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Effects of Certain Environmental Factors on Net Assimilation in Cotton[1]

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IT IS often necessary to test new cultural practices in an effort to improve the status of a crop with respect to some pest or some growth limiting factor, or in order to better adapt the crop to mechanization. This testing would be greatly expedited if the agronomist had at hand a background of information on the reaction of the variety in question to each element of the crop environment and a description of the physical and chemical environment likely to result from his proposed cultural treatment of the crop. With this in mind a series of experiments was conducted to determine the photosynthetic responses of a field stand of cotton to light intensity, air temperature, humidity, and atmospheric CO_2 concentration.

MATERIALS AND METHODS

Soil and Plant Material

The experiments were conducted in the vicinity of State College, Mississippi, on a Vaiden clay. This soil has a high water-holding capacity and is approximately 35 inches deep in the experimental area. *Gossypium hirsutum* L., Deltapine Smoothleaf cotton, was planted in 40-inch rows which were oriented in an east–west direction. At planting, fertilizer was applied at the rate of 81, 26, 44, and 27 pounds per acre of N, P, K, and Mg, respectively. The cotton was sidedressed with an additional 33 pounds of N.

Equipment

Apparent photosynthesis by 23 plants was measured in a semiclosed system (Figure 1). Air entered the chamber at the north end, was removed at the south end, and was recirculated through the large black hose. The system was sealed off at the ground with plastic. Theoretically there was no change of air with the outside; however, there was some leakage. Leakage was measured and found to be negligible when the chamber air concentration was 300 ppm CO_2 by volume. The data collected at concentrations other than 300 ppm CO_2 were adjusted for leakage.

The wind velocity was spatially uniform, averaging 0.8 mph around the leaves on the upper halves of the plants, but it varied considerably in time (gustiness) and the upper leaves waved visibly.

The water condensed by the air conditioner was measured at the end of each 15-minute period, providing a direct measure of transpiration. Humidity measurements made at the end of each period made it possible to adjust the transpiration data for any change in the amount of water held in the air.

A sample of air was removed at the outlet end of the chamber, pumped to an instrument trailer for CO_2 analysis and returned. A CO_2 gas metering system wired to the analysis equipment maintained the CO_2 concentration in the chamber air at the desired level. The amount of CO_2 metered into the chamber each 15 minutes provided a measure of apparent photosynthesis.

The enclosed crop had a leaf area index of 5.7 and intercepted 93% of the incident radiation at noon. The mylar[3] film covering the chamber absorbed about 3% of the short-wave radiation and reflected about 12%, transmitting approximately 85% to the plants inside.

A net radiometer was installed over the plants at the north end of the chamber, thermocouples were installed in the outlet air stream and in an upper exposed leaf, and a LiCl Dewcel[3] was installed in the south manifold in a properly ventilated position. Solar radiation was measured by an Eppley[3] pyrheliometer located outside the chamber.

The millivolt outputs of these transducers were integrated over the same 15-minute periods as the CO_2 additions and were printed directly in appropriate units as averages for the period by a data recording system located in the instrument trailer. This unit has an accuracy of $\pm$ 0.2° C. on the temperature channels and $\pm$ 0.04 langleys/min. on the radiation channels.

Soil Moisture

The plot area was flood irrigated to field capacity at the beginning of the first experiment. Tensiometers were not installed during these experiments, but desorption data and the transpiration data suggested that the tension was 0.4 bar at the end of the first experiment and 1 bar at the end of the second experiment.

Experimental

The first experiment was designed primarily to test the influence of air temperature on the net assimilation rate of cotton. A CO_2 concentration of 300 ppm by air volume was maintained in the chamber air at all times during this experiment. An air temperature of 20, 25, 30, 35, or 40° C. was selected at random and held thermostatically for an entire day while measurements of apparent photosynthesis were made.

The second experiment was designed to measure the effect of atmospheric carbon dioxide concentration on the rate of apparent photosynthesis in cotton. An air temperature and CO_2 concentration were held constant for a full day while assimilation measurements were made. These treatments were imposed in the following order: 300 ppm, 25° C.; 400 ppm, 35° C.; 500 ppm, 25° C.; 200 ppm, 35° C.; 600 ppm, 35° C.; and 100 ppm, 25° C.

Statistical Analysis

The data from both experiments were analyzed by multiple regression. In each case a primary model was fitted containing linear and quadratic terms for each independent variable and all possible first order interactions. The computer program used[4] determined all the regression coefficients in the primary model, tested each for significance, dropped the least significant term from the model, and recomputed the coefficients on the new model. It continued this process until it had reduced the equation to one term.

RESULTS AND DISCUSSION

Effects of Light, Temperature, and Humidity

Two days' data typical of the first experiment are shown in Figure 2. Temperature levels of 40° C. and 35° C. were selected for 9–6–1963 and 9–9–1963, respectively. Because of the increased radiation load as the day progressed

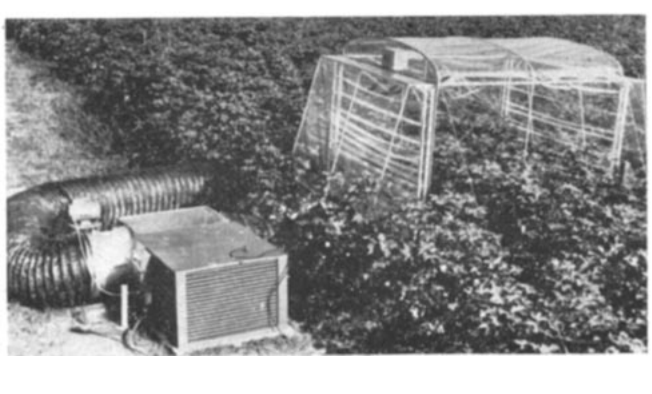

Figure 1. The semiclosed system.

[1] Contribution from the Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with Entomology Research Division and Mississippi Agricultural Experiment Station. Presented before Division C-2, Am. Soc. Agron., Denver, Colorado, November 20, 1963. Received June 10, 1964.

[2] Research Soil Scientist, Boll Weevil Research Laboratory, State College, Mississippi.

[3] Mention of a proprietary product does not necessarily imply endorsement of this product by the United States Department of Agriculture.

[4] "Multiple regression program for 44 variables" written by General Foods Research Center.

the compressors worked harder, removed more water and increased the vapor pressure deficit (VPD) between the leaves and the air. An inspection of the data, however, suggested that changes in VPD would not be enough to explain the progressive loss in efficiency shown in this figure. A hysteresis occurred here which is not explained by any of the measured variables. Therefore, time of day was included in the multiple regression analysis of the data. The equation obtained is as follows, $Y = a + b_8x_4^2 + b_{10}x_1x_3 + b_{11}x_1x_4 + b^*_{15}x_1x_2x_3 + b_{17}x_1x_3x_4$, where Y is apparent photosynthesis (mg. CO_2/dm.^{2} ground area/min.), x_1 is light intensity (ly/min.), x_2 is the vapor pressure deficit between an illuminated leaf and the air (millibars), x_3 is time of day (hrs.), and x_4 is air temperature (°C.). The starred term shown in the equation was next in line to be dropped. On dropping this term the first significant reduction in goodness of fit occurred. Therefore, this equation has been used to graph the solid. An effort has been made not to extrapolate beyond the data included in the analysis in graphing the solid.

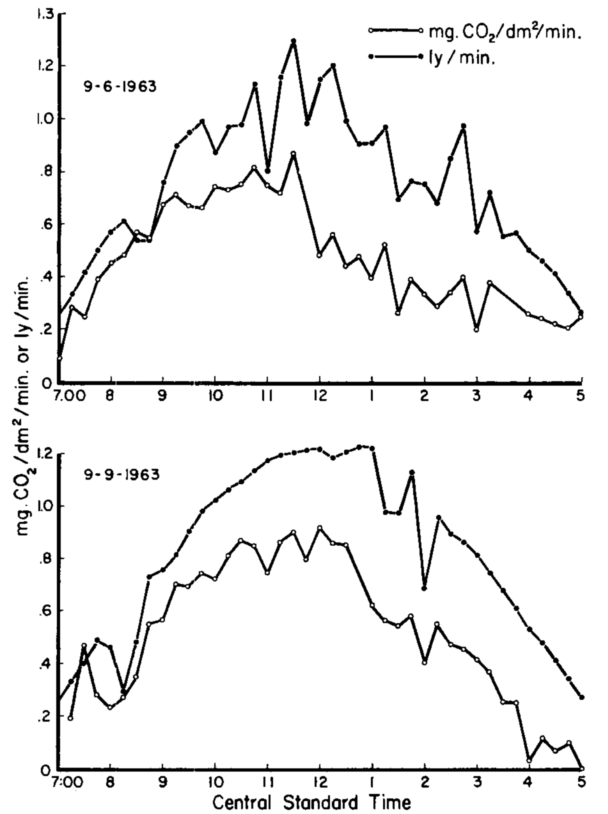

Figure 2. Time course of apparent photosynthesis (mg. CO_2/dm.^{2} ground area/min.) and light intensity (ly/min.).

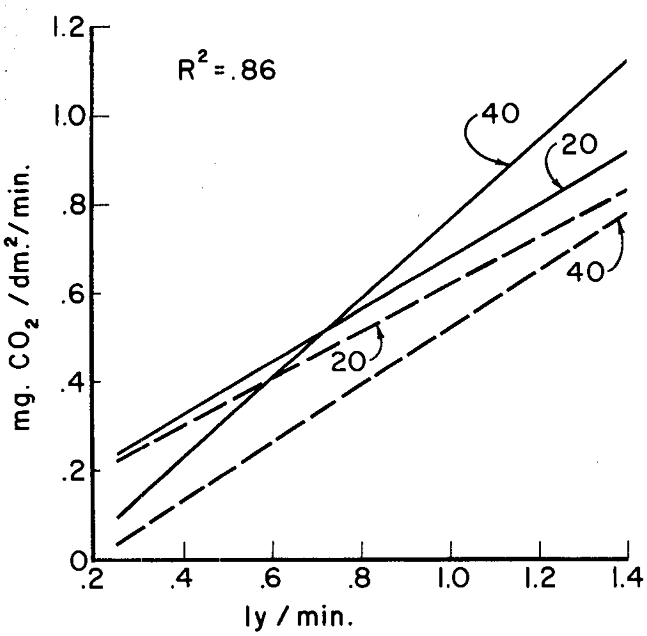

Figure 3. Apparent photosynthesis (mg. CO_2/dm.^{2} ground area/min.) vs. light intensity (ly/min.) at 30 mb. (Numbers on curves refer to air temperature, °C., solid lines represent data collected at 10:00 a.m., dashed lines represent data collected at 2:00 p.m.)

One plane of this solid is shown in Figure 3. It should be noted that a multiple R^2 of .86 was obtained in this analysis. Only the 20° and 40° C. curves are graphed in this figure, in order to show the trends. The other temperature curves fall between these. Several points of interest in this figure are:

(1) No data were obtained below about 0.25 ly/min., but over the range of light intensities (measured with the pyrheliometer outside the chamber) studied the model predicts a linear relationship.

(2) The "time of day effect" is plainly evident and shows that something which was not measured or controlled changed during the day. The model predicts that its effect depends slightly on the levels of the other variables.

(3) If the lines are extended to zero light intensity, different intercepts are obtained at 40° C. and at 20° C. suggesting differences in respiration rates.

(4) The slopes are steeper at 40° C. than at 20° C. Several workers (1, 4, 6) have estimated that the fraction of the total resistance to the diffusion of CO_2 from the leaf surface to the chloroplast that may be attributed to the stomates is small, assuming that all stomates are open in some degree. The estimates for different species range from 1/100 to nearly 1. This implies that partial closure of stomates should have little effect on CO_2 assimilation. If however, a change in diffusion resistance occurs as a result of a change in the number of stomates open rather than a change in the degree of opening, a change in assimilation rate is to be expected. Analysis of the transpiration data and the leaf temperature data obtained in the present experiment (c.f. Baker[5]) has demonstrated that stomatal diffusion resistance decreased in response to increasing temperature. Therefore, the differences in efficiency at different temperatures shown in Figure 3 may be due to differences in the rate of diffusion of CO_2 through the stomates.

Another plane is shown in Figure 4. The model predicts that apparent photosynthesis will decrease linearly with increasing vapor pressure deficits up to 40 mb. between the leaves and the air. This small but significant decrease in efficiency demonstrates a moisture stress effect at a very low soil moisture tension.

A third plane is presented in Figure 5, showing effects of air temperature. The lines here are curved slightly. The model predicts similar figures for other vapor pressure

[5] Baker D. N. The microclimate in the field. Presented at the 1964 Annual Meeting, Southeast Section, American Society of Agricultural Engineers, Atlanta, Georgia.

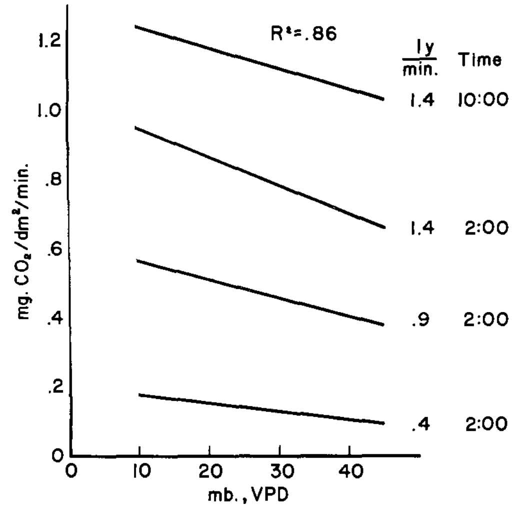

Figure 4. Effect of vapor pressure deficit (VPD) on apparent photosynthesis at 40° C. and at various light intensities (ly/min.) and times of day (hours).

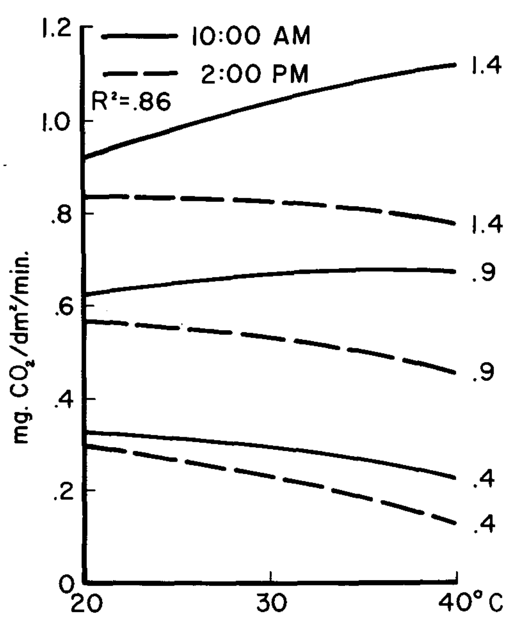

Figure 5. Apparent photosynthesis (mg. CO_2/dm.[2] ground area/min.) vs. air temperature (°C.) at 30 mb. vapor pressure deficit. The numbers on the curves refer to the light intensity ly/min.).

deficits except that they will be displaced up or down depending on whether the deficit is smaller or greater.

Effect of Carbon Dioxide

It was noted earlier that a soil moisture tension of approximately one bar occurred by the end of the second experiment. The data presented in Figure 6 were collected before beginning (9–11–63) and 2 days after completion (9–23–63) of this experiment. They were collected at 300 ppm CO_2 and under nearly identical conditions of temperature and humidity. The similarity in the data suggests that neither the progressive increase in soil moisture tension nor the exposure to various carbon dioxide treatments had any deleterious effect on the photosynthetic efficiency of the cotton.

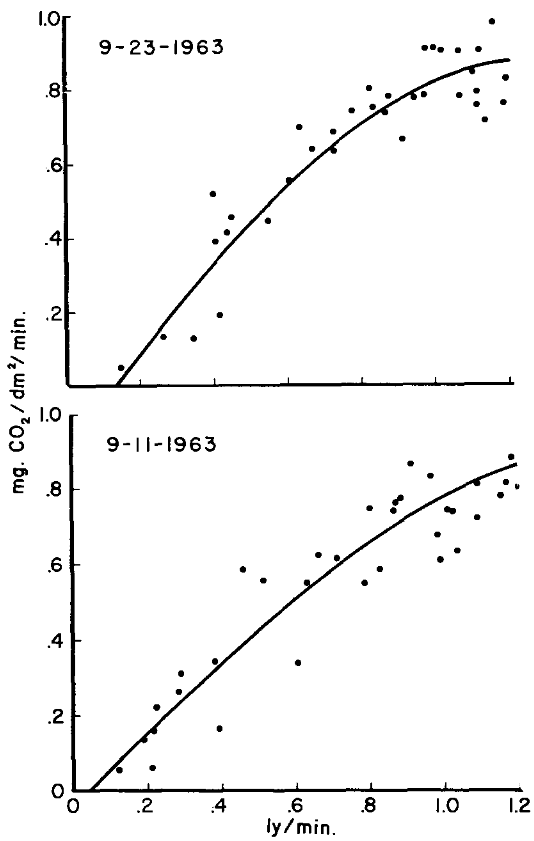

Figure 6. Apparent photosynthesis (mg. CO_2/dm.[2] ground area/min.) vs. light intensity (ly/min.).

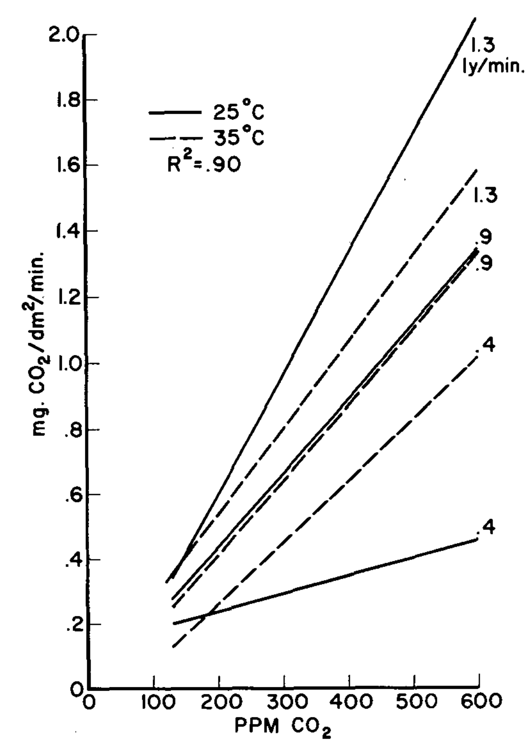

Figure 7. Apparent photosynthesis (mg. CO_2/dm.[2] ground area/min.) vs. atmospheric CO_2 concentration (PPM by volume CO_2 in air) at 18 mb. vapor pressure deficit and at various light intensities (ly/min.) and air temperatures (°C.).

The following regression equation was obtained in the previously described manner, $Y = a + b_1x_1 + b_7x_3^2 + b_9x_1x_2 + b_{10}x_1x_3 + b_{12}x_2x_3 + b_{13}x_2x_4 + b_{14}x_3x_4 + b_{15}x_1x_2x_3 + b_{16}x_1x_2x_4 + b_{17}x_1x_3x_4 + b_{18}x_2x_3x_4 + b_{19}x_1x_2x_3x_4$, where Y is apparent photosynthesis (mg. CO_2/dm.^{2} ground area/min.), x_1 is light intensity (ly/min.), x_2 is atmospheric CO_2 concentration (ppm), x_3 is air temperature (°C), and x_4 is the vapor pressure deficit (mb.). A multiple R^2 of .90 was obtained in this analysis. Time of day was not included in the primary model here because an inspection of the data suggested that it would lend nothing to the goodness of fit. This may have been due in part to the fact that many of these data were collected over half-day periods because of rainy weather.

The effect of CO_2 concentration is shown in Figure 7. There are two points of interest in this figure:

(1) While the effects described up to this point have been measurable and significant, they have been small by comparison with the light effect. By contrast, the interactions between CO_2 concentration, air temperature and light intensity shown here are extremely potent.

(2) A linear relationship is predicted over the range of CO_2 concentrations studied.

The present model predicts a linear response to light intensity at all CO_2 levels and the effect of vapor pressure deficit in this study was similar to that presented in the previous discussion. It should be noted, however, that the light × temperature response in this analysis is reversed from that of the previous analysis. There are not enough data here to warrant an interpretation of this.

Plainly the supply of carbon dioxide at the chloroplast limited photosynthesis in this study, and the degree of limitation depended on light intensity. It is evident therefore, that in cotton any appreciable reduction in the CO_2 level near the leaf will limit photosynthesis in a linear manner. It has been found that stomatal apertures in a number of species (1, 2, 3, 5, 7) are strongly affected by the CO_2 concentration of the air adjacent to the leaf. A significant reduction in stomatal aperture in response to increasing atmospheric carbon dioxide levels should cause curvature and a leveling off in the curves in Figure 7.

The fact that these lines are straight suggests that no great change in the gas permeability of the leaves occurred in response to CO_2 level. This assumption is supported by the transpiration data obtained in this experiment. Regression analysis of these data showed that increasing CO_2 levels up to 600 ppm caused a significant but *very small* decrease in the transpiration rate. It may be concluded, therefore, that CO_2 levels up to 600 ppm have very little effect on stomatal apertures in cotton.

SUMMARY

Apparent photosynthesis by cotton was measured in a semiclosed system at several levels of light, temperature, humidity and atmospheric CO_2 concentrations. The data were analyzed using multiple regression equations. A daily hysteresis in net photosynthetic efficiency was found which could not be explained by any of the measured variables or their interactions. Apparent photosynthesis decreased with increasing temperature except when measured in the morning under high light intensity. Linear increases in apparent photosynthesis were found in response to light intensity and to CO_2 level. The interactions between light intensity and CO_2 level were large. Evidence was presented suggesting that the resistance to gas exchange by cotton leaves does not respond to CO_2 concentrations in the range 130 to 600 ppm.

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