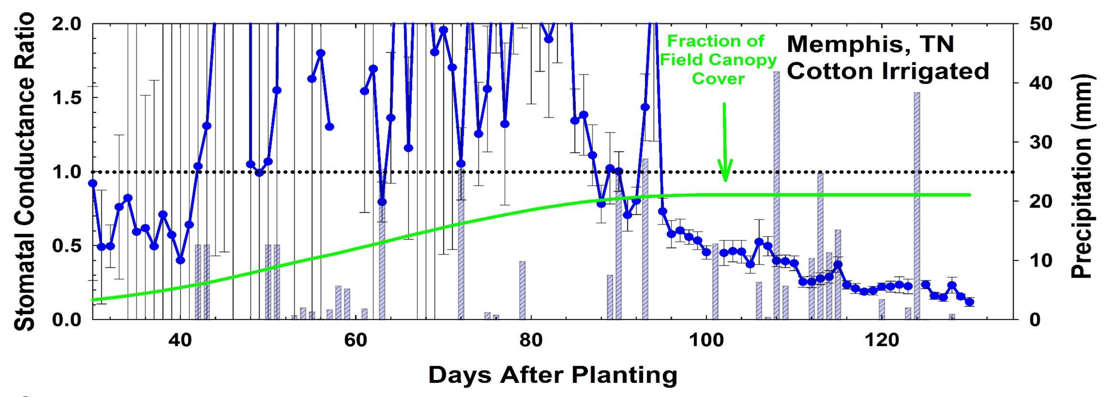
(Left)
Three representative corn crops with extreme, intermediate, and minimal degrees of drought stress.

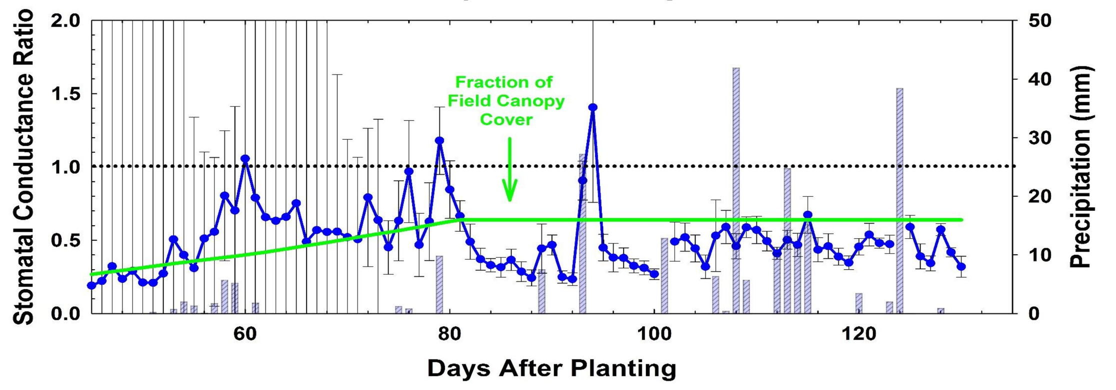
(Above)
Prediction of yield for 13 corn sites with the seasonal average SCR.
The corn life cycle was divided into five growth stage groups for pairing with associated weighting factors. Daily SCR values were multiplied by a weighing factor and averaged from the V12 to Soft Dough (R3) stage to obtain a seasonal SCR value for each site.

Modification of the Model for Cotton

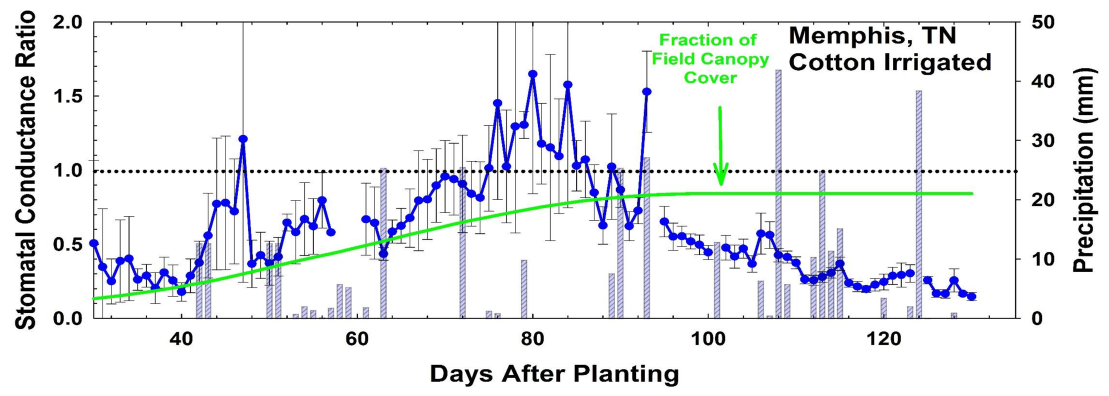
Non-uniform spatial distribution of incomplete ground cover, typical of row crops, changes the soil/plant radiation partitioning compared to complete ground cover. A vegetation radiation model (Campbell and Norman, 1998) was modified using a clumping index to account for the unique partial canopy cover of cotton.

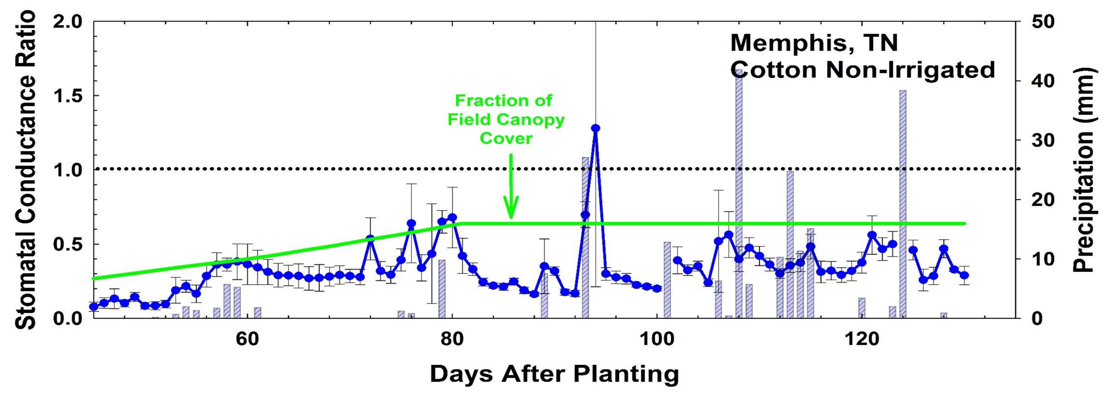
Before Clumping Correction





After Clumping Correction





Conclusions

1. Crop water status can be determined from the ratio of actual to potential canopy stomatal conductance.
2. Corn grain yield can be predicted using averaged SCR values.
3. SCR frequently exceeds one for one to two days after each precipitation/irrigation event and is not due to water on leaves that would affect canopy temperature. Further work on this is needed.
4. Radiation partitioning components need to account for the unique spatial distribution of row crops during incomplete canopy cover.

References

Blonquist J.M., Norman J.M., Bugbee B. (2009) Automated measurement of canopy stomatal conductance based on infrared temperature. Agricultural and Forest Meteorology 149:2183-2197.

Campbell, G.S., and Norman J.M. 1998. An introduction to environmental biophysics. 2nd ed. Springer-Verlag, New York.